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**WORLD
CONGRESS ON
AGROFORESTRY**
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**COMPENDIUM
OF ABSTRACTS**





WORLD CONGRESS ON AGROFORESTRY

DELHI – 2014

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Abstracts of the 3rd World Congress on Agroforestry

Trees for Life: Accelerating the Impact of Agroforestry

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The World Congress on Agroforestry 2014 was organized by the World Agroforestry Centre (ICRAF), the Indian Council of Agricultural Research (ICAR), the Indian Society of Agroforestry and Global Initiatives (GI) and was supported by, among others, the Australian Centre for International Agricultural Research (ACIAR), the Technical Centre for Agricultural and Rural Cooperation (CTA), the Flanders International Cooperation Agency (FICA), the CGIAR Research Program - Forests, Trees and Agroforestry (FTA), Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ), the International Fund for Agricultural Development (IFAD), Irish Aid, MARS Inc. and the Swiss Agency for Development and Cooperation (SDC).

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Preface

Held every five years, the World Congress on Agroforestry (WCA) brings together participants from the private, research and development sectors to share and debate information on the current state of knowledge, experiences and new ideas, as well as frame and contextualize the science and practice of agroforestry for the next five years and beyond. The first event in the series, held in 2004 in Orlando, USA, attracted over 600 participants while WCA2 held in 2009 in Nairobi, Kenya, attracted over 1000 participants from 96 countries. Building on and learning from the legacy of the previous Congress, the World Congress on Agroforestry 2014 sought to significantly boost the awareness, engagement and investment in agroforestry by acting as a springboard to accelerate the impact of agroforestry, build people's livelihoods, increase the vitality of the landscape and drive the adoption of large-scale innovations.

Held on 10-13 February 2014 in New Delhi, India, the Congress attracted over 1000 participants from over 80 countries. They comprised of researchers, policy makers, representatives from major businesses and students all with concerns for sustainable development. Themed "Trees for Life: Accelerating the Impact of Agroforestry", the Congress was structured to generate outputs that would shape the next steps in the field of integrative science, transformative change in landscapes, tree improvement, innovative tree-based value chain debates on global and tree tenure and holistic education. This was achieved with the passing of the National Agroforestry Policy of India just days before the Congress. The President of India, H.E. Shri Pranab Mukherjee, made the first public announcement during his inaugural address to the Congress. The theme of the Congress resonated strongly in the New Delhi Declaration on Agroforestry by the event participants as it called on the global community to harness the vital contribution of trees to human well-being development, climate change mitigation and adaptation and the sustainability of life across all spatial and temporal scales of operation. The declaration also highlights action-oriented recommendations to women and male farmers and consumers, policy makers and advocacy groups, business sector actors, scientists and research institutions, development actors, communicators and investment donors.

The Congress programme was organized around six breakout sessions: Agroforestry Systems, Income and Environmental Benefits; Climate Change, Multi-functionality, Livestock and Fish Systems; The Business of Agroforestry: Applying Science; Sustaining Development through Agroforestry; Applying Science to the Future of Agroforestry; and Policy Innovation and Global Issues. With the exception of breakout sessions 1 and 2, which had four and three sub-sessions respectively, all the other breakout sessions had six sub-sessions each.

Authors had the freedom to submit their abstract(s) under any of the 31 sub-sessions. The abstracts were then evaluated by the leaders of the sub-sessions, assessed and classified as either suitable for oral presentation, poster presentation or publication in the Congress compendium. A total of 1,158 abstracts were reviewed and of those, 181 were accepted for oral presentation and 692 for presentation as posters. These 873 abstracts along with 178 others have found their way into this Compendium. The abstracts are presented here under the headings of the six breakout sessions they were intended for.

The first part of this publication includes the abstracts of the oral presentations, the second part the abstracts presented as posters during the 2-day poster session and the last part contains the abstracts accepted only for publication in this volume. A list of all the posters presented at the World Congress on Agroforestry follows in Annex 1. The agenda of the Congress is presented in Annex 2 and Annex 3 contains information on the key scientific committees responsible for the content of the Congress.



Oral presentations

1.0 South Asia: Agroforestry systems, income and environmental benefits

1.1 Policy on agroforestry and tree-based farming systems

OP1.1.1. Agroforestry research in Indonesia: Where to go for the next two decades

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Agroforestry has been widely practiced by the Indonesian community for centuries. Nevertheless, intensive research in agroforestry was only started in the last three decades. It is therefore understandable that agroforestry has not yet been adopted in mainstream forestry and agriculture development in Indonesia. This paper aims to report the National Strategy on Agroforestry Research in Indonesia for the next two decades. The strategy was prepared by the team of authors following several phases, which include: a) review of research status of agroforestry, b) focus group discussions to involve a team of experts and related stakeholders in formulating research topic priorities and implementation strategies; c) dissemination of the strategy concept to a wide spectrum of stakeholders to obtain feedback; and d) launching of the national strategy to stakeholders that include representatives from research institutes, universities, government agencies, nongovernmental organizations, and other related parties. The National Strategy on Agroforestry Research proposes four priority research topics that will be the major research agenda in the field of agroforestry in Indonesia over the next two decades. These four priority topics are: 1) smallholder production systems and markets of agroforestry practices; 2) community-based forest management on state forest areas; 3) harmonization of agroforestry practices with global climate change, and 4) enhancing agroforestry practices for environmental services. In addition to these priority research topics, the national strategy also describes the implementation strategy of these four priorities.

Keywords: *implementation strategy, national strategy, research planning*

OP1.1.2. Mediating factors of agroforestry changes in Vietnam: Implications for agroforestry development

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Agroforestry has been changing as part of an overall tree cover transition in Vietnam. Through a mixed-method approach, we analyzed the spatial and temporal pattern and drivers of change in agroforestry in Bac Kan and Ha Tinh provinces, in the northeast and north-central regions of Vietnam. The results indicate that successive government reforestation projects since early 1990s have been the major driver of Vietnam's forest cover change impacting agroforestry in opposite ways. Reduction of agroforestry area due to conversion into plantation forest, shifting cultivation and paddy rice was observed in Bac Kan province; while an overall increase in agroforestry area within natural forests was found in Ha Tinh province. Reforestation has led to decreasing agroforestry area as financial support for tree planting was provided to farmers and markets for *Melia azedarach* timber became available in Bac Kan. In contrast, agroforestry expansion within allocated forestlands in Ha Tinh was attributed to farmers' acquired knowledge on tree planting from reforestation projects and the availability of market for pulp and timber from *Acacia* sp. Intensive implementation of government reforestation programs may lead to a

reduction of agroforestry areas where species used for forest plantation are different from the ones under agroforestry and vice versa. The data also revealed that agroforestry area is significantly associated with household income in Bac Kan, but not in Ha Tinh. In addition, households who have more income from livestock tend to invest more on agroforestry. Finally, our analysis suggests that agroforestry development in Vietnam is largely based on reinforcing factors such as government support, market creation for agroforestry products, local capacity development, and availability of, or access to, financial capital.

Keywords: *tree cover transition, agroforestry transition, reforestation, shifting cultivation*

OPI.1.3. The role of agroforestry in newly allotted forest lands in tribal Odisha

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Central India is covered with dry deciduous and moist evergreen forests and is inhabited by numerous tribal groups. In recent years many of these tribal men and women or families have received forest land and use rights either under a joint title or an individual title (in the case of single women and men). A number of village assemblies are also applying for Community Forest Resources (CFRe) titles under the Scheduled Tribes and Other Traditional Forest Dwellers (Recognition of Forest Rights) Act. The effects of the Act are now receiving attention from researchers and development groups. This research aims to bring out the gender-based developments arising out of the implementation of the Act with references to ground level practices and developments in Odisha. One of the key focuses is the issue of existing and emerging land use in these newly allotted forestland parcels and if this is influenced by the gender of the owner. Literature review shows that gaps exist in discussions concerning gender inclusion within the FRA provisions. Studies on suitability of agroforestry-based developments in forest fringes and in the regions of overlapping forest-farm interactions have found encouraging results from cases elsewhere. The research will also bring out information on existing agroforestry practices on these forestland parcels and will explore if agroforestry practices could further be promoted as a development strategy in these regions. The unique geographical and social settings of these small-sized individual and community forestland parcels in the forest ecosystems thus provide interesting cases for research and inquiry.

Keywords: *emerging land use, forest rights, forest-farm interactions, gender*

OPI.1.4. CAFNET – First effort in India to value ecosystem services from coffee-based agroforestry systems

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Kodagu district in South India is the largest coffee-producing region in India contributing to 35% of the production under shade grown systems. These diverse coffee plantations that cover 30% of the

landscape in the region not only provide valuable revenues to the rural community, but also provide vital ecosystem services to southern India. This is particularly the case for water since the origin of Cauvery, the most important river of the region, is in Kodagu with coffee plantations covering a large area of this watershed. The opening of India to the international coffee market and related intensification of coffee production have resulted in reduction in density and diversity of shade trees and associated biodiversity.

To improve the livelihoods of coffee farming communities while conserving natural resources in three major coffee regions located in the world hotspots for biodiversity, the project CAFNET was funded by European Union from 2007 to 2011 in seven countries. Kodagu district was the reference CAFNET site in India where a multidisciplinary team of researchers undertook studies in 38 villages in the Cauvery Watershed to:

- 1) Document local traditional ecological knowledge, biodiversity of trees, epiphytes, mammals and birds, economics and coffee quality on 150 farms on small, medium and large farmers.
- 2) Disseminate information on the ecosystem services such as water yield and carbon sequestration provided by coffee-based agroforestry systems to local and national stakeholders.
- 3) Formulate guidelines for sustainable coffee cultivation including agroforestry practices.
- 4) Help farmers in adding value to their coffee through better access to markets and ecocertification schemes with seven farmer groups being certified by Rain Forest Alliance and/or UTZ Certified. This effort is to make coffee cultivation more attractive for future generations through sustainable agricultural management principles while sustaining the environment.

Keywords: *coffee agroforestry, environmental services, ecocertification, Western Ghats*

OP1.1.5. Agroforestry systems in China: A proposed classification for Chinese tropical agroforestry

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China is one of the richest countries in agroforestry systems, especially in tropical areas. Most natural forest is found in that area besides the primary forests in southern Yunnan and Hainan Island; these are very precious resources. A clear and specified classification applied to the tropical zone in China can be useful for the sustainable management of natural resources and species conservation. Based on this classification, it will be possible to differentiate the management measures for systems.

We collected information of agroforestry systems worldwide and in China. Classifications from different authors were reviewed and evaluated. We studied representative cases in tropical China, and designed this proposed classification. In order to distinguish the management strategy for natural forests and artificial forests, this classification was made according to woodlands which are dominant in the system. First the classification distinguishes if the agroforestry system developed is based on a naturalized environment or an artificial plantation, and if its ecological function is protection or restoration. Depending on where it is established, the first level of classification could be divided into two categories: natural forest and artificial forest.

The second level of classification distinguishes the forest type, which is classified by characteristics and the use of woodland. Natural forests are divided into primary and secondary forests depending on the status and characteristics. Artificial plantations are divided into four parts by the use of trees: wood, non-timber products, shelterbelts, and home gardens. At the third level we classified their components.

The four basic components were forest, trees, crops (including medicinal plants and Lianas) and animals. Furthermore, more detailed classification was done according to their main components and structures. To illustrate that, we chose some representative cases of each type and introduced the history, the integration between species, the advantages and disadvantages, etc.

Keywords: *agroforestry system, classification, natural forest, tropical, China*

OP1.1.6. Trees on private lands: A regulatory impact analysis in select states in India

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Trees outside forests areas are an important source of timber providing up to two thirds of the domestic supply. Historically, trees on private lands in India have been broadly classified into regulated and exempt –broadly depending on their value, and their importance in the forest lands of the state. In recent decades there has been a process of partial deregulation in the agroforestry sector driven largely by the impulse to reduce the regulatory burden and dis-incentives for farmers subject to not increasing the risk of illegal felling in state forests. More recently, export market demands stemming from legislation like the Lacey Act (USA) and the EU Timber Regulations require that wood products be shown to come from legal sources. In addition, local agroforestry systems also provide valuable subsistence and ecosystem service benefits. This paper will review the regulatory system in select states, analyse the official regulations as well as how they are implemented in practice, assess the costs and benefits for both the regulator and the regulated, and identify options for sustainability, sustaining local ecosystem services, and income for both domestic supply and exports.

Keywords: *cost benefit analysis, regulation, Regulatory Impact Analysis (RIA)*

1.2 Agroforestry for rural employment and income generation

OP1.2.1. Tree borne oil seed crops –a step towards building energy security in rural India

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Non-edible tree borne oil seed crops are known to be multipurpose trees in the agriculture system. Adoption of multispecies consortia of non-edible oil seed trees in agroforestry systems supports productivity in food crops. The recent trend of using vegetable oil for biofuel production locally is of great relevance. The fact is that these resources are recycled locally without being detrimental to the carbon sinks. Among the consortia of species, *Pongamia pinnata*, *Azadirachta indica* and *Simarouba glauca*, *Calophyllum inophyllum*, *Mesua ferrea*, *Aphanamixis polystachya*, and *Jatropha curcas* are a good combination of trees in agroforestry systems with wider adaptation to dryland and to semi-wet crop fields. The consortia support the sustainable yield of food crops, improve soil fertility and help in pest management in the crops. Besides, these species also provide for production of energy from seed oil on par with petrodiesel. Involvement of a community in harnessing this energy locally through a biofuel value chain is the developed model. Participation of a community in growing selected trees in agroforestry systems as a component; processing of seeds for oil extraction; using the oil locally for agricultural machinery as an energy source and for production of electrical energy for local needs; and use of by-products like oil cake as a source of manure, biogas production and animal feed is interesting.

A successful model developed and implemented in the state of Karnataka, India with participation of a farming community organised on the lines of a milk union existing in the state is presented.

Keywords: *biofuel value chain, tree borne oil seeds*

OP1.2.2. Santalum yasi Seem: A vital agroforestry species for rural employment and livelihoods development in Fiji

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Fiji, located between 176°53'E to 178°12'W and 15°42' to 20°S, comprises three hundred and thirty islands of which only 110 are inhabited. Viti Levu and Vanua Levu are the two major islands that cover more than 87% of the total land area. 83% of the total land in Fiji is owned by 'mataqalian itaukei', a term representing the land owning unit. Forests have always been an integral part of the people in Fiji. In the beginning of the nineteenth century, Vanua Levu was famous amongst navigators, adventurers and treasure hunters as Sandalwood Island. Mass exploitation of *Santalum yasi* Seem (Fiji sandalwood or *yasi*) during that time for its valuable and prized aromatic oil contained in the mature heartwood made the species rare in this country. Due to non-existence of a substitute for sandalwood oil, *yasi* is still very much in demand around the world. Therefore the present study was conducted with an attempt to understand the scope of promoting *yasi* as a vital agroforestry tree species for rural employment and livelihoods development in Fiji. Random farm visits were conducted during 2012 and 2013 in the two major islands, namely Viti Levu and Vanua Levu, to observe the scope of *yasi*. It revealed the existence of a strong preference among farmers in Fiji for agroforestry. Farmers usually allow naturally regenerated tree and fruit species to grow and also transplant them in their farms. One hundred and seventeen species (including four introduced tree species) were recorded in the farms. These species are directly or indirectly utilized by farmers and can comfortably be regarded as agroforestry species. Interestingly six species observed in all the farms are considered as suitable hosts for *yasi*. The study recommends promotion of *yasi* as a vital agroforestry species for rural employment & livelihoods development in Fiji.

Keywords: *agroforestry systems, Pacific Island Sandalwood, sustainable livelihood*

OP1.2.3. Implementation of agroforestry for poverty alleviation and livelihood improvement in the state of Tripura: India

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In the state of Tripura under recognition of the forest rights act, forestland was allotted to the local tribes. These tribes practised 'jhuming' (shifting cultivation) on these lands. Due to pressure on the forestland, continuous jhuming was practiced in a particular land for more years than usual which led to depletion of soil fertility and reduction in jhum crop yield. To address this problem and increase the income of the tribal people, 9 agroforestry models were implemented under the project sponsorship of Japan International Co-operation Agency (JICA) in seven districts and 32 ranges during 2012-2013 as follows:

(1) Bamboo+jackfruit+maize+pineapple

- (2) Ghamhar+lemon+ginger+pigeon pea
- (3) Bamboo+arecanut+dalbergia+maize+black pepper
- (4) Acacia+litchi+lemon+maize+turmeric
- (5) Teak+jackfruit+maize+ginger
- (6) Bamboo+mango+maize+pineapple
- (7) Agar+arecanut+turmeric+black pepper
- (8) Banana+acacia+turmeric
- (9) Orange+acacia+papaya+turmeric

Among all these, bamboo+arecanut+dalbergia+maize+black pepper in the south districts of Tripura, acacia+litchi+lemon+maize+turmeric and bamboo+mango+maize+pineapple in north districts of Tripura most popular with the highest implementation.

Keywords: *Bamboo, dalbergia, jackfruit, teak*

OP1.2.4. Role of agroforestry in poverty alleviation at Ghatail Upazilla of Tangail district, Bangladesh

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The Forest Department of Bangladesh initiated an agroforestry program for the poor in order to alleviate poverty. This study explored to what extent the agroforestry program had reduced poverty and what constraints were faced by the participants. The research made use of Head Count Index (HCI) to determine to what extent poverty was decreased. To understand the main constraints of the agroforestry program, this study focused on macro-meso-microlevel analysis technique. Data were collected through semi-structured questionnaires for face-to-face interviews within the study area i.e. Ghatail upazila (sub-district) of Tangail district, Bangladesh. Fifty agroforestry participants were randomly selected to form the study for this research. The results showed that this program had alleviated poverty at a significant level (64% of the respondents) which improved their livelihood situation considerably. The income of the settlers in a similar participatory forestry program varied due to their socio-economic factors such as months of food sufficiency, family size, distance to market and institutional loan. These were the main reasons for the income differences among the settlers. As regards the constraints as perceived by the three level analysis frames, bureaucracy, monopoly of the market system, poor road infrastructure and lack of loan facilities were considered to be the main problems to reducing poverty with this program. Considering the overall results of the study, it can be concluded that the Participatory Agroforestry Program (PAP) was quite successful for increasing income as well as alleviating poverty. If we can overcome these constraints then there are better possibilities of agroforestry contributing more to poverty alleviation in this study area as well as in Bangladesh.

Keywords: *head count index, livelihood, Participatory Agroforestry Program (PAP), poverty alleviation*

OP1.2.5. Ensuring integrated timber and NTFP marketing for improving rural livelihoods: lessons learnt from Indonesia

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Agroforestry has been an important alternative in land management systems to improve rural livelihoods. Timber and Non-timber Forest Products (NTFPs) have been the most important components in the agroforestry system, and to rural villagers' household income portfolio including in Java and eastern Indonesia. However, the marketing strategy for these two components at the household level has been quite disintegrated and resulted in low benefit margins along the value chain continuum. Eventually, the low benefit margins are perceived by rural households as unattractive incentives to improve their integrated management practices at farming level, and households tend to cultivate products that are highly demanded by the market. This could lead to a less diversified agroforestry system. Realizing this critical problem, a value chain analysis of timber and NTFPs is needed to ensure integrated marketing of timber and NTFPs which in turn will improve the rural livelihoods. Through a better understanding of different product value chains, locally tailored interventions could be promoted to ensure more cost effective and strategic value chains in improving households' profit margins of various products under integrated agroforestry systems. Preliminary analysis has indicated there is a limited involvement of local households in value-added activities of different products due to a lack of understanding of products demanded by the market. With regard to timber, lack of understanding on relevant policy and regulations has been the main constraint. Intervention should be directed to improve local villagers' knowledge and capacity to understand the market characteristics of both timber and NTFPs and on how to optimize the seasonal calendar of the different products with a fluctuated market demand for sustainable income along the year.

Keywords: *integrated, agroforestry, rural, livelihood*

OP1.2.6. Yamunanagar –a model of symbiotic relationship between farmers and wood-based industries

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In India, Haryana state with deficient forest resources is a leader not only in agriculture but also in commercial agroforestry. The state has the biggest farm-grown wood market (annual turnover of about INR 10 billion) of the country at Yamunanagar. In this market, one third of farm-grown wood comes from Haryana state while two-thirds comes from the adjoining states of Punjab, Uttarakhand and Uttar Pradesh. This town is a hub of the wood-based industries (WBIs) as 84% of the plywood/veneer (PV) units of the state are located here. Yamunanagar is known as the plywood capital of the country as the units in this town itself produce about 50% of the plywood of the country. PV units provide employment opportunities to about 0.15 million workers and contribute nearly INR 220 million each towards the sales tax and excise duty annually to the state exchequer. This model has resulted into increased farmers' income and created immense employment & business opportunities for different stakeholders like contractors, commission agents, labourers, factory owners, etc. This model has saved the natural forests of the country and has contributed towards environmental conservation through

carbon sequestration by adopting the agroforestry cropping pattern. This model is the living example of a win-win situation for both the farmers and WBIs in India.

An effort has been made in this paper to analyse the reasons that have led to the development of this model and to quantify the benefits of employment generation and increased income to the different stakeholders. This paper recommends the strategy for further consolidation of this model in consultation with the different stakeholders and the measures required for its replication in other states of India and different countries of the world.

Keywords: *PV units, stakeholders, wood-based industries, yamunanagar*

1.3 Land reclamation: Biodrainage and salinity control

OPI.3.1. Biodrainage: An eco-friendly agroforestry technique for controlling waterlogging, livelihood security and carbon sequestration

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Introduction of canal irrigation in arid and semi-arid regions without provision of adequate drainage causes a rise in the ground water table leading to waterlogging due to seepage and secondary salinisation. About one-third of the world's irrigated area faces the threat of waterlogging. In India, the total degraded land due to waterlogging is 6.41 Mha. As sub-surface drainage is costly and disposal of effluents has inherited environmental problems, a viable alternative is biodrainage, which is 'pumping of excess soil water by deep-rooted plants using bioenergy'. The impact of block plantations of *Eucalyptus tereticornis* was tested and found effective in Indira Gandhi Nahar Paryojana area, where ground water under the block plantation was reported to fall by 15.7 m over a period of six years. In another experiment it was observed that the ground water table underneath the strip plantations was 0.85 m during a period of three years and it reached below 2 m after five years. The average above ground oven-dry biomass of five and a half-years-old strip plantation was 99.9 kg tree⁻¹ resulting in 24.0 t ha⁻¹ above ground biomass of 240 surviving trees. The average below ground oven-dry biomass of roots was 8.9 t ha⁻¹ and the total oven-dry biomass was 32.6 t ha⁻¹. The carbon in the oven-dry biomass was 15.5 t ha⁻¹. The average transpiration rate (measured by sap flow) of ground water by these plantations ranged from (litres day⁻¹ tree⁻¹) 44.5 to 56.3 in May and 14.8 to 16.2 in January. The annual transpiration rate was equal to 268 mm per annum. The wheat grains yield was 2.15 t ha⁻¹ as compared to 0.64 t ha⁻¹ in the nearby untreated fields without plantation. The farmers earned INR 72 000 ha⁻¹ at a rotation of five years and four months resulting in a benefit-cost ratio of 3.5:1 at 12%

Keywords: *biodrainage, carbon sequestration, livelihood security, waterlogging*

OP1.3.2. Rehabilitation of degraded sodic land through agroforestry and monoculture plantations

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Sodic soils are widely distributed in north India occupying about 1.6 M ha in Uttar Pradesh, which is 10% of the total cultivated area of the state. In this study, rehabilitation status of sodic land was compared through agroforestry system (*Populus deltoides* with medicinal plants) and monoculture plantations of *Prosopis juliflora* (leguminous) and *Terminalia arjuna* (non-leguminous). Tree density, basal area and standing biomass of *P. deltoides* was higher than monoculture plantations.

Physicochemical [water holding capacity, bulk density, pH, electrical conductivity (EC), exchangeable sodium percentage (ESP), soil organic carbon (SOC), nitrogen, phosphorus], biological [microbial biomass, soil respiration, microbial quotient ($C_{mic}: C_{org}$), metabolic quotient (qCO_2)] and biochemical (dehydrogenase, β -glucosidase, alkaline phosphatase, acidic phosphatase and protease) properties of soil were compared with unplanted sodic land. Soil bulk density, pH, EC, ESP and alkaline phosphatase decreased significantly, while other soil properties increased in rehabilitated systems irrespective of land use propositions. However, SOC was significantly higher (7.45 g kg^{-1}) in agroforestry ecosystems than monoculture plantations i.e. 4.79 g kg^{-1} and 3.12 g kg^{-1} in *T. arjuna* and *P. juliflora*, respectively. The activities of soil enzymes, except alkaline phosphatase, were significantly higher in agroforestry system than monoculture plantations. Thus, agroforestry system with multiple cropping of medicinal plants showed maximum increase in soil fertility than monoculture plantations of either leguminous or non-leguminous species. The relationships of soil microbial biomass and enzyme activities were established with soil sodicity parameters (pH, EC, ESP and SAR) which indicate negative correlations, except alkaline phosphatase. The study concludes that agroforestry system is more efficient for rehabilitation of degraded sodic lands in comparison to monoculture plantations.

Keywords: agroforestry, enzymes, microbial biomass, rehabilitation, sodic soils

OP1.3.3. Biodrainage as successful models for combating waterlogging in canal commands –some case studies

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Irrigated agriculture covering about 17% of the total cropped area of the world contributes 40% of the total food production. In India also, about one-third of area under irrigation produces two-thirds of the food grains. During last 50 years, the net irrigation potential has increased from 95 million hectare (Mha) to 260 Mha in the world, and from 22.5 Mha to 62 Mha in India. Expansion of irrigation in the past provided large dividends in terms of increased food production and nutritional security. However, introduction of canal irrigation in arid and semi-arid regions without provision of adequate drainage causes a rise in the water table leading to waterlogging and secondary salinisation. To combat such a situation, biodrainage offers practical solutions in such agro-ecologies. Presently, about one-third of the world's irrigated area faces the threat of waterlogging, about 60 Mha is already waterlogged, and 20 Mha is salt affected. In the predominantly agricultural state of Haryana, nearly 50% of the area faces a rising water table and salinity problems and about 10% of the area (0.44 Mha) is already waterlogged resulting in reduced crop yields, low profits and abandonment of agricultural lands. Many scientific

studies conducted in different districts on Haryana under abandoned waterlogged degraded land indicated that trees like *Eucalyptus* hybrid, *Eucalyptus tereticornis* C-10, *Eucalyptus tereticornis* C-130 and *Prosopis juliflora* can be categorized as fast biodrainers. *Eucalyptus tereticornis* C-3, *Callistemon lanceolatus* and *Melia azedarach* fall in the category of medium biodrainers whereas *Terminalia arjuna* and *Pongamia pinnata* are slow biodrainers. Strip plantation of trees on such models of agroforestry system raised on farmers' field bunds lowers the saline water table and such depression was found to the maximum magnitude beneath strips of *Eucalyptus* species (80-97 mm), *Prosopis juliflora* (82 mm) and *Tamarix aphylla* (79 mm). Decline in the water table was observed on such pilot projects thus making it arable. The socio-economical and environmental benefits of some pilot plants have been described in the paper.

Keywords: *biodrainage, waterlogged ecosystem, India*

OPI.3.4. Cultivation of intercrops inside biodrainage (Eucalyptus sp) vegetation under waterlogged ecosystem in Odisha

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To address the problem of waterlogging in deltaic Odisha and with an objective to increase its productivity by improving drainage situations through biological drainage, an attempt was made to use a *Eucalyptus* plantation in an inland waterlogged area. The yield performance of different intercrops grown over four years under biodrainage plantations was also assessed.

Inside the *Eucalyptus* plantation, the paddy yield as an intercrop was 3.5 t ha⁻¹ in 2005, 3.37 t ha⁻¹ in 2006, 2.25 t ha⁻¹ in 2007 and 2.12 t ha⁻¹ in 2008. The paddy yield outside the plantation which served as a control in corresponding years was 2.6, 2.65, 2.20 and 2.02 t ha⁻¹ respectively. Even though during initial two years the influence of vegetation on intercrop was conceivably minimal, the paddy yield inside plantation was significantly more. However, after two years of growth the plantation did not influence the yield of 'kharif' paddy significantly in comparison to the control field without vegetation. In 'rabi' season, in the first two years groundnut was cultivated as an intercrop inside a *Eucalyptus* plantation. In 2005-06, one year after establishment of the plantation, the groundnut yield was comparable to that of the field without *Eucalyptus* vegetation. However, in the 2006-07 in 'rabi' season, the groundnut yield was significantly higher in the biodrained field than in the control field without vegetation. Nevertheless, there was a marginal decrease in the groundnut yield under *Eucalyptus* vegetation from 1.4 t ha⁻¹ in 2005-06 to 1.2 t ha⁻¹ in 2006-07 with growth of vegetation. In the next two years due to better market prices of pulses, farmer switched over to greengram in 2007-08 and to blackgram in 2008-09. Even though there was a marginal increase in the yield of pulses in the biodrained area in comparison to the area without plantation in both years, there was a significant drawdown in the water level underneath the biodrainage vegetation.

Keywords: *biodrainage, Eucalyptus sp., waterlogged ecosystem, Odisha*

OP1.3.5. Biodrainage for salinity control: myth or reality for Indian monsoonal climate

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The prime requirements for rehabilitating salinity-afflicted land are that of reverting the flux of water for leaching salts beyond the active root zone. Though engineering approaches like surface and subsurface drainage have been standardized for rehabilitating the saline waterlogged soils, their adoption on a large scale is hindered by high capital investment, associated operational and maintenance problems in addition to suitable alternatives for drainage water disposal. As an alternative, use of plantations (biodrainage) is being advocated as an 'eco-friendly' option without any long term experimentation and verification. The main force behind such a notion is high water use and deeper rooting systems of trees. In fact plantations, especially Eucalyptus, have been shown to draw down the water table; of course their spatial extent being governed by tree transpiration rates and hydraulic characters of soils. We determined the sap flow values for a whole life cycle (10 years) of irrigated Eucalyptus plantations at various densities. The annual values increased from 53-140 cm (increment of about 14 cm/y) from two to six years and stabilized thereafter indicating little advantage of trees over crops (rice/maize/cotton/wheat) will occur only after about five years of plantation. The values improved considerably with density plantation (96-160 cm/y), but for these to be effective land requirements would be very high. The other issue related to plantations is salt accumulation once the deeper-rooted trees skim out the water. All these factors indicate towards the myths being created for biodrainage without presenting the real data from long-term experimentation and validation. The alternatives proposed to overcome salt problems are 'walking plantations', boundary plantations and even integrating sub-surface drainage and tree plantations. The utilization of recent tools in GIS and RS for prognosis of hot spot areas to be covered under plantations, further information on high density plantations of tolerance tree species, hydraulic parameters of soils and models to predict salinity with plantations, should help in afforestation designs and highlight management options and priorities.

Keywords: *reclamation, saline-waterlogged soil, tree plantations, evapotranspirations, seepage control*

OP1.3.6. Potential of tree plantations for wastewater disposal: Long term use in Eucalyptus

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Population growth with increasing urbanization and industrialization is encroaching upon the share of agricultural water and is leading to production of quantities of wastewaters, which are beyond the capacity of natural systems to assimilate. Soils are considered to be the ultimate and probably the most logical sink for these wastewaters. Irrigation of forest species grown for non-edible products like fuel and timber with wastewater is another approach, which can help in overcoming health hazards associated with sewage farming. Developing green belts around cities with forest trees under wastewater irrigation also helps revive the ecological balance and improves the environment. These systems of agroforestry are known as HRTS (high transpiration rate systems). They promote the treatment of wastewater through renovating the capability of living soil filter thus enabling recycling and reuse of wastewater. Although very tall claims have been made for sewage disposal through plantations, the real estimates on the loading rates of such plantations without the contamination of ground water show that the annual ET rates increased from 53-140 cm (an increment of about 14cm/y) between two and six years and stabilized thereafter indicating little advantage of trees over crops (rice/maize/cotton/wheat) will occur only after about five years of plantation. The values improved

considerably with density plantation (96-160 cm/y) but for these to be effective, land requirements would be very high. Thus, there is not much difference in quantities by land disposal and through forestry plantations but the latter would still result in economic returns in terms of fuelwood production and environmental services. Additional advantage of tree plantations would be the harvesting of large amounts of toxic metals as trees are known to sequester, tolerate and accumulate higher levels of these toxic metals. Adoption of agroforestry systems further reduces the farmer's direct contact with, and exposure to, sewage and carbon sequestration has an additional bonus.

Keywords: *effluent use; high rate transpiration system, land treatment, renovation, Eucalyptus*

1.4 Drylands and agroforestry

OP1.4.1. Design and development of agroforestry systems in low rainfall regions of India for combating climate change

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Climate change, the greatest global challenge, is already a reality for the farmers of the arid regions of India. It is increasing the pressure on already scarce resources and if proper measures are not taken, migration towards the cities will soon reach new heights. Given the fragility of the resource base in arid regions, agriculture is a high risk activity. Climate change poses formidable challenges to the animal husbandry sector as well. Agroforestry with livestock integration is a practice in these regions and offers a great scope in combating the ill effects of climate change.

Tree growing in hot arid regions is basically concerned with the management of trees for conservation and for limited production objectives like wood for fuel, poles, and fencing material; leaves for livestock fodder; and pod/seeds for many types of use in human diet. Agroforestry with suitable tree species in different arid land forms thus assumes much significance for desertification control and ecosystem services.

Agroforestry systems combining tree/shrub, crop, grass and livestock have a great scope and role in optimizing land productivity and environmental protection, more so from the angle of climate change. More adoption of agroforestry in the region is recommended for maintenance of productivity and sustainability in this region. Trees which are generally considered environmentally beneficial are on account of their ability to utilize incoming solar radiation throughout the year; to enrich micro sites by depositing litter in the topsoil for its subsequent utilization by crops/grasses; and to modify the microclimate which can bring about a favourable effect on the soil and associated plant species. The appropriate combination and management of tree/shrub (both forest and fruit), crops, grasses and livestock units (in mixed herds) will make agriculture a profitable and risk free proposal in light of emerging climate change challenges in the region.

Keywords: *livestock, rangelands, silvipasture, Thar Desert*

OP1.4.2. Improving productivity of common grazing resources in the hot arid region of India through participatory pasture development

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Livestock rearing is the major component in the hot arid regions of India. Although there are relatively large areas as common grazing resources, fodder scarcity is becoming an increasing concern for households. Krishi Vigyan Kendra (KVK- CAZRI), Jodhpur, identified the silvipasture system as a major thrust area for the district and demonstrated its benefits to farmers. The intervention was on a total of 56 ha common land in four 'gram panchayat' (16 ha in village Ketukallan and 13 ha in Bhalu Ratangarh of Balesar Panchayat Simiti, 10 ha in Begaria and 17 ha in Govindpura of Osian panchayat samiti) during 2009-10 in collaboration with Gramin Vikas Vigyan Samithi (GRAVIS).

Technical backstopping and improved seed of range grasses were provided by KVK, CAZRI and field implementation was facilitated by GRAVIS through village committees in the respective villages. Improved cultivars of *Cenchrus ciliaris* (C.C. 358), *Cenchrus setigerus* and *Lasiurus indicus* were sown in the interspaces of the trees planted at 10 m x 10 m. Tree components in the system were *Acacia senegal*, *Acacia tortilis*, *Azadirachta indica* and *Prosopis cineraria*. Among tree species, higher survival was observed in *A. tortilis*, followed by *A. senegal* and lowest in *A. indica*. After three years of establishment, productivity of common lands improved significantly (2.7 t/ha dry fodder from Ketu Kallan, 2.4 t/ha from Bhalu Ratangarh, 2.3 t/ha from Begaria and 1.5 t/ha from Govindpura) compared to natural pasture (< 0.5 t/ha). Farmers collected 6500 kg grass seed of *Cenchrus ciliaris*, *Cenchrus setigerus* and *Lasiurus indicus* from developed silvipasture pasture in 2011-12, and provided to other NGOs for community pasture development. Harvested biomass was stored after chopping at the respective sites as 'fodder bank' and made available to the weaker section of the society during stress periods. The feedback from farmers in those areas revealed that the productivity of animals increased due to availability of quality fodder during dry months. Thus the preference for rearing milking animals of better quality becomes evident against the prevailing practices of keeping large number of animals of less productivity.

Keywords: *grazing resources, hot arid region, India, pasture development*

OP1.4.3. Livelihood diversification through agroforestry in semi-arid regions of India

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Semi-arid regions in India are distributed in an area of 111 m ha (about 37% of the area) and are primarily characterized by low and erratic rainfall with high variability, shallow soils with low inherent fertility status, unabated land degradation, and poor economic status of farmers. Trees provide a range of products such as fruits, fodder, fuelwood, commercial/ pulpwood and environmental services such as conserving soil and water, carbon sequestration, etc. A number of agroforestry systems were developed and some of them have been adopted by farmers in the semi-arid regions of the country. Some are fruit tree based systems viz. mango (*Mangifera indica*), guava (*Psidium guava*) and aonla (*Emblica officinalis*); and others are timber/pulpwood based systems (viz. *Eucalyptus* spp, *Leucaena leucocephala*, *Casuarina equisetifolia*, *Anogeissus* and *Gmelina arborea* and teak – *Tectona grandis*) distributed in an area of 13 m ha. Fruit tree based systems are reported to generate net returns up to INR

32 000/ha/year in mango, INR 24 408/ ha/ year in aonla, INR 3916/ ha/ year in guava. Net returns in wood based systems are INR 21 875/ha/year in eucalyptus and INR 19 695/ ha/year in leucaena which are about three times more than that of annual crops. The benefit cost of these systems can be up to 5.5 and provides reasonable returns during the years of low rainfall. Management practices, viz. introduction of animal component and high value intercrops, high density planting, canopy management, and organic production practices in the case of fruit trees can improve returns. The impact of these systems can be further enhanced by integrating them in developmental programs aimed at arresting land degradation and employment generation. The paper discusses the potentiality of agroforestry systems in enhancing returns to communities and opportunities for enhancing their impact further in semi-arid regions.

Keywords: *agroforestry, diversification, drylands, livelihoods, profitability*

OP1.4.4. Cultivating resilient landscapes –opportunities for restoring degraded and vulnerable lands with agroforestry systems

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Shifts in global land use have led to loss of biodiversity, land degradation and declines in ecosystem services. In many geographical areas the deterioration is currently at a near catastrophic scale and the impact is huge both in terms of food production and deforestation. If managed correctly, ecological restoration can offer a chance to reverse environmental degradation as well as help mitigate climate change.

This study identifies such opportunities by analysing how expansion of agroforestry management onto degraded land may restore productivity and ecosystem services. Using reforestation as a restoration alternative has been widely recognized, however, the provision of ecosystem services may be limited. In contrast, agroforestry offers the possibility to generate a wide variety of both environmental and socioeconomic benefits and through that also a higher potential for success. With a combination of qualitative and quantitative approaches, the project captures a broad spectrum of drivers of degradation as well as possibilities to overcome obstacles that hinder restoration. The study includes a comprehensive assessment of opportunities and risks associated with ecological restoration of degraded land. More specifically, the aim of the study is to propose practical solutions for restoration of degraded land with a focus on multiple ecosystem services. The results and recommendations will be based on comparative field research from Sri Lanka and Vietnam.

Keywords: *agroforestry, degraded lands, homegardens, restoration*

OP1.4.5. Bamboo based agroforestry for livelihood security and environmental protection in the semi-arid region of India

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Bamboo is a very important non-timber forest product providing food, raw materials, and shelter for a good part of the world's population. It grows quickly, sequesters more CO₂, can be harvested annually and is more profitable compared to other tree species. The economic viability of bamboo

(*Dendrocalamus strictus*) based agroforestry system was studied during 2007-2010 in the semi-arid region of central India. The growth and quality of *D. strictus*, planted at 10x10 m and 12x10 m spacing, did not vary significantly either grown as sole or with intercrops. However, total culms were higher in sole bamboo and growth of bamboo was better in 10x10 m spacing. Reduction in grain yield of sesame was 9.24, 20.16, and 19.88% and in chickpea was 4.53, 6.92, 8.15% over that of sole crop after one, two and three years of plantation respectively. Maximum reduction in intercrop yield was recorded nearby (0.5 m distance) of bamboo clumps, while there was no reduction in crop yield at ≥ 3 m distance from bamboo clump. The economics of the bamboo based system indicated that during the initial three years, benefit-cost ratio (B:C ratio) of chickpea intercrop varied from 2.05-2.86 as compared to B:C ratio (2.13-3.60) of sole crop. The B:C ratios of sesame intercrop varied from 1.14-1.95 as compared to B:C ratio 1.43-2.43 of sole crop. Bamboo will compensate the monetary losses of intercrop through the harvesting of culms. Thus, total returns will be much higher than sole cropping. Soil pH, organic carbon and available phosphorous increased, while EC decreased in sole bamboo and intercropped area. Maximum improvement in soil quality was under sole bamboo. Large row spacing (≥ 10 m) and low spacing between plants within lines is recommended for cultivation of intercrops for longer periods. Planting of bamboo lines in east-west direction will reduce shade effect. Both will increase economic returns. Bamboo based agroforestry will act as a buffer for farmers of drought prone areas, conserve and enrich soil and improve the environment.

Keywords: *bamboo economics, environment soil quality*

OP1.4.6. Beyond the project cycle: ex-post assessment of agroforestry adoption and management in semi-arid Karnataka

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Relatively little is known about the long-term impacts of agroforestry extension projects. Assessment of technology adoption (particularly agroforestry given the gestation time of trees and woody perennials) is difficult in the immediate aftermath of an intervention. Projects, due to their time-bound and resource-constrained nature, rarely possess the capacity to monitor and evaluate outcomes occurring after operations cease. Where ex-post studies have been conducted, low adoption rates and post-project abandonment of introduced technologies are frequently observed outcomes. Another issue relates to the implementation and management of introduced practices. Figures purporting to quantify the scale of adoption and diffusion may be misleading since they can give the impression that *N* farmers have adopted *X* technology in a uniform and standardised manner. Evidence suggests, however, that technologies are frequently adapted and modified by farmers to achieve a best fit within their own household circumstances and land management objectives.

For these reasons, there is a strong case to be made for revisiting agroforestry project sites years after interventions have ended. This paper reports upon a follow-up case study conducted in 2010/11 in one south Indian village where a DFID-funded agroforestry project was implemented between 2002 and 2004. Using a combination of geospatial mapping, plot surveys and farmer interviews, the fate of an introduced agroforestry technology was analysed in a temporally and spatially explicit manner. In this case, 97% of adopting households (*n*=34) were found to have retained the technology albeit in differing forms and under varying management regimes, and 21% had subsequently expanded the practice on to additional areas of their landholding. Limited diffusion to non-project households was also found to have occurred. At village-landscape scale, fruit-based agroforestry now covers around 15% of suitable agricultural land (excluding low-lying areas of rice cultivation) representing a patchwork effect rather

than a wholesale transformation. Reasons for success will be discussed along with constraints to more widespread adoption.

Keywords: *adoption, dryland, fruit-based agroforestry, management intensity*

OP1.4.7. Below-ground carbon stocks of 21-year-old Grevillea robusta stand in the humid tropics of Kerala

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Tree root biomass production and turnover play a key role in improving soil productivity in land use systems involving woody perennials. Also, tree roots provide substantial contribution to the soil carbon pool which however varies with tree species and management regimes. A field study was conducted at Vellanikkara, Kerala, India in a 21-year-old *Grevillea robusta* stand (460 trees ha⁻¹) to quantify the extent of belowground biomass production and carbon sequestration along with soil carbon stocks. A total of 18 trees were excavated using destructive sampling. The study also explored the distribution of C in the various root size fractions and at various soil depths up to one metre. Mean tree root biomass production based on diameter class ranged from 12.94 to 59.81 kg tree⁻¹ with a mean annual increment (MAI) varying from 0.62 to 2.85 kg tree⁻¹ yr⁻¹ while root biomass production at the stand level was 18.45 Mg ha⁻¹ with a MAI of 0.88 Mg ha⁻¹ yr⁻¹. Based on the diameter class elemental carbon storage in the belowground root, biomass of a mean tree varied from 5.58 to 23.58 kg tree⁻¹. *Grevillea robusta* stand sequestered 8.04 Mg C ha⁻¹ and 77.45 Mg C ha⁻¹ in the root system and soil respectively. On the whole, the net below-ground carbon sequestration (soil + roots) was 80.28 Mg C ha⁻¹. The high root biomass and C sequestration suggest the potential to enrich the soil nutrient status of polyculture systems involving *Grevillea robusta*. Tree tap roots by virtue of their higher biomass and longer soil residence time may greatly contribute to below-ground C sequestration.

Keywords: *silver oak, C stocks, nutrient content, root size classes, soil carbon*

2.0 South Asia: Climate change, multi-functionality, livestock and fish systems

2.1 Agroforestry for climate change mitigation and adaptation

OP2.1.1. Climate change and agroforestry management in Sri Lanka: Adverse impacts, adaptation strategies and policy implications

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Climate change has become a serious environmental, social and economic threat particularly to natural ecosystems, biodiversity, and livelihood of agricultural and forest fringe communities. Climate change is becoming a key driver in agriculture and forest management, but its complexity and magnitude threaten sustainability. Agriculture along with forestry can play an important role in climate change adaptation through diversified land-use practices, livelihoods and sources of income. Sustainable

agroforestry has a tremendous potential to serve as a tool in adapting climate change, protecting ecosystems and livelihoods, and creating a foundation for economic and social development. There are a range of adaptation options available to agroforestry with behavioural, institutional, technological and policy adjustments. This paper reviews the literature and discusses the adverse impacts of climate change on forest and agriculture; adaptation of agroforestry strategies to the climate changes; and policy implications required to promote agroforestry adaptation in Sri Lanka. The adverse impacts of climate change on forest and agriculture are identified as: endangering the natural assets; prevalence of pests and diseases; crop failures and livestock deaths; high levels of food insecurity; and risk of migration into forest areas. Adaptations of agroforestry strategies are revealed in terms of: increase the tree cover outside forests; enhance carbon stocks; conserve biodiversity; reduce risk and intensity of damage; maintain health and vitality; and scale up 'multiple benefit'. Changes in legislation; awareness creation and capacity building; planning for climate-smart farm forest landscapes; uncertainty and risk management; 'no-regret' options; research and appropriate technology development; climate change adjustment programs; and building alliances are explained as the important policy implications. It could be concluded that agroforestry has an important role in climate change adaptation to enhance resilience against climate impacts in farming systems with favourable policy environment.

Keywords: *climate change, agroforestry impacts, adaptation policy*

OP2.1.2. Yield, carbon density and climate change impact on Bagras (Eucalyptus deglupta Blume) in corn-based hedgerow intercropping

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Hedgerow intercropping system using *Eucalyptus deglupta* is an essential option for smallholder agroforestry farms for the reason that they amalgamate timber and food production. Matching tree species to appropriate site conditions and stand management is vital for sound agroforestry timber production. In this study, the multiple linear regression analysis was used to develop appropriate prediction models for estimating yield, biomass expansion factor and future climate impact from soil chemical properties, physiographic characteristics, stand attributes, rainfall, temperature, biomass inventoried volume of bagras planted in hedgerow intercropping agroforestry system. Results showed strong association of independent variables with the dependent variable based on the output of multiple regression analysis in all site index, yield prediction and biomass expansion factor models. It was found that about 96.20% proportion of variance of yield can be predicted from site index, age, basal area and rainfall. Comparison of yield and aboveground biomass accumulated by bagras from alley cropping and other agroforestry systems was in order woodlot > boundary planting > alley cropping. Rainfall in this model also posed considerable influence in volume (2.8% per 100 mm increase). The yield of bagras was negatively affected by the changes in future climate. Yield will decrease linearly with seasonal mean rainfall and in 2050 volume will be reduced to an approximate amount of 0.0190 m³ (8 bd ft) per tree.

Keywords: *agroforestry, bagras, carbon density yield*

OP2.1.3. CO₂ sequestration estimation for the Litsea-Cassava agroforestry model in the central highlands of Vietnam

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The Litsea-Cassava agroforestry model has been popularly practiced in the Central Highlands of Vietnam, producing a stable volume and contributing significantly to household income. This model overcomes the shortcomings of mono-cultivation of cassava on land under shifting cultivation; and according to many cycles, the model helps store carbon. It is therefore it is significant in reducing the greenhouse effect, which has become a global concern in recent years. In order to estimate the environment value of stored carbon of this model, the experimental method involves: sample plot, destructive sampling, conducting chemical laboratory tests to determine the stored carbon in the components of the tree; and then using multi-variables to estimate the biomass and stored carbon in the agroforestry models. This procedure forms the basis of predicting the CO₂ concentration in woody trees in the agroforestry model according to the age period, the cycle, and different combinations. The cycle of Litsea business varied over the 5-10 year period, while absorbed CO₂ in the agroforestry model varied from 25 to 84 tonnes per hectare. Within cycle two and three of this model, maintaining 2-3 shoots/stump of Litsea will have the greatest effect not only on productivity, but also on absorbed CO₂.

Keywords: agroforestry, cassava, CO₂ sequestration, *Litsea glutinosa*

OP2.1.4. Assessment of carbon stocks and fractions under agroforestry plantation in the hilly ecosystems of northeast India

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Soil organic carbon (SOC) degradation is very common in northeast India due to shifting cultivation on hill slopes coupled with unscientific management practices and high rainfall in this region. Agroforestry has a potentially important role to play in climate change mitigation through increased carbon storage in the above ground biomass and below ground soil. A 25-year-old agroforestry plantation consisting of four multipurpose tree species (MPTs) (*Michelia oblonga*, *Parkia roxburghii*, *Alnus nepalensis* and *Pinus kesiya*) maintained at ICAR Research Complex for NEH Region, Umiam, were compared with a control plot (without tree plantation) for soil organic carbon (SOC) stocks and fractions. Soil samples were collected from 0-15, 15-30, 30-45, 45-60 and 60-75 cm and analyzed for SOC stocks and fractions. MPTs showed significant influence on SOC stocks with the mean values ranging from 47.8 to 60.2 Mg ha⁻¹ and followed the order: *A. nepalensis*>*M. oblonga*>*P. kesiya*>*P. roxburghii*>Control. Land conversion from fallow to agroforestry plantation significantly enhanced the total organic carbon (TOC), particulate organic carbon (POC), KMnO₄ oxidizable C (labile C) and microbial biomass carbon (MBC) fractions in soil. The increase in these fractions was greater with *A. nepalensis* compared to other MPTs including control. Overall, on average, MPTs increased the TOC, POC, labile C and MBC by 26.3, 54.9, 27.1 and 34% respectively relative to the control plot. Similarly, approximately 17% increase in SOC stocks was observed under MPTs compared to control. All these C fractions including SOC stocks decreased significantly with soil depths. The increased values of lability index and carbon management index under MPTs revealed that land conversion from fallow to agroforestry plantation have more sensitivity to the changes in SOC and other C fractions in soil. The labile soil carbon fractions were significantly ($P<0.05$) correlated with TOC indicating that the changes in TOC content of

soils is mainly influenced by the labile C pools. The correlation between the TOC and MBC ($r=0.493^{**}$) was higher than that between POC and MBC ($r=0.487^{**}$). The data support the conclusion that conversion of fallow lands to agroforestry plantation is important to mitigate climate change through increased carbon sequestration in soils besides their vital role in improving soil quality.

Keywords: *agroforestry, carbon management, index carbon stocks and fractions, northeast India*

OP2.1.5. GHG Mitigation in a landscape perspective: A case study from semi arid regions of India

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Global warming and climate change are important environmental issues affecting human lives and systems of planet earth. There is a need to reduce the GHG intensity without compromising productivity in order to achieve low carbon development. A whole landscape approach to reduce emissions and increase carbon stocks can help to achieve reasonable quantities of emission reductions by aggregating smallholders' carbon assets and make it possible to take up multiple mitigation activities by involving the same communities. A study was conducted to quantify the extent of emission reductions and carbon sequestration in a contiguous area of 5000 ha (a grid) involving about 2000 households in three villages in southern India. The extent of emission reductions and the potential involved in sequestering carbon by agroforestry was studied. The activities considered were as per the guidelines for the preparation for the national GHG inventories. The extent of GHG emissions are 18 114 t CO₂/ year. The maximum contribution to emissions is from the use of fuelwood for cooking and heating, followed by livestock and paddy cultivation. Low cost alternatives such as efficient lighting and energy efficient stoves can minimise the emissions to the extent of 30%. Integrating high value trees such as teak (*Tectona grandis*) on farm boundaries at a distance of 1.2 m can alone reduce the emissions to the extent of 60% if taken up in the entire rainfed area of the grid. Linking such agroforestry activities with those of the developmental programs operational in India can fetch substantial returns (up to INR 20 million) to communities excluding the benefits from trees. Activities such as agroforestry (integration of trees in landscapes) and introduction of energy efficient systems though individually are compatible with that of the Clean Development Mechanism (CDM), but an umbrella methodology integrating these interventions at a landscape level is lacking. Such an approach will not only help to realize the benefits from trees but also make possible returns from carbon finance mechanisms by integrating smallholders in future.

2.2 Tropical homegardens: multi-functionality and benefits

OP2.2.1. Carbon stock and tree diversity of dry-zone home gardens in southern Sri Lanka

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Tropical homegardens hold a large potential for climate change mitigation and adaptation due to their multifunctional role in providing income and ecosystem services while decreasing pressure on natural forests. However, there is still lack of quantitative data on homegardens and their landscape potential for

carbon sequestration services. In this study, tree diversity and above-ground biomass carbon of woody species was estimated on dry-zone homegardens in the dry south-eastern part of Sri Lanka. A total of 45 homegardens were sampled on size, floristic composition of trees, diameter at breast height (GBH) and height of trees. In total, 4278 trees were sampled and 82 different tree species were recorded. The Shannon Wiener index used to evaluate biodiversity ranged from 0.76–3.01 with a mean value of 2.05. Using allometric models, we find a mean above-ground biomass stock of 13 Mg carbon (C) ha⁻¹ with a large range among homegardens (1–56 Mg C ha⁻¹, *n*=45) due to a variation of tree diversity, species and composition between individual homegardens. Per unit area basis, mean above-ground carbon stock was higher in small homegardens (<0.2 ha, 26 Mg C ha⁻¹, *n*=11) than medium (0.4–0.8 ha, 9 Mg C ha⁻¹, *n*=27) and large (>1 ha, 8 Mg C ha⁻¹, *n*=7) homegardens due to a higher tree density. The results show a vast heterogeneity in terms of carbon and biological diversity within the dry zone homegardens; results that will contribute to closing the knowledge gap of the less studied dry-zone homegarden systems and their functions in storing carbon and providing multifunctional benefits to the users. The results are also useful for whether homegardens should directly or indirectly be considered for inclusion as an activity within Sri Lanka's newly commenced UN-REDD National Programme.

Keywords: *carbon stocks, diversity, home gardens, REDD+*

OP2.2.2. The multiple drivers of homegarden decline in Kerala, India

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Homegardens are a long established and important land use in Kerala, India. These highly diverse agroforests are found in concurrence with rural smallholdings and are estimated to constitute roughly 25% of the state's total land cover, and 50% of agricultural land. While these systems have received a disproportionately small amount of scientific attention, they are widely considered to be model ecosystems that meet human needs while preserving ecosystem integrity. However, recent accounts have suggested that homegardens are being threatened by more economically enticing land uses (e.g. cash-crop plantations). The purpose of this study was to verify the aforementioned hypothesis by determining whether or not smallholding agriculture is losing importance in Kerala, and identifying the drivers of these changes. Semi-structured interviews were conducted between June and November 2013 with land owners at 115 randomly selected rural homesteads in eight of Kerala's 14 districts. The objective was to gain a broad understanding of recent land use changes by: (i) setting the demographic context; (ii) determining the relative importance of major land uses over the last 10 years; and (iii) understanding farmers' land use preferences and the reasons for any changes that may have occurred. Overall, our study found that landholders are becoming less dependent on their homegardens for both subsistence and commercial agriculture. Over the past 10 years there have been declines in the production of food crops, cash crops, spices, timber and livestock. Farmers identified increasing labour costs as the primary driver behind decisions to reduce reliance on agriculture. However, other commonly cited causes included unreliable climate, low returns on investment, and increased prevalence of pests and disease. Thus, while homegardens are declining in importance, it is not due to preference for cash crops, but rather a cocktail of environmental, socioeconomic and political circumstances that have combined to make farming less appealing to smallholders.

Keywords: *homegardens, Kerala land use/land cover, smallholdings*

OP2.2.3. Floral and avifaunal composition, richness and diversity of traditional agroforestry homegardens in the Konkan coast of Maha

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The diversity of trees, shrubs, herbs, climbers and birds in traditional agroforestry homegarden systems contribute to provision of ecosystem services. Homegarden systems involve deliberate management of multipurpose tree species in intimate association with agricultural crops and invariably livestock. This study characterizes the floral and avifaunal diversity and composition in the homegardens of Jaitapur in Konkan coast of Maharashtra. For the investigation, 40 homegardens were selected randomly over a 460 km² area for floral diversity analysis and among them 11 homegarden sites selected for seasonal bird diversity analysis. Quadrature sampling technique and point transect survey method based on distance sampling was used for phyto-sociological and bird diversity analysis, respectively. In total, 206 plant and 76 bird species were recorded in the study area. The homegarden vegetation consists of 88 tree, 48 shrub, 44 herb and 26 climber species. The highest number of plant species belongs to Fabaceae family followed by the Apocynaceae and Cucurbitaceae. The bird density in homegardens was 39 individuals ha⁻¹. The study indicates that homegardens contribute to the provision of ecosystem services such as food, fodder, timber, firewood, vegetables, medicinal values, fertilize soil, carbon sequestration, control pollution and protect the environment. The research findings suggest that homegardens of the region are ecologically and ethno-botanically rich. The wide variety of floral and avian species indicates the high species richness and diversity. This study provides a basis for developing measures for the conservation and management of natural resources. The homegardens and surrounding regions are prone to drastic anthropogenic land-use changes. The present study concludes that land clearing, land breaking and nuclear power project installation will affect the biodiversity and carbon balance. Therefore, the study suggests that the nuclear power project installation should not be started at Jaitapur for future environmental health, safety, public health, security and to avoid future hazards of loss of biodiversity.

Keywords: *agroforestry systems, biodiversity and conservation, ecosystem services, floral and avifaunal diversity*

OP2.2.4. The potential of palms in SE Asian agroforestry systems and home gardens

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Throughout SE Asia, palms constitute an important component in agroforestry systems and home gardens. Most species are used for multiple purposes based on their structural or nutritional properties. Except for a few commodities of worldwide importance such as palm oil, coconut and rattan, many palm products are almost invisible in national statistics because either i) they do not enter the market, ii) they are traded at the microeconomic level or, iii) they are merged with other products in the trade statistics, which makes it difficult to assess their importance. Here we focus specifically on these 'invisible' products and provide an overview of both their sustainability and economic importance throughout SE Asia. We will rank the most important palms according to their versatility, which is an extremely important property especially for smallholders who depend on subsistence agriculture.

Finally, we provide a number of recommendations on future research directions based on experiences from a recently completed EU 7th Framework project.

Keywords: *economic importance, palm products, subsistence farming, sustainability*

OP2.2.5. REDD+ benefits to encourage good practices outside forest lands: a case study in Vietnam

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Vietnam has a long history of incentivizing stakeholders for forest protection and development through reforestation and conservation efforts; most recently through a national programme on payment for forest environmental services (PFES). A benefit distribution system of PFES was formulated and identified as a prototype for REDD+'s benefit distribution and sharing (BDS). The questions remain on how the PFES-based REDD+'s BDS is designed to be compliant with international standards and still be locally appropriate, and how to ensure that the local communities have their share from the scheme while the legal framework for REDD+ particularly on carbon and land rights is unclear and overlapping.

This paper examines the process of formulating a sub-national REDD+ BDS in Bac Kan province, northwest of Vietnam, with a view to minimize negative impacts from uneven forest/land resources, access opportunities, and maximize the share of local communities' benefits through an innovative approach of reducing emissions from all land uses (REALU) e.g. incentivizing "carbon rich land uses" outside of forest including agroforestry. We found that the BDS under REDD+/REALU in Bac Kan would likely work on the principles of PFES where land managers receive incentives for their conservation investments with specific re-arrangements on land and forest tenure required. Local stakeholders' preferences over land use right benefits clearly indicate the importance of formalized resource access rights in benefit sharing. We also found that incentivizing local communities to shift from current unsustainable land use practices to collective forest management and agroforestry development activities will help to avoid land tenure gaps and create more motivations for participation than "only forestry" approaches. In sum, a REDD+ incentive system is possible within prevailing systems with adjustments only at the level of local implementation provided local communities, authorities, and their myriad partners unilaterally agree to adapt, reflect, learn, and improve the system as deemed necessary.

Keywords: *agroforestry, benefit sharing, REDD+, tenure rights, Vietnam*

OP2.2.6. Homegarden agroforestry for socio-economic, ecological and environmental sustainability in Sri Lanka

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Homegarden agroforestry in Sri Lanka has been described as the oldest land use activity, next only to shifting cultivation. It is one of the major forms of land use in the island that has evolved through generations within the available resource frontiers to suit socio-economic, cultural and ecological needs. Though this land use system existed in Sri Lanka for centuries, and claimed to account for 13.1% of the total land area of the country, it started receiving national recognition only recently. During the past two decades, numerous studies have been conducted on homegarden systems by researchers from various

disciplines. Having realized the importance of homegardens, the national development plan has now included strategies to expand and improve food and timber production in such landscapes of Sri Lanka. Development of homegardens in Sri Lanka has been the priority of many development programs implemented over the past few years; among them 'Divi Neguma' (Livelihood Development) program with the target of strengthening 1.5 million homegardens in order to achieve self-sufficiency in vegetables and reduce vegetable prices. This paper shows how homegarden land use system plays a critical role in the agricultural, ecological and environmental sustainability of the country and how beneficial homegardens are to socioeconomic development of the human well-being. Strategies to achieve such goals in the country, the critical gaps that exist, and mechanisms to overcome such gaps are discussed in detail.

Keywords: *homegardens, sustainability, Sri Lanka*

OP2.2.7. Quest for an appropriate bamboo species in tropical homegardens: can *Dendrocalamus stocksii* (Munro) fit the bill?

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India has a rich diversity in bamboo with 23 genera and 130 species. Recently there has been an emphasis on bamboo cultivation in private lands by National Bamboo Mission, Government of India. Farmers in peninsular India are generally reluctant to adopt bamboo in agroforestry practices unlike in northeast India. Though several bamboo species are found in peninsular India, these are mostly difficult to manage due to an excessive branching pattern, distorted shape or thorny habit. Therefore, we initiated a quest for an appropriate species and narrowed down to *Dendrocalamus stocksii* (Munro). The reasons behind the choice of the species and the likelihood of its acceptance in tropical homegardens in peninsular India are discussed.

D. stocksii is naturally distributed in Central Western Ghats, in Karnataka, Goa, Kerala and Maharashtra. It is a strong, solid and thornless bamboo that can attain a height of 10 m, diameter of 2.5-6.0 cm and internodal length of 15-29 cm. Presently, it remains confined to the coastal tracts where it is cultivated in homesteads, and in farm and community lands as a live fence and/or block plantations. Multi-location trials have shown that this species performs well in humid, sub-humid and semi-arid zones, which expands the scope for its cultivation across peninsular India. On-farm trials have shown success in intercropping with *Ipomea batatas*, *Eleusine coracana* and *Curcuma longa*. Larger culms (>4 cm diameter) have demand in furniture and construction sectors while smaller culms (<4 cm diameter) find use in agricultural implements, handicrafts, fencing material, etc. In a few villages in Maharashtra, cultivation of this species is a major source of income and livelihood. The species also has an ideal ideotype for agroforestry. However, large-scale adoption is hampered by non-availability of planting stock. Lack of viable seeds and scalability issues in macropropagation techniques have led to the nascent steps in micropropagation protocol development. There is also an immense potential for improving species through selection and breeding programs.

Keywords: *Central Western Ghats, Dendrocalamus stocksii, multi-functionality, tropical ecosystem*

2.3 Tree fodder and animal nutrition

OP2.3.1. Sustainable fodder production strategy through utilization of wastelands in hills

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Fodder cultivation and management in hills has always been neglected although livestock rearing is an important occupation of farmers in the area. It is imperative to conserve and utilize wasteland resources most efficiently so as to meet the growing needs of food, fibre and fuelwood for human and fodder for livestock consumption. Hybrid Napier was found to be the best on the sloping and degraded lands and under pine and deodar trees and produced 400-800 q/ha. *Grewia optiva*, *Morus alba*, *Robinia pseudoacacia* and *Quercus leucotrichophora* can be grown through improved pits on degraded steep slopes (30-40% slope) and shallow lands. Erect growing grasses like *Setaria kazungula*, *Setaria nandi*, *Panicum coloratum*, and *Pennisetum purpureum* can be grown on the field terrace risers. Kudzu vine (*Pueraria thumbergiana*) was found extremely suitable for protecting unstable, sensitive and highly degraded sites. In silvipastoral system *Digetaria decumbense* with *Bauhinia purpurea*, *Quercus leucotrichophora*, *Grewia optiva* and *Cenchrus ciliaris* with *Celtis australis* produced 1800 to 2450 g/m²/year green biomass. In silvi horti system, green forage yield varied from 5.7 kg/tree by *Quercus leucotrichophora* to 7.7 kg/tree by *Bauhinia variegata*. In the case of grassland management two years of effective closure increased forage production four fold (38.3 q/ha vs. 9.7 q/ha in control). In hills during winter months *Lolium perenne*, *Festuca arundinacea*, and Grassland manawa gave encouraging yields ranging from 210 to 350 q/ha. Among legumes white and red clover were promising. Dual-purpose varieties of wheat (VL Gehun 829 and 616) are capable of providing substantial quantities of green forage (70-80 q/ha). Thus, the production of fodder from the wastelands would reduce the gap between demand and availability, and well-fed livestock would ensure higher productivity and income to hill farmers in addition to environmental security of the hills.

Keywords: *silvipastoral, sustainable tree fodder, wasteland management*

OP2.3.2. Nutritional value and mineral profile of forest foliages in temperate sub Himalayas

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Tree leaves of eleven species (*Celtis australis*, *Ficus nemoloris*, *Ficus palmate*, *Ficus roxburghii*, *Grewia oppositifolia*, *Quercus floribunda*, *Quercus semicarpifolia*, *Quercus glauca* and *Quercus leucotrichophora*, *Alnus nepalensis*, *Bauhinia variegata*) available in temperate sub Himalayas of India were evaluated for their chemical composition, in vitro organic matter digestibility, mineral profile and tannin content. A wide variation in the chemical composition and mineral profile was recorded among different tree leaves. The contents (% DM basis) of organic matter, crude protein, ether extract, neutral and acid detergent fibre (OM, CP, EE, NDF and ADF) ranged between 85.4 to 95.9, 9.5 to 21.1, 3.9 to 5.8, 38.4 to 69.4, and 40.1 to 70.5, respectively. The macro mineral (Ca, P, Mg) level (%) ranged between 1.1-3.0, 0.2-1.5, 0.08-0.18, respectively; whereas, the micro mineral (Zn, Mo, Cu, Fe, Mn and I) level (ppm) ranged between 31.6-83.0, 3.8-7.9, 5.2-8.0, 121-177, 42-402 and 0.06-0.09, respectively. In vitro organic matter digestibility (%) ranged between 52.6 -77.2. The condensed tannin level was found to be low to moderate (1.5-4.2%) in temperate hills. The crude protein level of *G. oppositifolia*, *F. nemoloris*, *F. palmate*, *F. roxburghii*, *Bauhinia variegata* and *Celtis australis* was found to be higher (P<0.05) than other species and the fibre fractions were negatively correlated with the protein content and in vitro organic matter digestibility. The macro mineral (Ca, Mg) and micromineral (Zn, Mo, Fe,

Mn, Co and Se) content of tree leaves were higher than the normal range of requirement. However, the level of P, Cu and I was below critical level in most of the tree leaves. It may be concluded that the mineral contents were adequate in most of the foliage except P, Cu and I. *Grewia oppositifolia*, *Ficus nemoloris*, *Ficus palmata* and *Ficus roxburghii* can serve as good proteinaceous source with higher digestibility in animal's diet.

Keywords: digestibility, mineral, tannin, tree leaves

OP2.3.3. Fodder production through agroforestry: a boon for profitable sheep and goat farming

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Agroforestry models for fodder production viz., silvipasture, hortipasture, horti silvipasture and agrisilvi system were established in degraded cultivable wastelands. The wastelands could be effectively utilized for fodder production vis-à-vis livestock production through agroforestry system, which is also an environmentally safe system of land use. Silviculture, silvipasture and hortipasture systems are viable technologies to rehabilitate degraded wastelands. By effective utilization of wastelands for fodder production, the agroforestry system serves as a sustainable land use technology for livestock production.

Silvipastoral system increased the dry fodder biomass yield from 1.25 to 4.50 tonnes (natural pasture), to 4.50-8.70 tonnes per hectare per year and could hold 8-15 sheep per hectare. The average dry fodder production potential of the hortipasture, hortisilvipasture and hortisilvi system were 3.855, 4.410 and 1.282 tonnes per hectare per year respectively under rain fed conditions. Agrisilvi system of fodder production (Napier-Bajra hybrid grass + *Sesbania grandiflora*) yielded more dry fodder biomass and protein under irrigated conditions.

Among the agroforestry models, Napier-Bajra hybrid grass + *Leucena leucocephala*/*Sesbania grandiflora* as agrisilvi system of fodder production was more successful for irrigated lands. Silvipasture with *Leucena leucocephala* + *Gliricidia sepium* + *Albizia lebbek* as tree components and *Cenchrus ciliaris* + *Stylosanthes scabra* as pasture components was recommended for greening of wastelands in rain fed condition. Lambs (10-12 kg) when integrated in silvipasture (*Leucena leucocephala* + *Gliricidia sepium* + *Cenchrus ciliaris* + *Stylosanthes scabra*) at the rate of 30 numbers/h increased the body weight gain per day by 68% and the animal holding capacity by 50% as compared to natural grazing land during rain fed season. Goats (12-13 kg) when integrated (8goats/h) on mixed silvi pasture gained 62.98% more body weight (50.02 vs 30.69 g per day) compared to goats raised in natural grazing lands. When lambs (12-15 kg) were integrated in legume hortipasture (48-50 lambs/h) by giving one hour additional complementary grazing, they gained 20% and 26% more body weight in lush and lean season respectively, compared to lambs grazed in natural grazing land.

Keywords: agroforestry, fodder production, sheep and goat, integration

OP2.3.4. Development of suitable silvipasture models for meeting fodder requirements in TamilNadu

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There is a gap between fodder availability and supply in TamilNadu and hence livestock growers are facing fodder shortage during the lean season. Experiments were conducted to develop suitable silvipasture models for the drylands of TamilNadu. The silvipasture experiments were conducted with *Acacia leucophloea*, *Ailanthus excelsa*, *Gmelina arborea*, *Tectona grandis* and *Pongamia pinnata*. Among eight fodder crops tried viz. 3 grass fodder viz. *Cenchrus ciliaris*, *Cenchrus setigerus*, *Cenchrus glaucus*; 2 cereal fodder viz. fodder sorghum (COFS 27), fodder sorghum (COFS 29); and 3 legume fodder viz. lucerne, desmanthus and stylosanthus tried under *Acacia leucophloea*; *Cenchrus* spp was found to be the suitable fodder crop for *Acacia leucophloea*-based silvipasture system. The results showed that among the four fodder crops viz. fodder cowpea, fodder sorghum, stylosanthus and desmanthus tried under *Ailanthus excelsa*, fodder cowpea was the suitable fodder crop for *Ailanthus*-based silvipasture system. Among the following six fodder crops viz. fodder sorghum (COFS-27), fodder sorghum (COFS-29), fodder maize, fodder 'cumbu', fodder cowpea and desmanthus raised as intercrops under teak, fodder cowpea was the suitable fodder crop for teak-based silvipasture system. Among the five fodder crops viz. blue buffel, para grass, cumbu napier hybrid, guinea grass and desmanthus raised under *Gmelina arborea*, guinea grass was the suitable fodder crop for *Gmelina*-based silvipasture system. The following fodder crops viz. fodder sorghum, cenchrus, guinea grass, desmanthus, stylosanthus and lucerne were raised as intercrops under *Pongamia pinnata*. The results showed that cenchrus, guinea grass and desmanthus were suitable fodder crops for *Pongamia pinnata*-based silvipasture system. It is concluded that the adoption of suitable silvipasture models in the drylands of TamilNadu would not only meet the fodder requirements but also enhance the productivity of the drylands of TamilNadu.

Keywords: silvipasture model, *Acacia leucophloea*, *Ailanthus excelsa*, *Gmelina arborea*, *Tectona grandis*, *Pongamia pinnata*

OP2.3.5. Growth and yield of agricultural crops intercropped under three multipurpose trees (MPTs) in Mizoram, northeast India

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A field study was carried out in Mizoram University campus to assess the growth behaviour of three multipurpose trees (MPTs) viz *Gmelina arborea*, *Melia azadirach* and *Aluns nepalensis* and their effect on three agricultural crops (ginger, turmeric and maize) over a three-year period. The tree height and collar diameter were always higher in the intercropped plots than that of the sole crops. The canopy cover, litter fall and green biomass productivity were maximum in *Gmelina arborea* intercropped, followed by *Aluns nepalensis* and *Melia azadirach*. The soil pH and organic carbon show a significant ($P < 0.05$) variation between the treatments with comparatively higher values in plots having species mixture than those of control treatment. The NPK level in general was maximum under tree-crop interaction than in sole crop (control). The yield of crops differed significantly ($P < 0.05$) between the treatments and was influenced by tree association. Ginger (6.22 t ha^{-1}), turmeric (5.64 t ha^{-1}) and maize (7.07 t ha^{-1}) registered maximum yields under *Alnus nepalensis*. The distribution of above ground biomass (g/plant) on dry weight basis was much variable among the tree species and the biomass production was more pronounced in *Gmelina arborea* (16.03 g/plant) followed by *Melia azadirach*

(16.00 g/plant) and minimum in *Alnus nepalensis* (15.06 g/plant). Above ground biomass of crops was always higher in tree-crop association. Maize registered higher density (47 295.85 plants ha⁻¹) under *Alnus nepalensis*, followed by ginger (45 850.53 plants ha⁻¹) and turmeric (42 523.05 plants.ha⁻¹). Better finger size and yield were recorded in ginger and turmeric from intercropped plots than sole crops while the maize yield was higher under sole cropping. Land Equivalent Ratio (LER) was found maximum in *Alnus nepalensis* (2.54) intercrop plot, followed by *Melia azedarach* (2.50) and *Gmelina arborea* (2.13).

Keywords: MPTs, intercropping, crop productivity, Land Equivalent Ratio (LER)

OP2.3.6. Traditional agroforestry systems for rural development in the hills of Garhwal Himalaya, India

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The study was carried out in traditional agroforestry systems in different parts of Garhwal Himalaya, India during 2012-13 with varying altitudinal ranges (1000 to 1500m, 1500 to 2000m and 2000 to 2500m asl) comprising northern and southern aspects to assess the change in various tree crop combinations and their utilization for rural development and the needs of the local people.

The major traditional agroforestry systems viz. agrisilviculture (AS), agrisilvihorticulture (ASH) and agrihorticulture (AH) systems were studied with reference to change in elevation and aspects. The tree-crop combinations adopted on the different study sites were dependent on the climatic and geographical situations and accordingly these combinations are used by the local people for their livelihood. During the study the very common and important agroforestry trees *Grewia optiva*, *Celtis australis* and *Melia azedarach* were usually present with agricultural crops such as *Triticum aestivum*, *Zea mays*, *Eleusine coracana*, *Echinochloa frumentacea*, *Amaranthus caudatus*, *Phaseolus vulgaris*, etc in the elevation ranging 1000 to 1500m. In the middle Himalayan region (1500-2000m), the common tree species such as *Quercus leucotrichophora*, *Grewia optiva*, *Celtis australis*, *Prunus armeniaca* (fruit tree) were present with agricultural crops like *Triticum aestivum*, *Eleusine coracana*, *Amaranthus caudatus*, *Phaseolus vulgaris*, *Solanum tuberosum*, etc. In the elevation 2000 to 2500m, the agroforestry tree species like *Quercus leucotrichophora*, *Quercus floribunda*, *Quercus semicarpifolia*, *Juglans regia*, and *Malus domestica* (fruit tree) form the basic combination with agricultural crops such as *Solanum tuberosum*, *Pisum sativum*, *Amaranthus caudatus*, and *Phaseolus vulgaris*.

The farmers of the study area showed a close relationship between the traditional agroforestry systems and their daily domestic requirements for fuel, fodder, fibre and fruits. However, the change in altitude and aspects play a major role in the availability of these multifarious benefits from existing agroforestry systems.

Keywords: traditional agroforestry, altitudinal gradient, aspect, agrisilviculture (AS), agrisilvihorticulture (ASH), agrihorticulture

3.0 The business of agroforestry: applying science

3.1 The viability of trees as crops: agroforestry, pulp and wood-based enterprises, cocoa, coffee

OP3.1.1. Agroforestry for food and wood security: an industry experience in India

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World over the common practice for growing pulpwood plantations is to plant a single species in a block on a forest area which was acquired, clear felled and planted. However, ITC's initiative on agroforestry plantations started on private lands in 1992 to meet its wood demand for production of paper and paperboard. The clonal plantations under agroforestry gave a productivity of 25 t/ha/yr as against 6 t/ha/yr from seed origin plantation.

By now the company has successfully promoted 158 000 ha plantations. In the first phase, block plantations are raised with a spacing of 3 x 1.5 m with 2222 trees/ha. The intercrop is taken in between the lines in the first year only as the canopy closes in the second year onwards. A new concept was evolved after a series of experimental trials with different planting geometry wherein pulpwood trees are planted apart either in a single or double row (alley cropping) leaving a wide gap of 8 m to allow maximum sunlight for growing food crops in between the lines. The model accommodates 2000 trees/ha and the land allocation is 25% for tree crops and 75% for agricultural crops. Every year the farmer can take food crops regularly and harvest the trees after 4 years interval. In case of crop losses due to drought, floods, pests and diseases, the income from the trees hedges the risk. The novelty of the agroforestry model is to improve farm productivity and profitability while conserving the environment and bringing diversification on farm lands. By now, ITC has put up “agroforestry for wood and food security” demo plots in Andhra Pradesh and Madhya Pradesh over an area of 4000 ha.

The agroforestry plantations of 158 000 ha over one cycle of four years create an estimated wood asset value of INR 5530 cr (yield of 100 t/ha and an average price of INR3500/t), offset 28.9 million tonnes CO₂, and create employment for 71 million people from various activities thus greening the triple bottom line (environmental, societal and economic) and creating enduring value to the nation.

Keywords: *spacing, alley cropping, wood yield, pulp wood, clonal plantations*

OP3.1.2. Highest wood production by poplar (*Populus deltoides*) clones under agroforestry systems in the Punjab State of India- a case study

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NABARD, in collaboration with WIMCO –a wood-based industry, promoted *P. deltoides* clones-based agroforestry irrigated plantations in the Indian states of Punjab, Haryana and Uttar Pradesh from 1984 to 1995, which became highly successful. The spacing followed was 5 m x 4 m accommodating 500 trees per hectare. Generally the cost of cultivation was around INR 0.1 million (US\$ =INR 60) and the income was around 0.8 million, with agriculture income being 10%. Due to overproduction, the poplar wood price started falling in 2002 and reached the lowest price of INR 800 per tonne in 2004, hence the farmers stopped growing poplar. In the year 2000, the Hon'ble Supreme Court banned tree felling and

poplar resurfaced again with much vigour. To ascertain the position, the author undertook a study in Chahal village, Nawasar district of Punjab along with WIMCO officials and held discussions with the farmers and plywood manufacturers, and then met two progressive farmers who had 20 hectare irrigated land and planted poplar in such a way that every year they could harvest 2 ha plantations. They followed a 6-year rotation cycle when trees reached an average height of 18 m and a girth of 90 cm, which yielded 180 tonne wood per hectare and clocked an income of INR 0.72 million at a sale price of INR 4000 per tonne. The projects were both technically feasible and financially viable with more than 50% IRR. Sugarcane and wheat were intercropped only for two to three years. Marketing of wood was no problem, because in Yamunanagar there were more than 1000 wood-based industries. It was concluded that poplar based clonal agroforestry worked wonders and both the farmers and wood industries used it sustainably. Besides, it assisted in environmental amelioration, conserved genetic resources and mitigated climate change.

Keywords: *agroforestry clonal poplar, wood*

OP3.1.3. Small farm diversification strategies by coffee farmers around Mount Kenya in Kenya

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Improved understanding of the main drivers that influence productivity patterns in smallholder coffee farming systems can help better target agricultural innovation. The purpose of this study was to investigate if smallholders with decreasing or increasing coffee production around Mount Kenya invest in enterprise intensification and diversification strategies such as with maize, banana, livestock and agroforestry trees. Using functional typologies of smallholder coffee farms determined *a priori*, coffee yield data from 180 farms was used to identify and analyse productivity on farms with increasing, decreasing and constant coffee production trends. Simple descriptive statistics such as means, range, counts, enterprise scoring, diversity analysis, pair-wise correlations and general linear regression analysis were used to compare farm typologies.

Results show similarities in smallholder farm diversification strategies; coffee production is nonetheless declining in smaller farm sizes compared to farm sizes where it's increasing. Data suggest that on decreasing coffee, farmers with smaller land size diversify into crops such as banana and maize probably in a strategy to secure household food security. Results showed that smallholders expanding coffee production are also associated with productive milk enterprises. Analysis was consistent that land size, coffee production (number of bushes, cherry yields/ha), livestock units, trees, banana, maize value, nutrient inputs (manure and fertilizer) and labour costs influence coffee farms' productivity and are useful indicators to distinguish farm typologies. In conclusion, this study highlights the importance of increased awareness by policy makers on coffee production trends and the need to promote enterprises that are of interest to farmers.

Keywords: *coffee, agroforestry, farm diversification, productivity, tree densities*

OP3.1.4. Cacao Agroforestry System (CAS) improving productivity and profitability of smallholder cacao in Sulawesi

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Indonesia is the third largest producer of cacao in the world after Côte d'Ivoire and Ghana. Cacao production began in Sulawesi in the 1980s. It is now a major crop on the island, covering over 950 thousand hectares, equalling 59% of Indonesia's cacao-growing area. By 2010 Sulawesi accounted for 67% of Indonesia's cacao production. As in other countries, smallholder production is the norm in Indonesia. Approximately 2.2 million smallholder farmers cultivate 1.5 million hectares of cacao, supplying 92% of the national production. A study was conducted in Sulawesi to understand smallholder cacao systems and the importance of cacao to smallholder livelihoods. The study identified the range of productivity, agrobiodiversity and economic profitability associated with smallholder systems. A typology of four smallholder cacao systems was identified: monocultures, cacao integrated with shade trees, cacao integrated with fruit and timber trees, and homegardens. Cacao is the dominant species in all systems, except homegardens where it is a minor component. In south Sulawesi and southeast Sulawesi, farmers earn IDR 5.0 million (14% of total household income) and IDR 14.5 million (52% of total household income), respectively. The productivity and profitability of smallholder cacao systems has been decreasing over the last 10 years. Yields have plummeted from 1000-1500 kg/ha to 500-700 kg/ha. Discouraged, many farmers want to switch to other commodities which could have a devastating effect on the cacao industry. Key problems with smallholder production are the high incidence of pests and disease, limited access to quality planting material, and the low level farm management. The paper provides analysis and recommendations based on the results of a scoping survey, garden inventory, and group discussion with farmers regarding how to improve the productivity and profitability of smallholder cacao livelihood systems, while maintaining sustainable environmental management.

Keywords: *Cacao Agroforestry System (CAS), productivity, profitability, smallholder, cacao, Sulawesi*

OP3.1.5. Cocoa agroforestry systems vs. monocultures under conventional and organic management - results from tropical Bolivia

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Cocoa is one of the most important export commodities for many developing countries and provides income for millions of smallholders. The expansion of cocoa production has resulted in habitat destruction, biodiversity loss, and soil degradation. The prevalent cocoa production systems worldwide are conventional monoculture full sun systems. Agroforestry systems are argued to be a viable strategy for sustainable cocoa production. However, data-based information on the advantages and limitations of different cocoa production systems is limited. Pairwise comparisons on the long-term performance of cocoa monocultures and agroforestry systems under conventional and organic management are inexistent.

FiBL is pioneering to fill this knowledge gap with a unique long-term field trial in tropical Bolivia established in 2008. The trial consists of six treatments: two monocultures (MONO CONV/ORG) and two agroforestry systems (AF CONV/ORG) under conventional and organic management; one organic

successional agroforestry system (SAFS) with dynamic shade management; and a fallow of the same age serving as a reference for biodiversity and soil fertility studies. The treatments are representative for current cocoa production systems of smallholders. Parameters regularly assessed include canopy openness, cocoa stem diameter and bean yield, pests and diseases, soil fertility, carbon stocks, economic data and biodiversity.

Five years after planting, results showed significantly shorter tree circumference (18% and 33%) in AF systems and SAFS, respectively, compared to MONO systems. Tree circumference correlated strongly with cocoa bean yield, and highest bean yields were recorded in MONO CONV as expected. Additional products like banana/plantain, cassava, pineapple, etc. were harvested in AF systems and SAFS, which may compensate for lower cocoa yield in the first years. First results indicate that disease incidences were higher in MONO systems compared to AF and SAFS.

Future research will investigate cocoa performance after the establishment phase and thus provide indications on the long-term sustainability of the different systems.

Keywords: *agroforestry, cocoa, organic, agriculture, systems comparison*

3.2 Biofuels: using trees as a sustainable energy resource

OP3.2.1. A tool for more sustainable fuel use? Carbon finance for cookstoves in India

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Replacing less efficient traditional cookstoves with improved models of stoves has the potential to create a number of social and environmental benefits. Increased burning efficiency leads to reduced fuel demand, while emission reductions of particulate matter and climate forcing species lead to both improved health and climate change mitigation. In India, the majority of the population still lacks access to clean cooking stoves or facilities. With 90% of the rural population and 31% of the urban population still primarily depending on solid fuels for cooking, the switch to using improved stoves has the potential to greatly reduce the demand on biomass fuel resources while also improving livelihoods and addressing climate change. On this basis, there have been a number of cookstove dissemination initiatives in India (home to a past national cookstove program), many NGO efforts, and a slew of commercial initiatives. Still overall none of the dissemination efforts have been successful at achieving both a significant distribution scale and sustainability. Carbon finance provides an opportunity to address some barriers in dissemination, providing additional financing which can be used to subsidize stove costs making them affordable to lower income consumers, while allowing for the scaling up of dissemination efforts at the same time. Despite these potentials, actual impacts of carbon finance on cookstove projects are not yet well known. Therefore to examine the potential of carbon financing as a tool for promoting cookstove dissemination, this research looks at the impacts of carbon finance on organizational activities and business models using India as a case study. Results based on 19 semi-structured interviews provide an overview of different organizational approaches employed, perceptions around carbon financing from both those choosing to and not to apply for carbon certification, and identification of the opportunities, challenges and unknowns surrounding the use of carbon finance for cookstove dissemination.

Keywords: *cookstoves, India, carbon finance*

OP3.2.2. Alley Coppice: an innovative agroforestry system that combines timber and energy wood production

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The push to combat climate change and greenhouse gas emissions and reduce our dependency on non-renewable energy sources has never been more topical. One aspect of this is the need to decrease human pressure on natural forests, which poses questions as to how timber, food, and bioenergy production on agricultural land can best be obtained. Agroforestry and Short Rotation Coppice (SRC) are recognised as separate economically viable and sustainable cropping systems. But little is known about the agricultural and ecological interactions if the two are combined. This mixed approach, which we call alley coppice, has potential advantages including: (i) regular income guaranteed from the SRC component; (ii) improved stem formation of timber trees and reduced pruning intensity in mixed systems, because of competition for light between species; (iii) planting of timber trees at final density, avoiding expensive thinning costs; (iv) reduced wind and storm damage to timber trees during the initial years of tree growth, due to the protection provided by the SRC component, and; (v) improved ecological impacts such as increased biodiversity, reduced spread of diseases, reduced soil erosion, and reduced soil nutrient depletion.

This approach is being assessed within the European AGROCOP project (Woodwisdom-Eranet EUPF7; <http://www.agrocop.com/>) and involves seven research institutes from five countries: France, Germany, Ireland, Italy, and the United Kingdom. One of our research objectives is to evaluate the yield of alley coppice system in comparison to monocultural systems using the Land Equivalent Ratio (LER). We also focus on water, nutrient and light competition.

Results presented were obtained in a seven-year-old experimental field located in northern Italy. This has *Pyrus* and *Sorbus* as timber trees, and poplar SRC grown in a two-year rotation cycle. We analysed the yield and survival rate of SRC poplars, and the leaf phenology and stem form of timber trees.

Keywords: *greenhouse gas, short rotation coppice, soil erosion, forests*

OP3.2.3. A novel model for mangrove agroforestry to provide livelihoods and biofuel feedstock

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Mangrove plantations have traditionally been done as part of restoration of degraded natural mangrove forests and rarely for agroforestry. Mangrove species have the unique characteristic of being able to survive on seawater without requiring freshwater which most other tree species require for their growth. From the perspective of cultivation for providing feedstock for biofuel production, this is the best way to overcome the food versus fuel issues which most other biofuel feedstocks have with respect to land use and requirement of water. We describe a novel model for achieving mangrove cultivation in non-native coastal areas or degraded mangrove forests through a technique called Riley Encased

Methodology® developed by mangrove.org®. This will help in creating livelihoods for the local population through the sale of sustainably harvested mangrove biomass to commercial biofuel producers and since the mangrove ecosystem is known to improve growth of aquatic species, this will also provide improved opportunities for sustainable aquaculture.

The Riley Encased Methodology® (REM) has been developed for the purpose of establishing mangroves along high-energy shorelines, revetments, and bulkheads where natural recruitment does not occur and where conventional planting methods are ineffective. The principles of REM include the processes of individual seedling isolation within tubular encasements and adaptation of the juvenile plant to the external environment of the plantation site. The success of REM results from specifications for encasement preparation, propagule or seedling selection, and positioning of both encasements and seedlings according to elevation and tidal regimes.

In addition to providing livelihood opportunities through biofuel feedstock and aquaculture, employing REM in non-native areas would provide protection from coastal erosion and other benefits that natural mangrove forests provide.

Nandan Cleantec is conducting R&D for producing second generation biofuels from biomass and mangrove biomass would be a sustainable feedstock for commercialization of this technology.

Keywords: *agroforestry, biofuels, mangroves model*

OP3.2.4. Trees as a global source of energy: from fuelwood and charcoal to pyrolysis-driven electricity generation and biofuels

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Future increased demand for energy worldwide must be based on renewable sources of energy to avoid catastrophic increases in atmospheric CO₂ and to replace non-renewable sources of energy that have already passed their peak production. Trees can provide renewable biomass in the form of fuelwood, charcoal, pyrolysis-driven electricity production and biofuels. People's access to energy is often referred to as "the missing Millennium Development Goal". Energy is important for development and it is certain that energy access will be included in the post-2015 development agenda within a new set of Sustainable Development Goals. Unfortunately, current global policy initiatives to ensure universal access to sustainable energy essentially ignore the potential of tree-based bioenergy. This is because of partially correct perceptions that wood fuels are associated with poverty and are polluting and dangerous; and generally false assumptions about links between woodfuel use and environmental degradation. Problems associated with the use of tree biomass could be overcome relatively easily. There have been valid concerns that growing crops for bioenergy might compete for resources for food production. However, bioenergy provides farmers and land users with new and important sources of income and fit well into integrated food-energy systems. Trees provide multiple benefits to agriculture, including soil fertility, water management, fruit production, fodder production, fuelwood and timber. Tree growing is eminently scaleable, suitable for large-scale production in woodlots and small-scale production on farms under agroforestry systems. Even where large-scale processing of products is needed, such as the processing of biofuels or biomass production for community electricity generation, small-scale landowners can provide products for collection and bulking up as currently happens in a number of agricultural value chains. An unprecedented global partnership is needed to ensure that renewable tree-based bioenergy plays its proper role in future global energy mixes.

Keywords: *biofuels, biomass, energy policy, institutional framework*

OP3.2.5. Agroforestry –a promising option for tree borne oil seeds production

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India has a large diversity of traditional agroforestry systems aimed at multiple benefits. The focus of these traditional agroforestry systems are crop production and trees which are grown in rows along with crops or along boundaries or bunds. Biofuel crops can also be incorporated into traditional agroforestry systems without affecting the production of food crops. In some situations, biofuel crops such as *Pongamia pinnata* grown on bunds could enhance crop production. Tree borne oil seed-based agroforestry system is an alternative model available for the rehabilitation and utilisation of the vast expanse of wastelands and degraded land in the country. Another matter of great concern is meeting the energy needs of the rapidly growing economy of the country. In this situation, biodiesel has emerged as one of the promising options. Hence production of raw materials for biodiesel such as oilseeds is now gaining importance. The use of wastelands to produce tree borne oilseeds can realise the twin objectives of rehabilitation of a vital land resource and obtaining an energy substitute. Although there are definite advantages in this approach, achieving the desired outcome is not easy. The major constraint is the lack of accurate information about the cultivation practices of the species, their potential yields and income. Though there are several trees yielding oilseeds, *Jatropha curcus*, *Pongamia pinnata*, *Madhuca indica* and *Azadirachta indica* are the species of high potential. The systematic approach backed by scientifically validated information is necessary in the promotion of these species. Therefore, in order to use agroforestry systems for biofuel production and sustainable development in India, the research, policy and cultivation practice will have to focus on improving the traditional and modern agroforestry systems; and enhancing the size and diversity of agroforestry systems by selectively growing trees by designing context specific multipurpose agroforestry systems for biofuel production.

Keywords: *biofuel, intercrops, tree borne, oil seed, wasteland*

OP3.2.6. Assessment of trees outside forests for selected districts of Haryana, India through high resolution remote sensing

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Yamunanagar and Panchkula are key districts in Haryana state, which are not only enriched with natural forests along the Shiwaliks, but also full of agroforestry activities in the plains. Agroforestry has become popular in these districts due to better returns and easier marketing facilities of farm grown wood. Hence a precise assessment of tree cover and its growing stock, especially in the light of its role in carbon sequestration, is essential as an important climate change mitigation strategy. Indian high resolution remote sensing sensors such as Cartosat-1 Panchromatic (Carto PAN) and LISS IV multispectral sensor offer scope to assess TOF with high precision.

A study was conducted to prepare spatial database using orthorectified Carto PAN data involving detailed classification of TOF configurations. Spatial structure of TOF was considered under three categories, viz., individual trees (scattered), linear and patch. Patches ≤ 1 ha in size were considered as constituting tree cover. Trees outside forests included tree cover as well as planted areas of ≥ 1 ha.

Spatial distribution of TOF was prepared at 1:10000 scale with detailed classification of configuration corresponding to origin or association of the vegetation. Grid-based scheme was prepared at 5 km spacing for each major TOF configuration and geographical coordinates representing strata were chosen for field measurement. GIS tools were used for estimating strata volumes based on spatially explicit plot wise volumes.

Satellite data oriented interpretation showed that Yamunanagar and Panchkula districts showed tree cover of 111 km² (6.3%) and 44 km² (4.8%) respectively. Based on stratified random sampling approach and stratum wise extrapolation, we estimated that Yamunanagar district comprised 41.9 'lakh' trees whereas Panchkula district had 27.9 lakh trees with growing stock of 7.6 and 2.7 lakh Cu M respectively.

Keywords: growing, stock inventory, remote sensing, GIS, trees outside forests

3.3 Improving nutrition through agroforestry: the business case

OP3.3.1. Potential of fruit trees in the drylands of sub-Saharan Africa for food and nutrition security and income generation

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Many fruit tree species in drylands of sub-Saharan Africa (SSA) provide edible fruits which are locally of great importance for food security, nutrition and income generation particularly during droughts and the 'hunger gap' periods occurring at the beginning of the cropping season. Women and children are often strongly involved in and benefit from wild fruit collection, processing and trade. Cultivation of exotic and indigenous fruit tree (IFT) species in agroforestry systems diversifies production options for small-scale farmers and can bring significant health, environmental and economic benefits particularly in the face of climate change. In this study we present case studies from different dryland regions in SSA to showcase the importance of tree fruits for nutrition and food security and for local livelihoods.

In Adjumani district, Uganda, 44% of 68 respondents reported to use the fruit pulp of *Balanites aegyptiaca*; 84% of the fruits were harvested from the wild mainly by children and women. In Mwingi district, eastern Kenya, the 104 respondents consumed fruits of 57 IFT species; 36 species were found on-farm and 21 in the woodlands. During the 'hunger gap' periods, at least 12 IFT species have mature fruits. In semi-arid eastern Kenya, mango farming generated mean annual incomes of 320 USD per household (n=87) from 77 mango trees on average. In the Miombo region of southern Africa, on-going participatory domestication of *Uapaca kirkiana*, *Strychnos cocculoides* and *Sclerocarya birrea* has developed new tree crops to capture economic opportunities while at the same time reducing the dependence and exploitation of wild tree populations. Similar efforts are under way in the West African Sahel where *Adansonia digitata*, *Tamarindus indica* and *Ziziphus mauritiana* are currently being domesticated.

More efforts are needed in research and development to fully utilize the potential of fruit trees for improving livelihoods in the drylands of SSA.

Keywords: agroforestry, exotic fruit trees, indigenous fruit trees, participatory tree domestication

OP3.3.2. Indigenous trees incubators in agroecological zones in Kenya for the commercialization of nutritional foods

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The genetic diversity and traditional knowledge of indigenous trees is disappearing rapidly in Kenya. Many of these trees provide essential nutrients through their fruits, leaves, bark, and/or roots that are able to prevent human diseases. To commercialize nutritional foods from indigenous trees, a long term, iterative, participatory and multidisciplinary innovation strategy has been designed. The strategy involves the identification and prioritization of indigenous trees for their conservation, propagation, regeneration and commercialization. It utilizes a systems approach that depends on the fields of ethnobotany, horticultural science, agroforestry, rural sociology, food science, nutrition, law, and business development. This innovation is called Indigenous Trees Incubators (ITIs).

ITIs will be established in each of the agroecological zones in Kenya. Each ITI will serve as the research base for 1) participatory ethnobotanical surveys; 2) conservation of germplasm; 3) prioritization of cultivars with desirable traits; 4) development of propagation protocols; 5) integration of indigenous food trees into the farming and non-farming landscapes and national policies; 6) development and commercialization of nutritional food products; and 7) benefits sharing.

The force behind ITIs is a private company in Kenya concerned with the conservation and commercialization of healthy foods derived from indigenous trees. This private company serves as the hub, pulling together ethnobotanists, horticultural scientists, food, beverage and nutraceutical companies, food scientists, lawyers and policy makers. Extensive conversations and, in some cases, draft MoUs, are in place with Kenyan and international gene banks, National Agricultural and Forestry Research Centres, Ministries of Agriculture and Environment, county decision makers, community representatives, national and international research universities, national and international food and beverage companies, and research foundations.

This paper describes the 7-point ITI strategy in detail, providing an innovative pathway whereby the public and private sectors can pool their resources to integrate indigenous trees into national and international applied science programs and economies.

Keywords: *commercialization, incubators, indigenous, nutritional*

OP3.3.3. Wildlife, a forgotten resource of agroforestry and shifting cultivation landscapes

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Agroforests and swidden cultivation areas are not devoid of wildlife. They are generally inhabited by a suite of adaptable, fast-reproducing species able to withstand human activity; often rodents, small-sized, fast-reproducing and resilient to hunting. These species are not of immediate concern to conservation biologists and do not attract tourists. They however do have an important role in the food security and nutrition of farmers by being pests, raiding and destroying crops, and a source of nutrient-rich meat. This “garden hunting” is a very common activity as wild animals enter swiddens and fallows because of the relative abundance of food sources. Research shows that hunting in farmland is indeed disproportionately more frequent relative to field cover in the landscape, but also that offtake from farm

lands is much lower than from the fallows and remaining forests. In an idealized scenario, crop losses resulting from the presence of these species could be balanced by protein gains from hunting. We will review and present the actual evidence of the importance of this forgotten resource for the food safety, nutrition and livelihoods of local farmers and propose some management recommendations.

Keywords: *swidden cultivation, wildlife*

OP3.3.4. The effect of tree cover on child nutrition in Indonesia: examining the relationship between tree cover and consumption of micronutrient-rich foods

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There is growing recognition of the contribution of forests to food security and nutrition. In rural areas with poor market access, forests may provide an essential source of nutritious food. Micronutrient deficiency is a serious problem in Indonesia. Approximately, 100 million Indonesians suffer from one or more micronutrient deficiency particularly in iron, zinc, and vitamin A. However, the effects of forest cover on food consumption patterns in Indonesia have not yet been studied.

To test the effect of forests on the consumption of nutritious foods, we looked at the relationship between tree cover and consumption of micronutrient-rich foods by children between the ages of one and five years in Indonesia. We used consumption data from the 2003 Indonesia Demographic Health Survey (DHS) combined with GIS tree cover data for 2003 from the Global Land Cover Facility (GLCF). Our results show that tree cover is positively associated with the frequency of Vitamin A rich fruit and animal source food consumption. There is no statistically significant relationship between tree cover and the frequency of leafy green vegetable consumption. Our results suggest that Indonesian children living in areas with high tree cover enjoy diets that are richer in micronutrient-dense foods.

Keywords: *food security, nutrition, micronutrients*

OP3.3.5. Moringa – a vegetable tree for improved nutrition, health and income of smallholder farmers

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Moringa (*Moringa oleifera*) is a perennial softwood vegetable tree and widely grown in the tropics of Asia, Latin America, and sub-Saharan Africa. Most parts of the tree are edible. The leaves and flowers are eaten as salad, as cooked vegetables, added to soups and sauces, or used to make tea. The young, tender pods, known as drumsticks, are highly valued as a vegetable in Asia. Moringa is nutrient-dense and rich in essential micronutrients and vitamins as well as antioxidants and bioavailable iron.

According to data available at AVRDC's Nutrition Lab, moringa exceeds the micronutrient content of a tomato by a factor of 9 to 38: β -carotene content - 15.28 mg (x 38); vitamin C – 459 mg (x 24); vitamin E – 25.25 mg (x 22); iron – 10.09 mg (x 19); folates – 93 μ g (x 19); antioxidant activity – 2858 TE (x 9). Moringa is also rich in protein: 100 g of fresh moringa leaves contain 9.4 g of protein comprising all essential amino acids in nutritionally balanced proportions. Boiling fresh moringa leaves and dried powder in water enhances aqueous antioxidant activity and increases bioavailable iron by a factor of 3. Dried leaf powder is processed into moringa capsules and used as a dietary supplement. Depending on

the genotype, leaf fresh weight of the first two harvests ranges from 500 g to 2 kg per plant. Total fresh matter yield at first harvest (leaves and young shoots) depends on plant density and varies from 19.6 to 78 t/ha with a plant density of 95 000 and 1 million plants, respectively. Moringa has great potential to generate income for smallholder farmers and to enhance environmental services by controlling soil and wind erosion, and by providing shade and clean water. Given its multiple uses and wide range of adaptability, moringa is an ideal crop for sustainable food production.

3.4 Building livelihoods on tree products

OP3.4.1. Short-rotation coppice agroforestry for charcoal small business in Papua New Guinea

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Fuelwood is an integral part of the Papua New Guinea domestic economy with consumption estimated at 1.8m³/person/year. Fuelwood stress in many districts is evident by high prices and conflict generated by competition for gathered fuelwood. This paper describes three related activities to develop small businesses based on short-rotation coppicing (SRC) agroforestry systems. These activities were: 1) survey of domestic fuelwood consumers and vendors (n = 4,122) in fuelwood-stressed districts in urban and rural areas of lowlands and highlands; 2) field trials of 10 candidate SRC species, at 2 spacings, in two to three year rotations –measurements included wood volume after two years, coppice vigour, burning characteristics, and market acceptance; and 3] facilitating the establishment of SRC-grown charcoal businesses.

The survey found the fuelwood economy has a very short, direct supply chain in a completely informal environment. The paper summarises dimensions of the fuelwood economy illustrating the great opportunity to create a fuelwood supply chain that could deliver sustainably harvested and value-added fuelwood to consumers especially in urban areas and the commercial sector.

The SRC systems appealed to landholders because they could intercrop vegetables in the first year and had the option of carrying over some trees to grow on to poles. The best woodlot species were *Eucalyptus grandis* for the highlands and *E. tereticornis* for the lowlands. *Calliandra calothyrsus* is a suitable SRC species for alley systems in highland gardens. In the highlands, SRC firewood and charcoal production yield higher estimated returns to labour [43 and 24 Kina/person/day (USD 20-11)] compared with the main alternative crops of sweet potato and coffee (21 and 15 Kina/person/day respectively). As SRC-grown wood appears different to normal wood for sale, there may be resistance in the market. So we facilitated the establishment of charcoal producer groups in Mt Hagen and Lae.

Keywords: charcoal, fuelwood, Papua New Guinea, short-rotation coppice

OP3.4.2. Can farmers actually do business? A proposition on building smallholder-level livelihoods using a business approach

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Businesses in agriculture and forestry are usually built around large-scale suppliers ignoring that most of the world's farms are managed by small-scale producers. Smallholders are often excluded from

modern business channels due to a lack of access to services and information, high transaction costs, and poor infrastructure. For supply chain actors, this may increase the perceived risks and costs associated with purchasing from dispersed producers. While successful examples of smallholder inclusion into modern supply chains can be found, these do not reflect the overall value created and that profit distribution is in favour of farmers. Building farmers' capacity to become better business partners in supply chains may not be the only necessity. This paper raises the question on whether farmers can actually do business and, therefore, highlights a proposition on how to build livelihoods using a business approach at the smallholder level based on scientific observations of tree products utilization conducted in Sulawesi, Indonesia. The proposition includes business plans, village-based service providers who can deliver support, community-managed institutions, and a community-led business model to sustain benefits. This paper also observed that the private sector is required to adjust its business practices to smallholders' needs and conditions to promote sustainable business relationships. Capable farmers and keen buyers, together with an enabling environment such as consistent government incentives can establish durable and profitable business relationships.

Keywords: *business, smallholders, Sulawesi, tree products*

OP3.4.3. Timber production and poverty: management strategy of smallholder timber farmers in West Java, Indonesia

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When other islands in Indonesia are going through the declining phase in the forest transition curve, Java is already in the reforestation phase largely due to existence of smallholder timber systems. These systems have been practiced for generations. However, despite the high price of timber in the market, many farmers are still in poverty. We examined the relationship between socio-economic characteristics and earnings from timber systems for poor and non-poor farmers in Ciamis District, one of the main areas for smallholder timber systems in West Java, Indonesia. The categorization of poor and non-poor farmers was based on the information derived from the national census, which was verified during this study. We surveyed 59 farmers on education and age of household head, family size, plot size and distance from home, household income (non-timber), as well as management and utilization of timber systems practiced by farmers. Based on their timber harvest for the past 10 years, the average income of poor farmers was USD 133 and USD 680 for non-poor farmers. Using a simple correlation analysis we found that land size and non-timber household income are positively correlated with earning from timber; thus pointing out that to have good earnings from timber systems, natural and financial capitals are important. Small landholdings (natural capital) combined with low non-timber household income (financial capital) affected the poor households' capability in utilizing their timber systems as assets do not result in better earnings. Current programs for smallholder timber farmers, largely in form of subsidies (seedlings) or capacity building, rarely differentiate between the two types of farmers. This has very often led to ineffective program results. Future programs should consider the typology of farmers.

Keywords: *livelihoods, poverty, smallholder farmers, timber*

OP3.4.4. Agroforestry option for improving livelihood and environment: case study from eastern Indonesia

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Global climate change, expected to result in global warming, is the most serious environmental problem the world faces. The greatest impacts of climate change will be felt first, and most seriously, by the poorest countries of the world. Over the long term, climate change is likely to have a very serious impact on ecosystems and the world's poorest people who are the most vulnerable as they depend heavily on natural resources for their food and livelihoods. To anticipate these problems, it is important to promote land management that can improve livelihoods and the environment simultaneously. A recent study carried out in Sulawesi, Indonesia, found that farmers who practised agroforestry received higher benefits than farmers who did not. Agroforestry farmers obtained income as much as USD 2701 per year, which is twice higher than non-agroforestry farmers at USD 1300 per year. The land productivity of agroforestry was USD 907 per ha per year or 50 percent higher than non-land agroforestry. The practice of agroforestry is a livelihoods strategy for farmers with only small pieces of land (average landholding per household of around 1.4 ha) who plant mixed species of trees such as cacao, coffee, clove and fruit. Agroforestry is also a strategy to minimize risk from unstable commodities prices, pests and diseases and also from the negative impact of climate. Agroforestry can also provide environmental services. We assessed the carbon stock for each land-use system to value the environmental services. The time average of carbon stock of agroforestry systems at this site was 28–64 tonne. It is higher than the time average carbon stock of rice and maize, which is 0.7–0.9 tonne.

Keywords: *agroforestry, environment, land productivity, livelihood, vulnerable*

OP3.4.5. Promotion of teak under agroforestry system for enhancing rural livelihood

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Teak is a very valuable timber species of Central India. Due to its high demand in world trade and unsustainable supply from forests, large-scale teak plantations have been taken up outside forests. To encourage plantations and their scientific management, unique schemes of Lok Vaniki were adopted in Madhya Pradesh to encourage farmers and owners of trees for efficient management and marketing.

Teak has so far been the monopoly of large landholders. Its potential for small landholders as a tree-based livelihood option for the poor has received less attention. It can also contribute to poverty reduction and enhance livelihood in rural areas. Some models of teak plantation in the state were analysed. The paper discusses the issues relating to adoption of teak under agroforestry by different landholders, technology packages suitable for small farmers, market access, information and viability.

The current policies, legal and regulatory framework, innovations and suitable technology are outlined.

Keywords: *agroforestry, rural livelihood, small landholders, teak*

OP3.4.6. Socioeconomic factors influencing the position of women in fruits and vegetable value chains in the Coast region, Tanzania

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Women have the greater degree of participation in agricultural value chains including those of horticultural produces. However, most of them concentrate in early positions in value chains spectrum which are less profitable and temporary. This study aimed at identifying socioeconomic factors influencing women's position in fruit and vegetable value chains in the coast region of Tanzania. 250 households involved in fruit and vegetable enterprises were surveyed in the study area. Surveyed data were analysed using logistic regression model. Results indicated that education level, heading household and membership in farmers' associations positively correlate to the individual's position in the fruit and vegetable value chains spectrum. Most of the value chains interviewees (80%) have only attained primary education which is the lowest level in the country. This has the implication on the issues related to marketing strategies, accessing market information, negotiation and value addition skills. Participants to the study who were heads of their respective households comprised 9%. This shows a limit for the women to have their decisions and choices favourable to their fruit and vegetable business. Few respondents (7%) were found to be members of the farmers' associations, signifying low level of their engagement in networking, which consequently lowers their uplift potential in the value chains ladder. It was thus recommended to empower women in terms of education and skills, networking and gender equity in order to improve their position and significant profit gain in the fruits and vegetables value chain. This in the long run will enhance reduction of income, poverty, and improve livelihoods.

Keywords: *gender, horticulture, poverty reduction*

OP3.4.7. Access to resources filtered by socioeconomic and diversification structure of the Amazon nut value chain in Amazonia

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This empirical analysis aims at expanding the knowledge base for understanding the problems and scope for the access to resources by Amazon Nut (AN) gatherers as upstream actors of market systems in Amazonia. AN is the second most important Amazonian agroforestry tree product (AFTP). The study area encompasses four municipalities of the Lower Amazon Basin in Pará, which, while being the principal region of production and marketing of this valuable product, also has one of the lowest human development indices (0.66) in Pará (mean=0.76). The main problems faced by smallholders are high transaction costs (e.g. transport), market asymmetries, and incipient organization structures. *Agro-extrativistas* are poorly organized and trust systems of value chain (VC) actors are insufficiently developed. The lack of quantification and analytical understanding of relationships between social capital (SC) and the access to resources represents a key research gap, fundamental for the implementation of programs such as the National Plan for Developing the Value Chains of Products of Sociobiodiversity – PNPSB and long-term desired sustainable rural development. A socioeconomic household survey encompassing 185 interviews at the household level, was carried out. The SWOT analysis employed semi-structured qualitative assessment consisting of participant observation, group and key-informant interviews in the same randomized sample.

Findings indicate that (a) AN mainly occurs in the Oriximiná municipality, particularly in *quilombola* communities, where AN extraction accounts for 20% of income; (b) the only cooperative (CEQMO) has been able to market “best-practice” Amazon nut to a new buyer that pays a 37% price premium in 2012; (c) most *agro-extrativistas* only have cassava as an additional income source; (d) that lack of organization inhibits profiting from public policies (e.g. PNPSB) and participating in interventions for enhancing assets; (e) increased SC can contribute to reduced socioeconomic vulnerability of actors and reduced transport costs for AN within the VC.

Keywords: Market systems, social capital, product of socio-biodiversity, vulnerability

3.5 Public-private partnerships: adding value to develop markets for producers

OP3.5.1. Public-Private partnerships on tree domestication for sustainable agroforestry and business innovations: *Allanblackia* spp as a case study.

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Trees play a crucial role in almost all terrestrial ecosystems and provide a range of products and services to rural and urban people. As natural vegetation is cleared for agriculture and other types of development, the benefits that trees provide are best sustained by integrating trees into agriculturally productive landscapes –a practice known as agroforestry. Tree domestication is an indispensable process in agroforestry for provision of the required tree genetic materials to meet the desired objectives and provide high value products. In particular, domestication of new tree crops, often termed as “neglected and underutilised crops”, is one of the means for improving food and nutritional security in sub-Saharan Africa. In the last decade, a participatory tree domestication approach involving close collaboration of scientists, government institutions, investors, NGOs and farmers has been developed for the edible oil-producing *Allanblackia* species of the family Clusiaceae in West, Central and East African regions. The approach, being practiced in mixed agroforestry regimes, is enhancing diversification of species, incomes and rural business development. This paper highlights the achievement made in the domestication of *Allanblackia* species and the need for better engagement of public and private partners in future agricultural innovations.

Keywords: agroforestry, edible oil, participatory tree domestication, underutilized crops

OP3.5.2. Conservation and sustainable agriculture project in Bajo Mira and Fronterra territory, Colombia

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To integrate the local afro-Colombian communities with a multinational corporation in order to implement a conservation project of 46 000 hectares of forest, adopting agroforestry practices, and providing resilience to climate change the project set out to:

1. Strengthen local agriculture and foster growth of the local economy mainly through the implementation of shade-grown cocoa.
2. Build a business case, which integrates local communities to a multinational value chain while providing both parties with sustainable growth.
3. Provide training on other agroforestry practices in order to diversify their activities.
4. Monitor changes in crops while maintaining a reservoir of varieties that will be resilient to climate change.

Obtained results

1. Support was provided in shifting to sustainable cocoa from palm oil, which was attacked by a disease due to increased humidity and change in rainfall regimes.
2. Strengthening of existing cacao practices and logistic optimization by developing a more professional way of harvesting cacao as follows:
 - A nursery of cacao available to the community with the best varieties was built.
 - A centralized facility for cacao collection, drying (industrial oven) and fermenting was constructed so that homogenous and international quality standards could be obtained.

Expected results

1. Strengthening of agroforestry practices as a mean to conservation and adaptation:
 - Continue to strengthen cocoa plantations and others (i.e. acai), so that they can be integrated in an international value chain.
 - Improve hybrids of cocoa so that they thrive under prevailing climatic conditions.
 - Support fair-trade certification in order to access more specialized markets.
 - Broaden the development of sustainable extraction of other non-timber forest products (i.e. coconut, fibers, exotic fruits, etc.)
2. Conservation and climate change adaptation:
 - Implement conservation strategies such as biological corridors and restoration of mangroves.
3. Capacity building:
 - Establishment of capacity building programs on cacao, agroforestry, and climate change, among others.

Keywords: *cacao, acai, conservation agriculture, agroforestry, food security, climate resilience, non-timber forest products value chain, fair-trade certification, logistic optimization*

OP3.5.3. Attracting mainstream investment in agroforestry: the Global Sustainable Agroforestry Fund

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Given increasing global pressures on productive land, there is a clear need for promoting integrated responsible land management projects with multiple revenue streams such as agroforestry. Due to these businesses' inherent diversity, they tend to fall between sectoral cracks. Consequentially, sizeable catalytic funding required for agroforestry development has been lacking. As public funding is limited, a blend of public and private sources will be required.

The focus on one-dimensional agriculture or forestry projects by investors is unfortunate, as there is a clear opportunity for investing in multi-dimensional land management (agroforestry) approaches. With the right expertise, projects can be pooled into a Fund, which can meet return and risk criteria of mainstream investors and yield long-term sustainable development benefits.

To demonstrate the investment case for this approach, the authors developed an investment blueprint for the Global Sustainable Agroforestry Fund. The Fund targets an IRR of 10%, with an initial pilot size of USD 200 m to commence in 2014 and the prospect to scale to 500 m. The portfolio consists of a mix of agriculture and forestry projects, which as a pool will provide diversified and stable returns while screening and proactively managing Environmental, Social and Governance (ESG) impacts. The Fund forms a commercially, environmentally and socially attractive portfolio to drive investment at scale in multidimensional, sustainable, land management projects. To draw in the necessary cross-sectoral expertise and capacity, the Fund is developed by a coalition of finance experts, civil society groups, business people, scientists and government officials. The governing structure reflects this multistakeholder interest.

The Fund is incubated by the Green Growth Action Alliance –a public-private coalition assembled by the World Economic Forum to scale investment in green growth.

Keywords: *fund investment, public-private, sustainable agriculture*

OP3.5.4. Cooperation or capture? The politics of private partnerships for sustainable coffee agroforestry

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This presentation explores the politics of partnering with private actors in pursuing environmental sustainability in coffee production. Drawing on empirical research carried out in the Western Ghats, India, this paper shows that certification schemes and other forms of voluntary regulatory regimes for sustainable coffee present complex outcomes for biodiversity conservation and farmer livelihoods. In particular, competing interests, institutional design and governance structure of such public-private partnerships allow the regulatory process to be captured by powerful private actors. In the context of sustainable coffee, evidence shows that shade-grown certification schemes are modified and diluted such that they are made buyer-driven rather than producer or sustainability driven. This presentation argues that mutual cooperation and successful partnerships are more likely to emerge and be sustained

when both partners have sufficient resources, power and willingness to implement the regulatory regime in synergy with the overall purpose of sustainable agroforestry.

Keywords: *biodiversity, conservation, coffee, agroforestry, market-based incentives, political, ecology*

OP3.5.5. How do agroindustries influence cocoa growers' cropping practices in Cameroon?

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Cocoa is one of the main exported agricultural commodities in Cameroon with production estimated at 225 000 t/year. The sector is dominated by smallholders with an average of 1 ha/farmer. Traditionally cultivated under forest trees' shade in complex agroforestry systems, full-sun cocoa plantations can now be observed in some regions. What is the influence of agroindustries and exporting enterprises in the change of agricultural practices? Based on individual interviews of stakeholders all along the market chain, from the plantations to exportation, this paper analyses the strategies and impacts of the industrial actors on the cropping practices of cocoa smallholders. The study involved interviews in Douala and Yaoundé of the downstream actors of the value chain, and focus group and individual interviews of farmers in the region centre. It appears that industries mainly influence agricultural practices through certification. Since 2000, the demand for certified cocoa has been growing. Industries developed certification programs to answer this demand; these programs usually involve smallholder cooperatives which are helped by a certification organism and an industrial partner to organize farming schools and teach the recommended practices to farmers. This program is in much demand by smallholders who queue to engage into a partnership with an industry. This type of partnership is perceived by smallholders as a mean to access technical advice, inputs, and to secure the quick sale of their produce. Certification favours agroforestry practices and recommends maintaining a rich diversity of trees in cocoa plantations. Through this program, industries favour the continuity of agroforestry practices and promote sustainable use of inputs.

Keywords: *cocoa certification, agroforestry, smallholders' plantations, cocoa market chain*

OP3.5.6. The business of agroforestry: opportunities and challenges for commercial investment in agroforestry-based ventures

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Rising global demand for food, feed, fibre and fuel is driving commercial investment in primary agricultural production around the world. A significant share of this capital is being lured into developing countries in sub-Saharan Africa and Latin America by apparent reserves of uncultivated land, favourable agroclimatic conditions, and low-cost labour pools in these regions. Traditionally, agricultural production in these countries has been dominated by subsistence farming families cultivating small land areas (i.e. smallholders), relying on few inputs and typically achieving low or moderate productivity. Driven by their desire to boost productivity and maximize financial returns, the new wave of commercial investors into these markets are introducing broad-scale monoculture farming systems that have delivered significant productivity gains in more developed countries. Where smallholder farmers are engaged in such ventures, they are typically encouraged to adopt similar high-input monoculture farming systems on their own land to produce output for sale exclusively to the

ventures. While such arrangements can provide a vital new cash income stream for smallholders, they can also create increased vulnerability to market and climate shocks and reduce subsistence food crop production. Alternative approaches for boosting smallholder productivity, like agroforestry systems, have rarely been incorporated into these commercial ventures. This paper reviews the opportunities and challenges of commercial investing in primary agricultural production using smallholder-based agroforestry systems. Two practical business cases in Mozambique and India are presented and evaluated for financial returns, and associated socioeconomic and life cycle environmental impacts. The potential is demonstrated for smallholder-based agroforestry systems to increase return on investment and reduce risk for commercial investors in agribusiness ventures, while boosting long-term food security and livelihoods of smallholder farmers, enhancing local ecosystems, and mitigating climate change impacts.

3.6 Valuing the environmental services of trees in the landscape

OP3.6.1. Valuing the environmental services of trees in the landscape: an introduction

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The word 'value' can be used in financial terms but also in the broader meaning of respect and willingness to act in support of. Trees inside and outside forests provide goods and services that are important to the livelihoods, welfare and wellbeing of people inside and outside of the landscape. However, decisions to cut, plant or otherwise manage trees tend to be dominated by the direct benefits that the 'owner' or claimant of the resource expects. Most of the environmental services provided by trees such as regulation of micro- and mesoclimate, and roles in soil, water and biodiversity conservation, remain externalities to the decision maker. Various approaches exist to internalize such externalities and ensure that 'commons' are respected. Some of these approaches rely on valuation in economic terms, to allow direct equivalence to traded goods that can be extracted from the landscape, with or without forest and/or trees. Expressions of the economic value can be aggregated to inform estimates of changes in natural capital at national scale in assessments of green growth. Other studies have been designed to derive the opportunity costs to land owners of not removing trees and forests as basis for compensation, and/or for design of co-investment programs that support enhancement of environmental services. We will review what it takes to get agroforestry recognized in current green accounting systems.

Keywords: *ecosystem services, green accounting, reward mechanisms, valuation*

OP3.6.2. Synergies and trade-offs amongst multiple functions of trees in agricultural landscapes

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There has been a recent surge of interest in multifunctional landscapes within an agroforestry context but little formal assessment of the roles that trees play across the spectrum of ecosystem service

provision now considered important in Sub-Saharan Africa (SSA). We reviewed functions of trees in fields, on farms and in agricultural landscapes across contrasting landscapes in SSA to assess the scientific evidence base about their impact on ecosystem service provision. Data was gathered primarily from peer reviewed journal articles dating from 1995 to 2013, selected using a combination of electronic and manual literature searches. This resulted in 324 articles relevant to arid (3%), semi-arid (50%), sub-humid (25%) and humid (22%) agroecological zones. The articles referred to 184 sites across SSA. The majority of studies were from West and Central Africa (42%), followed by Eastern (37%) and Southern Africa (21%); of which 25, 66 and 45% of the regions' studies were conducted in Nigeria, Kenya and Malawi, respectively. The functions of trees were grouped into four major ecosystem service classes from the millennium ecosystem assessment: (1) provisioning (2) supporting (3) regulating and (4) cultural. The review shows that trees influence provision of food, fodder, fuel, timber and non-timber products; they support biological nitrogen fixation, nutrient cycling, primary production, soil fertility and water cycling; and regulate agro-biodiversity, carbon sequestration, genetic resources, microclimate, pests and diseases, soil erosion, weeds and wind speed either positively or negatively and to varying extent depending upon tree species, site and management. Food production, nutrient cycling, primary productivity and soil fertility are the foremost functions explored, contributing over 60% of the studies. Trade-offs and synergies amongst ecosystem functions of trees are evident across scales and it is clear that they often play a vital role in sustaining productivity gains from agricultural improvement through tightening nutrient, water and carbon cycles.

Keywords: *agroforestry, ecosystem services, livelihoods, sub-Saharan Africa*

OP3.6.3. Quantification and valuation of ecosystem services of temperate tree-based intercropping systems in Quebec, Canada

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This study provides the first complete framework for the valuation of several ecosystem services of agroforestry and uses a tree-based intercropping (TBI) system in southern Québec, Canada, as a case study to evaluate and monetize ecosystem services. Ten ecosystem services were estimated, all of which were of interest and directly applicable to most agricultural systems worldwide: nutrient mineralization, water quality, soil quality, pollination, biological control, air quality, windbreak, timber provisioning, agriculture provisioning, and climate regulation. A mix of mathematical models for the quantification and economic valuation of various ecosystem services were used. The results of the marginal analysis of all TBI ecosystem services revealed a total annual margin of 2645 CAN\$ ha⁻¹y⁻¹ (averaged over 40 years). The economic value of combined non-market services was 1634 CAN\$ ha⁻¹y⁻¹, which was higher than the value of marketable products (i.e. timber and agricultural products). An analysis of the present value of ecosystem services for a rotation of 40 years suggested that the provision of agricultural products ranked highest among the ecosystem services taken singly, followed by water quality, air quality, climate regulation, and soil quality. Total economic value of all ecosystem services for the rotation period was 54 782 CAN\$ ha⁻¹, only one third of which was contributed by agricultural products. However, although the benefits of the ecosystem services provided by TBI were higher, farmers only benefited from agricultural products and timber. Thus, government incentives are needed to interest and compensate farmers in adopting practices that benefit society as a whole.

Keywords: *economic valuation, ecosystem services, non-market benefits, tree-based intercropping systems*

OP3.6.4. The French Green and Blue Ways implementation process: challenges for agroforestry

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The emergence of the concept of sustainable development induced a generalization of the consideration of the environmental dimension in most planning policies during the 1990s. Threats on biodiversity became a subject of concern not only for scientists, but also for public authorities and citizens. In 2004, France launched a national strategy to stop the biodiversity loss. It was followed by the Grenelle Environment Forum in October 2007 to determine policy guidelines for sustainable development.

The environmental legal measures were completed by the Green and Blue Ways (GBW) laws. This conservation and land planning policy tool is a response to landscape fragmentation and loss of biodiversity 1) by participating in the preservation, management and rehabilitation of the ecological networks; and 2) by taking into account human activities, including agriculture, in rural areas. This became a grid of reading for the environmental policy of the State and territorial collectivities.

This paper focuses on the role that agroforestry systems can play as structuring elements of the landscape for the implementation of the GBW, and how it is revealing multiple territorial challenges related to biodiversity. It is based on the result of the INTERFACE research project conducted in the south of France. Agroforestry trees can be all at the same time markers of landscapes and an essential component of ecological corridors. Agroforestry systems thus occupy a paramount place within the framework of the implementation of the GBW, which intend to provide ecosystemic services and to be part of a virtuous circle which aims at decreasing the risks and the vulnerabilities of any type. Could GBW be seen as a way to promote agroforestry by the capacity of such systems to value the environmental services of trees in landscapes?

Keywords: *ecological networks, Green and Blue Ways, landscapes, public policies*

OP3.6.5. Can PES payments steer sustainable management of forest patches in an agricultural landscape?

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The viability of Payment for Ecosystem Services (PES) schemes to steer sustainable forest practices depends upon provision of sufficient compensation to forest owners for opportunity costs of foregone land use alternatives. A project “Developing an Experimental Methodology for Testing the Effectiveness of PES to Enhance Conservation in Productive Landscapes in Uganda” was implemented in Hoima and Kibaale districts within the Albertine Rift to reverse the trend of removal of forest patches from privately-owned agricultural lands. The project, led by the National Environment Management Authority, was implemented by various partners including Nature Harness Initiatives. It paid 840 private forest owners (PFOs) UGX 70 000 (USD 33) ha⁻¹yr⁻¹ for contractual forest management

interventions. However, PFOs found this compensation insufficient. To probe this, a survey was conducted to establish the net present value (NPV) at 12% social discount rate of net benefits from forest management by 102 PFOs with intact forests (IF) and degraded forests (DF) before and under PES. Estimates considered the short (3-year-project period) and long (30 years regeneration period for secondary forests) terms.

For the short term, NPV ha⁻¹yr⁻¹ under PES was lower for IF and DF (USD 77.4 and 61.4 respectively) than before PES (USD 137.6). The same was true for the long term, where compared to NPV ha⁻¹yr⁻¹ before PES (USD 25.4), IF and DF were only USD 20.5 and 15.1 under a 3-year PES compensation; and USD 26 and 20.6 under a 30-year PES compensation. Therefore, even if the project payment rate sustained for 30 years, it can compensate present landuse alternatives only for IF, but not for DF. Although this analysis did not take into consideration other benefits from not cutting down forests, the potential for payments alone to drive such a decision is quite low and may need to be supplemented by rules or norms.

Keywords: *sustainable forest management in agricultural landscapes, viability of PES payment*

OP3.6.6. Forest conservation policy and motivational crowding: experimental evidence from Tanzania

Brent Swallow^{1*}

Agroforestry adoption and forest conservation is being increasingly promoted through the use of incentive-based policies. One such policy is payments for ecosystem services (PES), which provides direct incentives to landholders to undertake agroforestry or forestry activities which produce environmental benefits. The use of PES has been questioned, however, due to the possibility for motivational crowding out: the detrimental interaction between a new monetary incentive and the pre-existing incentive structure that governs farmers' behaviour. Motivational crowding out can cause a policy to under-achieve the expected benefit, or lead to a net negative effect. Of particular concern for policy designers is the tendency for motivational crowding effects to linger longer than the policy itself. In this study we used an experimental economics technique, a modified dictator game, to test farmers' responses to four stylized policy types: an individual payments type PES, where farmers were compensated for any contribution they made to a public good (representing forest or agroforest), a collective type PES where a group of farmers were compensated as a whole for their contributions, and low and high level regulations where farmers were told they must contribute to the public good. The study site is the East Usambara Mountains, Tanzania, a global biological hotspot where agroforestry is a prominent land use. The stylized PES did not show evidence of motivational crowding out beyond the life of the policy, and the regulation treatments showed some evidence of the opposite: a positive effect beyond the life of the policy. The collective PES treatment was ineffective at eliciting contributions to the public good. Results were varied within the sample, with farmers with larger landholdings, women, and farmers not born in the village exhibiting crowding out behaviour due to PES. Our results provide experimental evidence that overall motivational crowding may not be a large cause for concern regarding the use of PES policies for agroforestry and forest conservation.

4.0 Sustaining development through agroforestry

4.1 Meeting development challenges with integrated approaches

OP4.1.1. Inclusive green economy, sustainable development and agroforestry with special reference to the South

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Green economy agenda of Rio+20 for the ‘The Future We Want’ should evolve to recognize the contribution of agroforestry to the agriculture habitat and food security, nutrient recycling, renewable energy, wasteland restoration, soil stabilization and water phytoremediation. Policy level leadership, strategic planning and stakeholder stewardship should motivate farm-foresters and their private-public partners to support green economy through productive propagation and sustainable harvesting of agroforests, backstopped by valorization and certification of their products, REDD related remuneration, and payment of ecosystems services.

The paper highlights green economy policy paradigms pertinent to agroforestry and trees outside forests for inclusive and equitable economic growth, green jobs, business and industry, cultural, economic, environmental and social dimensions. For their integration into policy planning and decision-making, it draws upon data, case studies and model examples globally. It demonstrates and introspects upon policies and institutions required to ensure holistic agroforests for optimal landscape management and sustainable farming systems so that the revisited green economy addresses the global rush for land, water, energy, food, forests and related renewable resources.

Agroforestry offers opportunities for harnessing the demographic dividend in the south and provides a resilient integrated landscape approach for biodiversity conservation and poverty reduction and for combating climate change, land degradation, deforestation, food insecurity and malnutrition. With futuristic policy perspectives, global green economy can prosper in harmony with humanity and the environment, *inter-alia*, through multifunctional agroforests planted and propagated by the people, for the people, privately and publicly.

Keywords: *agroforests, certification, climate change, ecosystems services, food security, integrated landscape, livelihoods, soil & water, sustainable development goals*

OP4.1.2. Agroforestry research in India: the experience of a hundred years with focus on an organized national programme

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Agroforestry research in India was initiated more than a hundred years ago with trials on tree-crop interactions in the tea estates, studies on silvopastoralism, intercropping experiments in plantation crops and successional studies in the ravines. Diagnostic survey and appraisal, initiated in the early eighties under the AICRP on Agroforestry, revealed that agroforestry practices abound in the country. There exists considerable variability in the nature and arrangement of the components and the ecological and socio-economic conditions under which such systems are practiced. Major practices include multifunctional improved fallows, home gardens, plantation crop-based mixed species production systems, alley cropping, woodlots, orchards, windbreaks, live fences, shifting cultivation and taungya. A

preliminary estimate indicated the area under agroforestry in India as 25.32 million ha. Germplasm of 184 tree species has been collected and evaluated and improved accessions of poplars, eucalyptus, Dalbergia, neem, Acacia, Leucaena, Ailanthus, Pongamia, Casuarina and Mangium hybrids have been identified. Other research themes include development of volume tables and growth equations for estimating tree productivity, development of location-specific agroforestry practices for different agroclimates and wastelands and economic analysis of these systems. Agroforestry has now emerged as a promising land use activity and it has the potential to enhance above- and below-ground carbon stocks to mitigate climate change. Carbon sequestration potential of smallholder agroforestry systems ranges from 1.5 to 3.5 Mg C ha⁻¹yr⁻¹. Agroforestry initiatives also resulted in a significant amount of wood production from outside the forestlands and promoted rural industrialization in certain localities which benefitted the small landholders and marginal farmers. Indeed, agroforestry provides the bulk of the country's domestically produced timber. Sericulture and apiculture along with value addition provide additional opportunities for augmenting economic returns of the agroforesters. However, there exists certain constraints that limit adoption of agroforestry and efforts are on to develop a national agroforestry policy to overcome the constraints.

Keywords: *agroforestry policy, carbon sequestration, ecological services, organized national programme*

OP4.1.3. Sustainable access to energy: charcoal for the poor to save biodiversity in Eastern Congo (RDC)

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About 40% of the global population still depends on a traditional use of biomass for energy. Wood fuel is the major source of energy in Africa. So it is in North Kivu. Besides the agricultural practice of “slash and burn”, the extraction of wood fuel is one of the main causes of degradation and encroachment of the forested area. In the case of North Kivu, war and wood fuel for charcoal (makala) leads to the degradation of the Virunga World Heritage Site –about 80% of the charcoal in Goma was cut from the Park. However, charcoal is critical for the lives of the poor, not only as a source of energy but also as a potential source of income.

Thus, in order to reduce the degradation of the forests, WWF adopted various strategies in North Kivu: introduction of more efficient cookstoves, and reforestation and afforestation in the so-called pilot project Eco-Makala.

Reforestation with the small-scale farmers in the surroundings of the park has the objective to minimize the illegal harvest and restore a more balanced ecosystem.

The total estimated amount of needed reforestation is about 23 000 ha, in the growing city of Goma (1 million of inhabitants). In the past years, 5000 ha forest was planted and 1.000 ha in agroforestry (cacao). The small-scale farmers already harvest the Eco-Makala to use or sell. An evaluation was made and lessons learnt. This paper shows the methodology used. Farmer associations play a key role in reforestation. WWF detected and evaluated them, put together the objectives and proposed a contract.

The associations cured the nurseries and gave the follow-up to the farmers. A monitoring system was built up and a system to measure production and carbon storage.

Keywords: *charcoal, commercialization, income generation, national park*

OP4.1.4. Assessing aboveground biomass carbon stock of miombo woodlands and (its) controlling factors in southern Africa

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Tropical forests have a great potential for mitigating global warming due to atmospheric CO₂ emissions. However, this potential is impaired by deforestation and forest degradation, which contribute about one fifth of total anthropogenic CO₂ emissions. Avoiding deforestation, afforesting degraded lands and proper management of forest resources are necessary to tackle problems of climate change and global warming. This requires adopting land use changes to those that are ‘forest friendly’ or stop further disturbance of forest resources. However, developing countries have little economic or policy incentives to adopt land uses that counter emissions. Against this background, a recent meeting at Kyoto devised a mechanism of compensating developing regions for the amount of carbon they sequester. To implement this, knowledge of the extent of carbon pool is necessary. This requires cutting a large number of trees and measuring biomass to get quantitative data on carbon storage and establish baseline information for future reference. However, measuring biomass is difficult in the tropics where diverse vegetation species exist. Accessibility and availability of resources also prohibit undertaking extensive survey and measure biomass. As a result, allometric equations are interesting alternatives to estimate aboveground biomass (AGB) on a wider geographical scale. We used dataset collected by the Africa Soil Information Service (AfSIS) project to estimate aboveground carbon stock of trees. Key tree attribute data such as diameter at breast height and tree height were measured for over 29 000 trees in 15 randomly selected sites of southern Africa. Ten generalized multispecies and species-specific allometric equations were used to estimate AGB of miombo woodlands. The results show that miombo woodlands have an average 35 kg C tree⁻¹. Statistical analyses of AGB vis-à-vis different environmental attributes reveal key determinants of AGB in the region to be cultivation, prevalence of erosion, and slope.

Keywords: *aboveground biomass, miombo, global warming*

OP4.1.5. Participatory agroforestry development and sloping land user group in DPR Korea

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Participatory approaches in agroforestry combine land, labour, and knowledge by blending local experience with external expert support for sloping land restoration. We describe and analyze over a decade of bottom-up agroforestry development processes that today are influencing national policies. In the 1990s, after economic upheaval following the collapse of trade with the USSR (Soviet Union), rapid conversion of sloping lands to agriculture, in association with heavy rainfall events, caused widespread erosion and landslides. In response, pilot scale ‘user groups’ obtained rights-to-use, rights-to-harvest and rights-to-plan or access to sloping lands for tree products and food. All three rights were novel in the DPR Korea and jointly contributed to success, together with active research support. Innovations in double-cropping annual food crops together with noncompetitive contour strips of valuable fruits (aronia berry: *Aronia melanocarpa*) and/or high-value timber (larch: *Larix leptolepis*) emerged as preferred local agroforestry systems. Broad support for agroforestry practices has now emerged within

the Ministry of Land and Environmental Protection as well as a number of universities and research centres. Further development will require increased engagement with agricultural and horticultural agencies, while the social dimensions of participatory agroforestry continue to provide rich learning.

Keywords: *sloping land management, Aronia, double-cropping, land use rights, larix, restoration*

OP4.1.6. Spice market value chains and implications for development in the East Usambaras, Tanzania

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Market and value chain interventions for agroforestry products are promoted as strategies to alleviate poverty and foster gender equitable market opportunities. The increase in demand for certified organic products from tropical Africa has led to the rapid growth of smallholder organic contracting schemes in the region. The potential of these schemes to meet development objectives depends on whether they improve market access for commonly marginalized groups, including poorer households and women. The objective of this study is to investigate the extent to which smallholder organic contracting is socially inclusive in the East Usambaras, a world-renowned biodiversity hotspot in Tanzania. A value chain analysis was used to compare production and marketing of cardamom and black pepper in certified and informal value chains. Next, 163 household surveys were administered to ascertain whether wealth and gender relations differ by chain. An asset-based approach was used to develop a local measure of wealth and was then analyzed using principle components analysis. Logistic regression model results showed that higher education and wealth were significant and positively correlated with participation in the certified contract scheme. Descriptive data results revealed that gender relations in the areas of production, labour, and marketing opportunities did not differ significantly between chains. Generally, women demonstrate lower rates of participation in decision making and marketing, while men report allocating more labour than women for farm activities. These findings suggest that the organic smallholder contracting scheme is not socially inclusive based on the measures used here. Local context specific factors and institutional dynamics mediate and shape producer opportunities and constraints to participation. Consideration of these factors is critical to enhancing the potential of value chain interventions to foster inclusive, broad-based growth.

Keywords: *organic smallholder contracting, value chain, spices, gender, wealth, Tanzania*

4.2 The gender dimensions of applying agroforestry innovation

OP4.2.1. Gender matters in agroforestry in dry and degraded lands? An analysis from tribal India

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This paper explores the gender dimension of agroforestry in semi-arid (with degraded land) tribal districts of western India. It examines men and women's participation in agroforestry activities in eight tribal villages that are devoid of basic infrastructure such as electricity, and piped drinking water supply. The agroforestry programme was introduced by a local non-governmental organization parallel to promote community forest management. The qualitative method includes key in-depth interviews and

focus group discussions to collect data related to who owns land, how men and women participate in decision making of agroforestry activities, and who (and why) controls the collection and marketing of the resources. The findings indicate that agroforestry in dry and degraded land has high value at household level. The majority of land is owned (or claimed) by men. The access rights to the land differ between men and women – women tend to have more access to resources. In the study villages, tribal men make decisions regarding the marketing while women make decisions related to planting and fodder productions. Men tend to ‘participate’ more in the meetings, but women are in-charge regarding improving the soil quality, and adaptive to agroforestry-related innovations to tackle droughts in the region. Further, the focus group discussions indicated that in terms of establishing networks within the villages compared to men women are more actively involved in communication and exchanging ideas. The gendered difference in access to land and trees and other products of agroforestry largely impacts on benefit-sharing within households. Overall, the findings of this ethnographic research highlights that semi-arid and degraded lands make it important for both men and women to play an active role in implementing agroforestry activities.

Keywords: *degraded land, dryland, empowerment, gender*

OP4.2.2. Gender, sheep and trees in Zan Coulibaly, Mali: methodological approaches

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Gender relations have been at the heart of a project about the integration of agroforestry and sheep feed in Mali. The aim of this project is to improve human food security through a better production of sheep fed with woody fodder. In the commune of Zan Coulibaly, situated 50 km from Bamako in Mali, both academics and the general population assume that there is a clear-cut sexual division of labour in almost all areas of activities in this rural zone. For example, trees would be a masculine domain and sheep-raising a feminine one. One of the challenges of this project has been to deconstruct these kinds of assumptions while engaging the population of the Zan Coulibaly commune in a participatory process. To meet this challenge, and taking into account a methodological engagement towards gender mainstreaming, we made sure to achieve an adequate representation of women both in the research team and in the samples used in the preliminary inquiries and the experimentation itself. We will present the methodology used to build the samples, how it was negotiated with the population, and how it was applied. Also, we will present the outcome of this inquiry in relation to deconstructing common knowledge about the gender and even generational division of labour in the areas of agroforestry and raising sheep.

Keywords: *division of labour, gender, methodological approach, sheep farming*

OP4.2.3. From rubber agroforestry to oil palm plantations in Sumatra, Indonesia: shifting gender roles

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In Indonesia, the island of Sumatra is one of the largest producers of rubber and oil palm. However, labour is based on family labour where a clear division of labour in agricultural land between women and men has operated since time immemorial. Women are responsible for the rice fields, their backyard and house work while men are responsible for rubber production and marketing. However, globalization heightened the demand for oil palm and rubber and in turn affected the roles and responsibilities between men and women in Sumatra. In this paper, we present the results of the in-depth interviews of ten households heavily involved in rubber agroforestry and oil palm production. We describe their new roles and responsibilities using two types of agricultural models namely, 1) rubber agroforestry and 2) oil palm plantation. In our analysis, women now have significant roles in the rubber agroforestry model where firewood, medicinal plants and wild fruits are also produced for household consumption while men are very much involved in oil palm production.

Keywords: *enrichment, rubber, agroforestry, gender inequality*

OP4.2.4. Gender equity in payments for environmental services: analysis of pilot projects in Asia and Africa

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A growing number of payments for environmental services (PES) projects are being implemented in developing countries as a cost-efficient way to achieve the twin goals of environmental conservation and poverty alleviation, but concerns about social and gender equity implications of these projects remain. This paper examines gender equity dimensions of five pilot PES projects to market watershed and carbon sequestration services in South East Asia and East Africa. We used a multidimensional equity framework to analyse gender equity in terms of distribution of outcomes (distributive equity), inclusion in decision-making (procedural equity) and pre-existing conditions that mediate access to a project and its benefits (contextual equity). Our analyses suggest that a neglect of contextual factors such as customary land rights and cultural norms around tree planting in the allocation of PES contracts can undermine gender equity by alienating the resource rights of women. Further, projects that specifically include women and marginal actors in the design of PES contracts tend to produce gender equitable and cost-efficient outcomes than if they were excluded. A gender analysis of roles and responsibilities within a PES project is a good start to gender inclusion; nevertheless, PES projects are limited in their capacity to alter traditionally embedded forms of gender exclusion. Two useful lessons for PES designers can be drawn from the study. Firstly, it is important for PES designers and project managers to take into consideration the interrelated dimensions of equity to enable an analysis of deeply-rooted norms and traditions that spur inequity and develop procedures to address them. Secondly, gender equity considerations can be mainstreamed only when equity is articulated as an explicit goal at the start of any PES project.

Keywords: *Asia, Africa, equity, gender, payments for environmental services*

OP4.2.5. Agricultural (in) justices: investigating feminization of agriculture and its implications to food security in Nepal

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Rural Nepal is going through the rapid socioeconomic and environmental change. The influential driver is the remittance economy associated with out-migration of an economically active male labour force from rural areas to urban centers and overseas countries to seek employment. This has led to an injustice in sharing of agricultural performance in which rural women are now forced to take up disproportionate responsibilities of agricultural work. This phenomenon can be described as the feminization of agriculture. This paper aims to investigate the causes and consequences of feminization of agriculture, created agricultural injustices and its implications to household food security in the middle hills of Nepal.

This study employs both qualitative as well as quantitative approaches to data collection in two mid-hill districts of Nepal using both household survey and key informant interviews.

Findings indicate that in the absence of a male counterpart, the female members of a household take more responsibilities in carrying out agricultural activities within the male dominant agricultural system. This is not only inappropriate but is also very unfriendly for women to function. In this situation, women increasingly take up the strategy of adapting less intensive farming practices as well as abandoning their agriculture lands. As a result, there is reduction in food production at the local level, hence food insecurity.

In conclusion, the study suggests that there is need for revisiting the agroecological practices to explore possibilities of reintroducing the low input and less labour intensive agroforestry practices, which can substantively reduce the workload of women as well as ensure food security at the local level by optimizing the use of local resources more efficiently. However, it is only possible when the policies, institutions and agroecological practices are reoriented considering these vital factors.

Keywords: *agriculture, feminization, food security, outmigration*

OP4.2.6. Mother Earth: women's role in cacao agroforestry decision process in Coastal Ecuador

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Our research examines gender relations in the Ecuadorian cacao sector. We study how the changing cultural norms and legal status in Ecuador impact women's empowerment in rural communities. Cacao provides a particularly relevant case as it is an important cash crop in the region and has been the focus of development efforts by the Ecuadorian government, non-governmental organizations, international donor agencies, and environmental advocacy groups. Cacao production is often the only source of cash income for many rural Ecuadorian households and traditionally the domain of men, who are often expected to manage household income and determine the economic activities of the household. Furthermore, cacao is traditionally grown in agroforests that are the last bastions of habitat for many endangered plant and animal species in the heavily deforested Ecuadorian coastal region. Thus,

women's involvement in cacao production would be an important indicator of women's status in rural Ecuador. However, research is lacking that examines women's roles in agricultural decisions.

We examined gender roles through 10 focus group meetings and 400 household surveys conducted from February through July 2013. We implemented a choice experiment, which allowed us to determine the differences in women and men's preference between agroforestry or monoculture cacao production methods. We found distinct differences between men and women in their land use preferences. Women were more likely to prefer agroforestry production methods than men were. They were more concerned about food production such as raising plantains, oranges and other fruits than they were about profits. They also were more likely to prefer this production system because of the environmental benefits it provides and the ability to have diversified income sources. The opportunity to obtain bigger yields and larger profits was more important to the male participants than the other environmental and social benefits provided by the agroforestry system.

Keywords: *Cacao Agroforestry System (CAS), Ecuador, gender roles*

4.3 Adapting to climate change

OP4.3.1. Choosing suitable agroforestry species, varieties and seed sources for future climates with ensemble approaches

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Adaptation to future climates requires that we plan interventions on the basis of reliable models for predicting how existing and potential future agroforestry systems will perform. Because process-based models are currently only available for a limited number of trees, species distribution modelling (SDM) is currently the most sophisticated approach to project climate change impacts for the majority of species. (The climate analogue methodology provides an alternative approach, whereby we will provide some examples how the SDM and climate analogue methods can be complementary.)

SDM is based on statistical inference to determine environmental niches (of species, varieties or seed sources), which then allow distribution maps to be drawn both in environmental and geographic space. The power of SDM has recently increased through the introduction of machine-learning algorithms, the application of ensemble approaches and the availability of high resolution raster data sets. Ensemble approaches are founded on weighted averaging of predictions from a large suite of algorithms, including maximum entropy-, boosted regression tree- and random forest-methods. As the options for modifying weights can result in an infinite number of ensemble models, we developed a statistical method for tuning input weights and a suitability mapping approach based on the number of algorithms that predict presence-absence. These methods have been integrated into the BiodiversityR package, including outputs that can be immediately scrutinized and shared through Google Earth.

We will provide examples to demonstrate our approach from recent studies in Africa, Asia and Latin America. Included are future suitability investigations of timber species in Latin America and food tree species in Burkina Faso, Africa. We will also show how information on potential natural vegetation can be combined with SDM approaches to improve seed sourcing strategies such that they better consider

climate change. Results from transect studies of mango variety turnover in Kenya will also demonstrate how production data can be included in ensemble suitability mapping methods.

Keywords: *BiodiversityR free software package, Climate Change, Agriculture and Food Security (CCAFS), ensemble models, potential natural vegetation*

OP4.3.2. In search of dynamic linkages between agroforestry and ecosystem-based adaptation: a case study of the mid hills of Nepal

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Rural Nepal is in a complex transition period involving out-migration, urbanization, and commercialization of the local economy. Climate change vulnerability assessments show that hills are highly vulnerable. Therefore agricultural practices have become less rewarding as a livelihood option. The multiplier effects of agroecosystem transformations due to climatic and socioeconomic changes are intensifying the associated challenges of a lower rate of productivity and return. The study thus tries to assess whether agroforestry can be an Ecosystem based Adaptation (EbA) option to adapt to changing climate, and the socioeconomic and resource paradigm. Agroforestry is a system embedded in agroecosystems, provides multiple benefits and ecosystem services (provisioning, regulating, supporting and cultural). EbA is a comprehensive adaptation approach for managing ecosystems and its services to increase resilience. Local communities were consulted and the study sites were assessed. Both primary and secondary methods were used to collect information wherein reconnaissance survey, key informant interviews, and group discussions were conducted for primary and reviews for secondary information. The study indicated that variety of agroecosystems typologies exists in landscapes: cultivated, abandoned land, grassland and agroforest. The changes have distinctly affected physio-morphic behaviour of traditional crops, cropping patterns and farming practices. In order to adapt to changing contexts, an agroforestry system has the potential to inbuild a large number of adaptation options. In the present context, agroforestry is an important system to address these impacts and vulnerabilities by providing ecological and economic benefits up to some extent; and has a higher potential to be a viable option for efficiency, resilience and sustainability through value addition (additionalities). The value addition option should be cost effective, accessible and different from business as usual, and then agroforestry practices would have the potential to be an EbA option. Rethinking agroforestry from the perspective of resilience thus is important.

Keywords: *agroecosystem, Ecosystem based Adaptation, ecosystem services*

OP4.3.3. Climate change adaptation strategies of smallholder upland farmers in the Philippines

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This research confirms that smallholder agroforestry farmers in the selected provinces in the Philippines have already been experiencing climate change in their respective areas as indicated by the change in

rainfall and temperature patterns. Using direct interviews and focus group discussions, the respondent-farmers highlighted that increased incidence of pests and diseases, stunted growth of crops, low crop productivity, delayed planting, delayed fruiting of some crops particularly perennial species, poor quality of produce, increased costs in farm operations, low income and decreased yield of some crops, are among the general impacts of climate change in their agricultural production systems. On the positive aspect, some crops had increased yield as an impact of climate change.

Farmers employ their local knowledge and skills in adapting to the impacts of climate change. Among these include changing cropping patterns, integrating more crops in the farm, engaging in other off-farm and non-farm activities as additional sources of income, changing the cultivated crops, mulching, and use of organic fertilizers. The research results also highlight the benefits that the respondent-farmers derived from agroforestry, a land use management system that is currently being practiced in the study sites.

Keywords: *upland farmers, climate change adaptation strategies, Philippines*

OP4.3.4. Livelihood improvement of farming communities vulnerable to land degradation and climate change

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Land degradation mainly due to heavy soil erosion is a common problem in agricultural fields especially in the central highlands of Sri Lanka where farming is the main livelihood of the majority of the rural communities in these regions. Climate change is evident in the intense and erratic distribution of seasonal rainfall with frequent droughts and floods and increased ambient temperature across the country, all of which affect livelihood options of rural villagers engaged in agriculture. Adaptation to climate change through different livelihood improvement approaches together with proper soil and moisture conservation measures to reduce land degradation were experimented using 200 farm families in one of the most vulnerable regions (Walapane in the Nuwara Eliya District) as a community-based case study.

Detailed ecological and socioeconomic surveys conducted before and after the project implementation period of two years revealed that capacity building carried out during the project period resulted in a significant improvement on the use of proper land management of both chena land and homegarden (4 fold), residue management and preparation of own compost (8 fold), use of organic fertilizer (8 fold), cultivation of drought-resistant crop varieties and development of a seed bank system, improvement of livelihood development activities through homegarden development, microenterprise development and revolving a loan fund, etc. Establishment of a 33 km long Gliricidia based hedgerows along contours across farmlands conserve around 1800-2400 m³ of soil volume after a one-year period. Introduction of alternative livelihood options such as dairy farming for this crop-based farming community enhanced family income (LKR 8000 per month) and nutrition status. 93% of the families reported that species diversity and productivity of their homegardens improved significantly. This study proved that less capable, affected and vulnerable communities could be converted into capable, resilient and productive communities through capacity building with proper guidance.

OP4.3.5. Agroforestry, a viable strategy for climate change mitigation and livelihood

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Clean Development Mechanism of the Kyoto Protocol has the potential to reduce rural poverty through payments to farmers who provide carbon storage through land-use systems such as agroforestry. Agroforestry is recognized as a carbon sequestration strategy because of its applicability in agricultural lands as well as in reforestation programs which will benefit not only the landowners or farmers but the society at large. Globally, agroforestry is practiced over one billion ha land area and has relatively high capacities for capturing and storing atmospheric CO₂. According to IPCC, agroforestry has a mitigation potential of 1.1–2.2 Pg carbon over the next 50 years. Further, 630 million ha of unproductive croplands and grasslands if converted to agroforestry could sequester 0.586 Tg C/yr by 2040. Carbon storage is an additional output that landowners might consider in their management decisions especially now when carbon payments are introduced. Although agroforestry is now receiving increasing attention, the potential of agroforestry as a strategy for carbon sequestration is still not fully recognized. This is due to lack of empirical evidence which could explain the potential of agroforestry systems on reducing atmospheric CO₂. This lack of understanding warrants research that would address both biophysical and socioeconomic issues of carbon sequestration by agroforestry. Thus to realize its potential of C sequestration in subsistence and commercial enterprises, innovative policies based on real field studies need to be adopted. The paper reviews the carbon storage potential of agroforestry and discusses ways to exploit it for the benefit of farmers and the society as a whole.

Keywords: *agroforestry, climate change, carbon sequestration strategy, livelihood*

OP4.3.6. Carbon sequestration and emission reduction through tree and energy-based interventions for mitigating climate change

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Carbon has become a tradable commodity due to the Kyoto and Cancun Protocol, whose market value was \$176 billion in 2011. The smallholders who collectively qualify the minimum tradable carbon amount through carbon sequestration and emission reduction are usually left isolated, mainly because of the rigid and expensive CDM protocol. The alternative protocol developed by ICRAF complies to the carbon trading rules in the CDM. In this approach, farmers are allowed to continue doing their normal farming practices but are encouraged to incorporate carbon sequestering and/or emission reducing practices. The protocol took a grid-based approach and it was located between 29° 34' 40" and 29° 37' 16" latitude and 79° 33' 33" and 79° 36' 31" longitude in Almora district, Uttarakhand, India, which covered 2624 ha area and 13 villages having 1062 householders. Horticulture in private lands and silvipasture in common land were implemented for carbon sequestration. Replacement of Edison bulbs with CFL, fuelwood with biogas and solar cooker, and kerosene lamp with solar lantern were implemented as carbon emission reduction interventions. The tree-based interventions i.e. 58 768 propagating materials of fruit and 8700 oak saplings were planted in private and community land respectively with the help of small and marginal farmers from 2010 to 2013, which covered 30 ha area. The energy-based interventions i.e. 2032 CFL, 68 solar lanterns, 10 solar cookers and six biogas plants were installed in

the grid area for carbon emission reduction. The standard methods were followed for estimation of carbon sequestration and emission reduction. The potential certified emission reduction (CER, 1 CER = 1 ton CO₂) through carbon sequestration from the grid area could be 18 865. The carbon emission reduction was about 251 CER year⁻¹. The reduction in the electricity bill was estimated at USD 17000 year⁻¹ by using CFL. Kerosene consumption was reduced by 1224 litre year⁻¹ with the use of the solar lanterns. Fuelwood consumption was reduced by 32 tonne year⁻¹ with the use of solar cookers and biogas plants in the grid area. Thus, the farmers' socio-economic status will be enhanced through increased livelihood opportunity. Further, the community will benefit from carbon trading and will be able to help in mitigating climate change through the implemented interventions.

Keywords: *carbon sequestration, carbon emission reduction, carbon trading, climate change mitigation*

OP4.3.7. Agroforestry interventions through carbon finance –a viable option in mitigation of climate change

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Climate change has emerged as a serious challenge for survival and sustainability of mankind and climate is changing very fast in the last 15-20 years. Only large companies and corporate houses have access to and benefit from CDM-based markets. The smallholders who sequester carbon and also reduce emission do not have capacity to comply with the rigid market requirements. Therefore a grid-based approach has been developed and validated by ICRAF. In the arid to semi-arid area of Rajasthan, an area of 5000 ha has been selected under Mavli Block in Udaipur District where mitigation options are implemented at farm level, household level and community level. At the farm level these consist of agroforestry, planting trees for timber, fruits and fodder on private lands, field boundary, community lands, degraded lands and wastelands. The field level emission reduction interventions are zero tillage, minimum tillage, spot irrigation, mulches, etc. The energy-based interventions include CFL bulbs and smokeless 'chulhas' at the community level, using solar power-charged batteries for street lights, torches, etc. For benefit sharing mechanisms, a cooperative society of 2000 beneficiaries was formed (Gramyajaan Sahakari Paryavaran Samiti) which coordinates all activities of interventions by farmers including validation, carbon trading and project sustainability. The important agroforestry interventions made were agrihorticulture, agrisilviculture, industrial wood block plantations and wasteland plantations. Energy-based household interventions are smokeless stoves, CFLs and solar lanterns. The potential CERs in the grid area is more than 25 000 CERs whereas in a three-year intervention more than 3000 CERs were assimilated. Through tree interventions more than 750 ha area was covered under plantations of orange, bael, pomegranate, clonal teak, paraspipal and mix forest sps. tecoma, etc. intercropped with maize, pearl millet, wheat, chickpeas, mustard and barley. A sustainable fund that generated up to 2.90 lakhs is the most significant visible indicator for project sustainability. People, especially tribal communities, were convinced about climate change, carbon sequestration and emission reduction. From zero, a 750 ha area was covered under tree interventions and generates CERs that benefit the farmers. If the intervention process continues, it would improve the livelihoods of small and marginal farmers without changing their current agricultural practices.

Keywords: *climate change, carbon trading, grid, interventions, CERs*

4.4 Bridging science and development

OP4.4.1. ZEF experience and track bridging science and development: agroforestry examples

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At the Center for Development Research (ZEF), University of Bonn, we aim to understand and support local and international efforts to improve human well-being and ecological balance. As both actors in and critics of development, we reflect about the role of science to tackle development. In this paper ZEF's understanding and how-to's are explained.

In the first section, ZEF's understanding of development as a multidimensional process in urban and rural settings is detailed. Our strategy encompasses research-based economic, social and ecological arguments, tools and methods to tackle specific developmental issues. Furthermore, through the integration of this knowledge by applying principles of transdisciplinarity, strategic partnership and capacity development, we attempt to transform research on development into research for development.

The second section focuses on research for development in practice through examples of long-lasting research projects such as wild forest coffee in Ethiopia, land and water use in Uzbekistan, and alternatives to slash and burn in the Brazilian Amazon. These examples targeted a wide range of agroforestry systems taking place in different socioecological settings, and looking for diverse goals.

We illustrate that if science in general and agroforestry as a specific case shall contribute to development, the background conditions to be fulfilled are: the research projects themselves have to be set up and implemented in a transdisciplinarity way, specific expertise is needed to transform research knowledge in land-use activities, and surrounding policies have to be supportive.

Keywords: *agroforestry, research for development, policy*

OP4.4.2. Scaling up science to create EverGreen agriculture in African countries

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For improving the living conditions and income situation for the rural population in Africa, the project cooperation between ICRAF and GIZ builds on demand-driven agroforestry science for development. The success of the project depends on its underlying political support from officials in various countries of Africa and the high potential for scalability to the large number of beneficiaries, farmers and households in Africa. Research is set up based on assessment of demand for innovation and matching supply within the international agricultural research for development arena. The results of the project will be evaluated and principles and guidelines will be developed to support policy development as well as local capacities in further scaling. Conflict of interest is smoothened and mediated by integrating ICRAF as an international AF-research center and GIZ as a non-profit development cooperation agency. While these partners do maintain a long lasting cooperation already, there is certainly potential for improvement by including further development partners as well as regional and local research expertise.

The “Scaling-Up the Science to Create an EverGreen Agriculture in African Countries” is an outstanding project. It intends to provide critical links between facilitators, implementers and researchers of sustainable agricultural development in order to embed the science of EverGreen Agriculture within development efforts. The EverGreen Agriculture Partnership draws together stakeholders from various sectors including policy and national government, education, farmer organisations, development organisations, donors and research. Through this project, these stakeholders will be engaged in a range of activities that will fill strategic gaps to maximize the effectiveness of current scaling up efforts and to identify and develop new opportunities to take EverGreen Agriculture knowledge and experiences further out. In so doing, the partnership will continue to enhance cooperation between researchers and development practitioners to scale up EverGreen Agriculture.

Keywords: *Evergreen agriculture, agroforestry, scaling up*

OP4.4.3. Agroforestry systems as components of agroecological transition processes in Eastern Amazonia and associated public policy

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Agroforestry systems are recognized as important components in the history of human occupation in the Amazon region, and nowadays are growing in importance as sustainable options supported by Brazilian public policies focusing towards local, territorial and regional development. This article will discuss some important agroforestry systems presently practiced in this region of Brazil, how they may be faced as outstanding components in many agroecological transition processes, and how they are directly or indirectly being contemplated by a growing number of public policies, either in national or state level, as is the case of the new Brazilian forest code. This analysis attempts also to understand the real importance of agroforestry systems in relevant current issues such as local and regional food sovereignty; water, carbon and nutrient cycling; integrated pest management (IPM), and additionally, to point to the need of considering a number of priorities in research, extension, communication, training/education, and policies formulation and implementation. Our article still raises the necessity of increasing the adoption of interdisciplinary and transdisciplinary approaches in agroforestry systems research.

Keywords: *agroecological transition, Amazon region, food sovereignty, public policies*

OP4.4.4. Exploring the incentives for on-farm adoption of agroforestry in degraded cropping areas in Uzbekistan

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Agricultural production in Uzbekistan is threatened by the degradation of irrigated cropland. The conversion of marginal croplands to tree plantations is an option for rehabilitation of impoverished cropland soils, saving of irrigation water, and carbon sequestration. We examined economic benefits of tree planting on marginal croplands, and policies that may facilitate the adoption of agroforestry. The results indicate that due to benefits from non-timber products, afforestation is a more viable land use option on marginal croplands than the cultivation of major crops. The field level analysis, considering

variability in land use revenues, indicated the need for a substantial increase in C prices to initiate afforestation on marginal lands. In contrast, when considering uncertainties in land use returns at the whole farm level, afforestation would be feasible without the C incentive. This is because of improved irrigation water use efficiency and thus cropping pattern, as well as reduced revenue risks through the land use diversification.

Next, we explored farmers' criteria in making potential adoption decisions on afforestation under the Clean Development Mechanism (CDM). The adoption decisions were explored *ex ante* through the Ethnographic Decision Tree (EDT) modelling approach. Based on findings of reviewing legal documents, semi-structured interviews, focus group discussions, and a survey with farmers, EDT incorporated farmers' major decision criteria for the adoption of agroforestry. The combined findings indicated the need for a set of policy measures to increase the flexibility in choice of crops, land tenure security, awareness raising and training about agroforestry and CDM benefits, institutional capacity building for coordinating collective action of farmers for the CDM project, enforcement of property rights protection and provision of ownership rights over tree plantations, as well as reduction of transaction costs associated with the implementation of CDM afforestation projects.

Keywords: *afforestation, carbon sequestration, farmer decision making, non-timber benefits*

OP4.4.5. Farmer to farmer interpersonal communication in agroforestry innovation dissemination in Sulawesi, Indonesia

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During the past 35 years, research in agroforestry has evolved significantly. However, in many countries, the dissemination of agroforestry information and innovation is constrained due to a lack of extension agents knowledgeable of agroforestry issues. In countries like Indonesia, where smallholder livelihoods are dependent on agroforestry production systems, the dissemination of relevant agroforestry innovations is essential to reducing poverty and ensuring food security. Farmer-to-farmer communication is a possible alternative method of disseminating agroforestry innovations when there is lack of an extension agent in the agroforestry sector. To evaluate the potential of the farmer-to-farmer communication, a study was conducted in November 2012 and April 2013 to identify and understand village-level communication systems. Semi-structured interviews of 146 farmers (40% female) in two districts in south Sulawesi province and two districts in southeast Sulawesi province were combined with qualitative analysis of agroforestry farmer field school activities. Based on the study, farmer-to-farmer interpersonal communication is crucial to the dissemination of agroforestry innovation particularly in places where: (a) language becomes a barrier for information dissemination; (b) the level of formal education is low; and (c) under-developed infrastructure (road, electricity, phone signal, etc) limits the free flow of information. Results also specify that lead farmers are the key actors in developing and supporting quality farmer-to-farmer interpersonal communication. The capacity of lead farmers should be enhanced by: (a) improving their information networking to ensure access to accurate information on agroforestry innovations, and (b) improving their linkage to the local government agencies. Support from multistakeholders (government, research centres and NGOs) in establishing an information centre or forum where lead farmers can consult on their problems and update new information will enhance the farmer-to-farmer role in agroforestry innovation dissemination.

Keywords: *agricultural extension, farmer field school, lead farmer, smallholder farmer*

OP4.4.6. Conservation and livelihood impacts of agroforestry system: A case study of Kavrepalanchok district of Nepal

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Agroforestry has been recognized as one of the most important systems to support livelihoods of many rural farmers in the Nepalese hills. However, its conservation value has received little attention. Moreover, there is no solid information that tells us precisely how agroforestry systems have changed over time, and what are their causes and consequences in terms of biodiversity conservation and livelihood improvement. Hence, this paper aims to investigate the changing impacts of agroforestry systems on improving people's livelihoods and delivering biodiversity conservation outcomes. This research analyses a case study of a local government area of Mahadevsthan in Kavrepalanchok district of Nepal. Mixed methodological approach (household survey and PRA) was used for data collection. The results indicate that the practice of agroforestry system has changed considerably over time, as a result of which more agroforestry species have appeared in private lands. A total of 145 different species were recorded, of which 56 species were medicinal plants followed by fodder trees and grasses and fruit trees. Study further revealed that species richness has increased mostly in upland terraces. This resulted in increased livelihood benefits to local people. The meat production from goat and milk from buffalo have increased considerably. The high income benefit is mainly associated with introduction of various fodder trees and grasses in private farmlands. It is concluded that there is a great need for agroforestry systems to integrate conservation benefits with the livelihood of rural people. One way to promote this integration is to improve policy and practices with a view to initiate and support farming cooperatives in the commercialization of agroforestry products and market the conservation values in the changing climatic context.

Keywords: *agroforestry, livelihood, biodiversity conservation, Nepal*

4.5 Increasing food production through trees on farms

OP4.5.1. Farmer motivations and participatory trial design for enhancing food security through developing farm tree resources in Ethiopia

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Ethiopia comprises millions of farm households who are resource-poor and food-insecure due to declining crop productivity and vulnerability to climate change. The “Trees for food security” project supports innovative research on the use of agroforestry systems to raise crop yields, enhance livelihoods and improve environmental outcomes. We hypothesized that thorough characterization of target sites and trying out appropriate options in participatory trials is critical in informing agroforestry options for adoption by farmers. A socioeconomic baseline was carried out in two contrasting agroecological areas of semi-arid East Showa zone and sub-humid East Welega/West Showa zones of Oromia regional state in Ethiopia. Respondents from over 300 households for each site, drawn from five and four districts in semi-arid and sub-humid areas respectively, were interviewed using a structured questionnaire. Issues captured were to establish the relationships between food security, tree and crop data, health and nutrition, and income. Two planting niches (farmlands and homesteads) were selected for establishing participatory agroforestry trials within each area. Treatments in the trials included: the effectiveness of

different seedling protection mechanisms in improving seedling survival; the effect of soil moisture retention mechanisms in five drier sites and manure application in three moist sites around homesteads. Trees and shrubs planted in the trials include *Cordia africana*, *Croton macrostachyus*, *Grevillea robusta* and *Moringa stenopetala* on farmlands and homesteads; *Faidherbia albida*, *Sesbania sesban*, *Leucaena leucocephala* and *Cajanus cajan* on farmlands; *Mangifera indica* and *Persea americana* in homesteads. Results show higher tree abundance and diversity in the sub-humid area than in the semi-arid area. The five most frequent reasons why farmers planted trees in both sites were mainly for firewood, income, shade, live fence and timber. The preferred niches were home compound, scattered in fields and live fences. Planting trees and shrubs in crop fields in a patterned fashion is a new experience for the farmers in the project sites. Participatory approaches involving farmers, extension agents and researchers in the research process is well embedded in the national program that makes it instrumental to scale up the use of trees within farming systems. Results from baselines and participatory trials will then be used to identify scaling domains for agroforestry options not only in Ethiopia but also in similar agroecological areas of Uganda and Burundi.

Key words: *baselines, farming systems, food security, participatory trial, trees*

OP4.5.2. Edible, multipurpose Australian acacias for agroforestry farming systems in Africa's dry lands

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Farmers in dry land areas of Africa are becoming increasingly vulnerable to climate change. Environmental degradation, high population growth, diminishing and unreliable rainfall contribute to low crop yields and extreme poverty. While progress has been made through Farmer Managed Natural Regeneration (FMNR), soil amelioration techniques and organic inputs, there is a need for improved farming systems to keep pace with rising food demands and rainfall instability. A new farming system called “The Farmer Managed Agroforestry Farming System (FMAFS)” has been developed in Niger’s 450 mm rainfall zone. The FMAFS incorporates FMNR, improved agroforestry trees, edible multipurpose Australian acacias and soil amelioration practices to complement annual cropping. FMAFS intensifies both the forestry and perennial farming systems component while spreading labour and income throughout the year. The main introduction is a suite of edible, fast growing, drought tolerant and multipurpose Australian acacias (*Acacia colei*, *A. torulosa*, and *A. tumida*) which also pioneer degraded land, fix nitrogen, produce sustainable fuelwood and biomass for mulch and wind protection for crops. In addition to enhancing yields of annual crops, Australian acacias also yield tasty and nutritious seed which is high in protein and can also be stored on-farm for over eight years and easily mixed into local foods. An economic assessment of FMAFS vs. control farms (2007-2009) in Niger showed a doubling of farm income and improved resilience to periodic drought. Since 2005, more than 1000 FMAFS farms have been established across Niger. The FMAFS is a robust, simple and transferable farming system developed over 30 years with potential to increase income, food and biomass production and is ready for widespread adoption by farming communities in dry land areas of Africa.

Keywords: *agroforestry systems, dry lands, edible acacias, food production*

OP4.5.3. Revitalizing African agriculture from the ground up: A case study of soil fertility, fertilizer subsidy and agroforestry

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Malawi has attracted global attention following enormous gains in crop yields following the introduction of a fertilizer subsidy in 2005, but the agronomic and political stability of this strategy are increasingly being called into question as Malawi faces repeated weather-related crop losses and a similar program is discontinued in Zambia due to the financial strain on government funds. Agroforestry offers an alternative method to improve crop yields and resilience to climate and weather at a relatively minimal cost, but adoption has been slow especially in comparison to farmers' response to fertilizer subsidies. We consider and reject hypothesis that this is because agroforestry systems do not actually increase yields outside of experimental or researcher-led settings. Data were collected during a household survey of 390 farms in Malawi to assess the impact of the tree species *Faidherbia albida* on maize yield. Regression results indicate an increase of 12% to 14% (169-201 kg) per hectare, much less than in experimental settings but greater than or equivalent to other crop management strategies assessed in the same communities, including fertilizer purchased under the subsidy. We then combine regression results with data collected on the financial and labour demands of fertilizer and agroforestry and farmer preferences to better elucidate how resource constraints affect farmers' choices between alternative crop management strategies. Agroforestry implementation is expected to increase on-farm labour demand by 11% to 14% at establishment and 1% in maintenance years but financial inputs are minimal, making the system a superior alternative in credit-constrained areas, but difficult in land-constrained communities. A ranking exercise identified system flexibility and compatibility with existing systems as the most important decision criteria in agroforestry adoption. Efforts to expand the use of the system must focus on these two areas rather than the existing focus on economic profitability.

Keywords: *Faidherbia albida*, fertilizer subsidy, Malawi, soil fertility

OP4.5.4. A synthesis of the contribution of local knowledge research to the ACIAR trees for food security project in East Shewa, Ethiopia and Gishwati, Rwanda

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Food insecurity is prevalent in majority of Eastern African countries. In both Ethiopia and Rwanda, this is attributed to low agricultural productivity resulting mainly from high population density leading to land fragmentation and reduced land holdings; reliance on rain-fed agriculture; and continued intensive cultivation of land with no fallows and soil and water management strategies. The present studies conducted under the 'Trees for Food Security Project', aimed to characterize farming systems and elicit local knowledge on the role that trees and associated management play in increasing food security. This study was conducted between March-June, 2013, using AKT5 (Agro-ecological Knowledge Toolkit) software and methodology including semi-structured interviews, focus group discussions, transect walks and participatory resource mapping. Through stratified sampling, 94 stakeholders in Ejersa Jorro and Jawee Bofoo villages, East Shewa Zone, Ethiopia and 39 stakeholders from Rushubi, Bahimba and

Nkomane villages in Gishwati, Rwanda were interviewed. In both study areas, tree retention on farms was mainly product and income-driven and less due to ecological services; with the overriding factors in East Shewa being dead fence, timber, fuelwood and farm and household tools; while in Gishwati were: fruits, climbing bean support poles, fodder, fuelwood and timber. This has resulted into frequent pruning that prevented tree regeneration and led to loss of trees' ecological services such as soil erosion control, nutrient cycling and soil moisture regulation. In Gishwati, 30 species were encountered, 15 native and 15 exotic, with an average of 5 species per household; while in East Shewa, 40 species were encountered, with only 4 being exotic. Realizing the full potential of trees in achieving food security would require increasing tree species diversity and density in order to increase farmers' resilience and benefits all year round. However, common factors limiting tree integration on farms in both study areas were: small land holdings and lack of tree germplasm. Other factors in East Shewa included livestock browsing, drought and farm mechanization; while in Gishwati farmers had low levels of knowledge on tree-crop interactions, ecological utilities and ecological suitability. In order to accelerate the adoption of trees, thereby contributing towards improved livelihoods, it is imperative to design interventions that build on the available local knowledge of trees and tackle the areas where knowledge is lacking on agro-ecological interactions.

Keywords: *food security, local knowledge, Ethiopia, Rwanda*

4.6 Building development abilities through education and capacity development

OP4.6.1. The Master TreeGrower and Peer Group Mentoring programs: building farmer and community capacity

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The first 8-day Australian Master TreeGrower (MTG) program was run in 1996 as an outreach program of the University of Melbourne. Since then, more than 100 MTG programs have been run across Australia involving over 2000 landholders. The award-winning capacity building program encourages farmers to truly aspire to be 'master tree growers' and provides some of the knowledge, skills and support required to launch them on that lifetime journey. Independent evaluation shows that participants enthusiastically support the program, increase the area and management of trees, are more inclined to provide a mix of both public and private good outcomes, and actively encourage others in their community to do the same. The Australian Agroforestry Foundation is now also extending the Peer Group Mentoring (PGM) concept developed by a farmer group in Australia (Otway Agroforestry Network) that trains then pays farmers to support others as they design and develop their own agroforestry projects.

In 2012 the foundation (with Beyond Subsistence) hosted a tour of African professionals to explore the adaptation and application of the MTG and PGM for Africa. This led to the first African MTG course in 2013 and the formation of the Kabale Agroforestry Network in Uganda. The aim was to facilitate the development of agroforestry and native vegetation management on farms in ways that reflect the aspirations and opportunities of local farmers. This contrasts markedly with many other programs that seek to entice farmers, with direct incentives, to adopt forestry models judged by outsiders as being the most viable.

This paper presents the philosophy underpinning the MTG and PGM models and the results of our evaluations to highlight the potential of building farmer capacity and facilitating community leadership in the development of agroforestry practices. We show that, when faced with the design and management of locally appropriate multipurpose agroforestry systems, farmers from Africa and Australia have much in common and that the MTG and PGM models are transferable. More

importantly, we demonstrate that agroforestry practices will be more diverse, spontaneous and sustainable when founded on landholder and community needs, a combination of local and conventional knowledge and information networks that engage farmers as equals alongside industry, NGOs and governments.

Keywords: *farmer groups, farmer-to-farmer extension*

OP4.6.2. Integrating knowledge management and ICT4D in capacity building for agroforestry and natural resource management

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Developing and assessing quantifiable engagement of knowledge-driven agroforestry farmers, Natural Resource Management (NRM) value chain employees, and value chain actors including the service providers at the national and regional levels, is critical for a harmonized knowledge-driven agroforestry perspective. In a region heavily challenged in its adoption of forestation, new approaches of reaching the land-resource owners must be created. A livelihoods model that focuses on natural resources as a vehicle for creating wealth and using the same to promote the formation of natural resource-driven collectives that can engage with the market for smallholder natural resource produce is not just necessary but is critical.

Engaging the youth to support NRM activities helps develop young talent, which then means that the capacity building model adopted must focus on the dynamics that attract youthful talent. VACID Africa uses a digital model that is driven by a Knowledge Management (KM) framework. When superimposed on a selected natural resource value chain, the opportunities to engage the youth and their family gets clear and lines of engagement and resource management and livelihoods is certain.

The Resources, Aquaculture, Value Addition, Agribusiness and Knowledge (RAVAAK) Centres provide the physical space to create relevant knowledge on the value of the natural resource. The critical aspect of this model is that it links natural resource with other environmental initiatives, thereby creating the potential to make capacity building multifaceted and presenting an opportunity to digitally integrate the concept of Nature Wealth and Power (NWP) with agriculture, agroforestry and climate smart initiatives.

VACID Africa's knowledge-driven model is piloting in the CAADP/ATVET Programme so that land and crop-based natural resources are used as the basis of early learning within TVET initiatives. RAVAAKs facilitate data mining to form knowledge at the ATVET educational institution.

Keywords: *NRM, NWP, RAVAAK, knowledge, VACID*

OP4.6.3. Two decades of agroforestry training, education and research at Université Laval, Québec, Canada

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With a population of 48 000 students, 17 faculties and over 400 regular programs, Université Laval, the oldest centre of education in Canada (4th oldest in North America) is ranked 7th among the top 15 Canadian universities in terms of research funding. The graduate master's program in agroforestry at the Université Laval was launched in 1993 and the first batch of MSc students graduated in 1995. This program offering a master's degree is unique in Canada and the only French-language program available in the Americas, also known as the New World. Ex-post analysis of this program was conducted for looking at its efficiency. The analysis took into account different aspects including the curricula, the demographic profile of students and their origins, as well as the socioeconomic and biophysical research conducted by graduate students and academic staff. Results showed a well-balanced curriculum between theory and practice, the importance of international student population in the program with special emphasis on tropical agroforestry. More recently, however, local students and temperate agroforestry have shown a growing interest. The graduates of this program are recruited by the governmental and non-governmental agencies but also by new opportunities of private sector at the individual and organizational levels for green economy. While socioeconomic dimensions have dominated research, there has been growing interest and recognition of biophysical research. This master's degree program will be available online in 2014, allowing students and professionals from French-speaking countries to be trained from their home countries with dual degree arrangements.

Keywords: *agroforestry curricula, Canada, ex-post analysis, temperate and tropical agroforestry, online master's degree program*

OP4.6.4. Reforming curricula for agribusiness education and training in Africa: The ANAFE Focus for the incoming years

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There has been a continual observation by African businesses and institutions about the quality and work place readiness of the African agriculture graduates. This may explain in part the low productivity experienced by the sector. This concern about producing sufficient, adequately qualified, and relevant graduates to address the challenges of African agriculture is one of the key reasons for the existence of the African Network for Agriculture, Agroforestry and Natural Resources Education (ANAFE) for the last 20 years. After having helped over 60 tertiary agricultural education institutions in reviewing and improving their curricula in agroforestry, ANAFE is engaged since 2010 in improving training and research in agribusiness. This is done through the implementation of two main projects namely the Strengthening Africa's Strategic Agricultural Capacity for Impact on Development (SASACID), a Sida supported programme working through 12 pilot institutions in eastern, southern and western Africa; and the DANIDA funded "Linking Universities and Businesses in Agricultural Innovations" (UniBRAIN) which has supported the establishment and work of six agribusiness incubators in Kenya, Ghana, Uganda, Mali and Zambia. The work done through those two programmes, including review of agribusiness programs offered in ANAFE member institutions, support to internship in agribusiness, tracer study of agribusiness graduates, stresses the need for ANAFE to support the development of

agribusiness curriculum at certificate, BSc, MSc and PhD levels. This was strongly supported by the 90 participants who attended the Agribusiness Education Fair organized on 10–12 October 2013 by ANAFE in partnership with ICRAF, CTA, FARA, PanAAC and the African Association of Business Schools. Recognizing the contribution of ANAFE in this area of curriculum review and development during the FARA Science Week held in Accra, Ghana in July 2013, ANAFE was mandated to provide lead in agriculture curriculum reforms in Africa. ANAFE is now working in harnessing and optimizing available resources for implementation of activities towards strengthening agribusiness education and training within its 136 member institutions scattered in 35 African countries. This paper will explain in detail what ANAFE has achieved through those two programmes, what further plans, and partnership support needed for strengthening agribusiness education and training to produce graduates who will be job creators and no longer job seekers.

Keywords: *education, training, capacity building*

OP4.6.5. Experiential learning practices in Nigeria's tertiary agricultural education institutions

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Agricultural education in African tertiary institutions have been found unable to develop skills and capacities for applying and analyzing useful knowledge adapted to their specific situations and to emerging issues. Experiential learning, known as a teaching process based on concrete experience, observations, generalization and conceptualization is well documented as the best teaching approach to develop skills and competencies for problem solving, decision making, critical thinking, professional and collaborative interactions. However, the implementation of this learning practice in African education institutions is still very poorly assessed. A study was undertaken by ANAFE with objectives to assess the experience of institutional actors, identify constraints and perspectives for expansion, and evaluate the current methods of integrating experiential learning in course content. The study sampled 33 administrators, 65 lecturers, and 52 students from 11 agricultural training institutions in Nigeria. The results showed that all institutions surveyed had practised experiential learning for at least 10 years with 94% of lecturers being familiar with this teaching approach. At least 83% of students agreed that experiential learning had improved their ability to assess community needs and diagnose development challenges among others. Administrators identified 4 institutional benefits in practicing experiential learning, among which were visibility and performance, links with communities, and partnerships. The most interesting experiential activities proposed by the administrators were remunerated internships (75%), collaborative research projects (57%), community services and laboratory practicals (51%) and projects with communities and private sectors (43%). It was also found that the number of courses, the proportion of the lecture though in experiential form, and the intensity of interactions with communities, increased as far as the student progressed in his training programme. The study highlighted some opportunities and constraints and proposed recommendations both to institutions and to ANAFE for the expansion of experiential learning practices in Nigerian agricultural education systems.

Keywords: *best practices, skills, competencies, knowledge, learning activities*

5.0 Applying science to the future of agroforestry

5.1 Humid multi-strata systems

OP5.1.1 Strong spatial variability of light use efficiency in a coffee AFS highlighted by 3D light and gas exchange model

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Above-ground net primary productivity (NPP) of individual arabica coffee plants [60 coffee resprouts of various ages (0 to 5 years, after pruning) located below or far from the shade trees] was assessed during two years in the field from repeated biomass estimations (via branch scale allometry) and litter harvest (30 litter traps) (Coffee Flux Observatory, <http://www5.montpellier.inra.fr/ecosols/Recherche/Les-projets/CoffeeFlux>).

Surprisingly, NPP was not influenced by the distance to the shade trees. MAESTRA, a 3D light interception model, was applied to map shade tree transmittance and to calculate yearly light budgets (absorbed photosynthetically active radiation, aPAR) of the coffee plants (Charbonnier et al 2013). Light use efficiency (LUE) of coffee plants was calculated dividing their annual NPP by plant aPAR.

MAESTRA showed that aPAR decreased severely for coffee plants located under shade tree crowns (down to 70%). However, we obtained a two-fold increase in LUE for coffee plants located under shade trees, and a spatial gradient of LUE according to the distance to the shade tree. The analysis revealed that the increase in LUE totally compensated the expected reduction of NPP due to the reduction in aPAR.

We will discuss the possible causes of such an increase in LUE and the genericity of this finding. We will also emphasize on the role played by the 3D light interception model in the demonstration of this crucial property for AFS.

Keywords: *coffee, agroforestry, light use efficiency, net primary productivity*

OP5.1.2. Invent a new model for cocoa smallholders: agroforestry, a credible alternative to face an uncertain future

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Sustainability of the world cocoa production is discussed more and more in the humid tropics. Cocoa cropping is still characterized by an increase of production areas to the detriment of forest areas. At the

same time, a part of the world cocoa production comes from agroforestry systems as observed in Cameroon where most of the cacao orchards are based on old cocoa agroforestry systems (up to 50 years old) still managed by small farmers. Paradoxically, improving cocoa production remains associated to intensification of agricultural practices: selected varieties, very light shade, mineral fertilizers, phytosanitary treatments. However, generally, this technical package does not match the strategies of cocoa farmers who do not have the financial resources to support such a model in a context of sharp fluctuations in the cocoa market. Consequently, when the prices fall, they question the very existence of farms depending on this speculation. The authors show that cacao agroforestry systems can be a source of inspiration for ecological intensification of cocoa production. With examples from research works carried out in Cameroon and Costa Rica, the authors show that agroforestry systems are able to produce sustainable cocoa for a very long time, contrary to what is usually described, without additional mineral fertilization and sometimes at levels that are comparable to those obtained by the conventional intensification model. For smallholders, cocoa agroforestry systems have also other interesting advantages. Firstly, they can allow them to use fewer chemicals by providing greater flexibility in their use as they ensure the maintenance of quality soil and offer an alternative way (environmental regulation) to conventional pest control methods based on the use of chemical inputs. Secondly, in addition to cocoa, agroforestry systems also provide farmers with a variety of products (fruits, medicines, timber, etc.). Thirdly, agroforestry systems provide greater resilience to changes in socio-economic context and farmers have more flexibility to manage them. This work confirms that agroforestry can be a credible alternative to the agricultural intensification package usually proposed to cocoa farmers.

Keywords: *agroecosystems, productivity, multifunctionality, sustainable crop production, intensification, the obroma cacao*

OP5.1.3. Linking local ecological knowledge to plant functional traits in coffee and cocoa agroforestry systems in Costa Rica

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Studies on local ecological knowledge (LEK) in agroforestry systems could be a powerful tool to understand how tree species affect ecological processes. Still, due to the qualitative nature of the information it is difficult to compare farmer's knowledge across regions with different environmental conditions, botanical composition and/or production systems.

In this study we use farmer's knowledge-based approaches with methods from functional ecology to determine:

1. How farmers rank trees according to their impacts on soil fertility, regulation of micro-climate, reduction of soil erosion and as shade providers in coffee and cocoa agroforestry systems; and
2. The correspondence between LEK on tree impacts on ecosystem processes and plant functional traits.

We carried out a ranking exercise for 20 tree species in coffee and cocoa agroforestry systems with 100 farmers in two regions in Costa Rica. We also measured specific leaf area (m^2kg^{-1}), leaf tensile strength (N) and tree height (m) for the same 20 tree species. Results from the ranking analysis and trait means were compared in bivariate (correlation) and multivariate analysis (principal component analysis).

Tree species perceived by farmers as good shade providers are also those which are seen to have a positive impact on soil fertility and microclimate, but do not coincide with species impacts on soil erosion. The correspondence of farmers' perceptions to functional traits varied per function x trait combination. In general, soil fertility and microclimate were related to leaf resistance to rupture, and soil erosion was related to tree height. SLA was poorly related to farmers' rankings.

Combination of LEK and functional ecology can be used to try to define a set of quantitative easily measurable indicators to facilitate comparative analysis and to develop tools that facilitate and give a functional basis to the selection of tree species for agroforestry purposes across different regions.

Keywords: *cocoa agroforestry systems, functional traits, local knowledge*

OP5.1.4. Understanding farmers: using Role Playing Games to explore futures of landscape management in Western Ghats (India)

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Mainstreaming biodiversity conservation into production landscapes requires careful consideration of the drivers, needs and constraints of farmers. In many cases, deforestation and degradation are the rational choice, not the result of a lack of awareness or knowledge. Here we present a case study where we used an integrated approach to understand the management of coffee agroforestry system in the district of Kodagu (India). Previous research established that farmers in this biodiversity rich production landscape are slowly replacing the complex and diverse original canopy with *Grevillea robusta*, a fast growing species originating from Australia. This happens despite local knowledge highlighting the agronomical and multipurpose values of the original tree species and specific tenure systems and policies enforced by the Forest Department protecting them.

We developed an integrated, participatory modelling approach to understand the drivers behind the described landscape transitions and to explore with the stakeholders the plausible livelihood and environmental impacts of a policy change once this was shown as critical. While the underlying ecological processes driving the system were modelled based on expert knowledge and published scientific literature, the actual elements of the system, the key actors and resources, and their interactions, were defined together with the stakeholders. The conceptual model was transformed into a Role Playing Game and after validating the model we conducted 7 workshops (52 participants in total) with a No Change scenario as baseline where the policy framework remains unchanged, and a Restitution of Rights scenario where rights over the native trees are handed over to the farmers. The results show the transition into a *Grevillea robusta* dominated landscape will continue unless there is a change to the policy framework. However, the restitution of rights risks speeding up the process instead of reversing it, as other factors, such as the tree species differential growth speed, kick in.

Keywords: *agroforestry, companion modelling, Grevillea robusta, Kodagu*

OP5.1.5. Impacts of coffee agroforestry system on the socioeconomic performance of Upper Sekampung Watershed in Sumatra-Indonesia

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This study examines the impacts of coffee agroforestry system on social-economic performance of Upper Sekampung Watershed in the Province of Lampung, Sumatra-Indonesia. Way Sekampung is the main watershed, major food basket and agricultural export of the province, covering a land area of 484 thousand hectare. It is however also known to have 49 percent of degraded land, 34 percent of potentially degradable land and only 17 percent of non-degraded land. The rate of soil erosion in the watershed is probably the highest in the country, averaging 67.5 ton per hectare per year, far higher than the tolerable rate of 25 ton per hectare per year. Coffee agroforestry system in the watershed is aimed at reducing land degradation and improving farm income in the region.

The study applies quasi-experimental impact evaluation method using a propensity score matching (PSM) technique by analyzing 408 farm households practicing coffee agroforestry in two subdistricts of Pulau Panggung and Pugung in Tanggamus Districts of Lampung. The PSM technique compares farm households that have grown high percentage of shade trees and multi-purpose tree species (MPTS) in their coffee farms and a control group that grows small percentage of shade trees and/or not applying shade trees. Observed characteristics of the “participants” are then matched to “control” groups, from basic demography, characteristics of coffee farms and shade trees, estimated income, off-farm and non-farm employment and income, perception on economic and environmental risks, and other related information such coffee certification, extension system etc. The average treatment effect of agroforestry system is then calculated as the mean difference in outcomes across these two groups (matching), representing the overall gain of agroforestry impact on social-economic performance. The study calls for a more structured and comprehensive action-research and development activities that facilitate the reward transfers for environmental services in the watershed.

Keywords: coffee agroforestry, impact evaluation, Sumatra-Indonesia

OP5.1.6. Coffee and climate change: the importance of systems thinking

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Studies around the world have shown that climate change will have a massive negative impact on coffee production. East Africa will not be the exception. In this study, we want to show how a systems approach in agricultural research is necessary in order to adapt coffee systems sustainably to climate change. To develop sustainable climate-smart practices, it is not only necessary to consider processes at the plot level, but also need to take into consideration the adoption drivers and trade-offs at household, landscape and institutional levels. We will illustrate this by studies on coffee systems in Uganda. In Uganda, coffee is one of the largest export products, generating some 20-30% of the foreign exchange earnings. Robusta accounts for about 70-80% and Arabica 20-30% of the export volumes of Uganda. To understand broadly the extent to which climate change will have an impact on arabica and robusta growing regions in Uganda, maps depicting the suitability changes of arabica and robusta due to climate change were developed using the MAXENT approach. This allowed us to focus on regions that were

most in need of adaptation measures. In these areas, data was collected at field and household level by conducting surveys. At field level, data analysis showed that climate change did not only have on the crop physiology but also pest and disease dynamics. Furthermore, by measuring yields and pests and disease incidence along an altitude gradient, future production and pest/disease trends could be predicted following the climate analogue principle. We found that some pests and diseases are likely to expand strongly in the future, but effects will be source and site specific. Farmer interviews confirmed findings concluded from field measurements. Farmers but also other coffee stakeholders largely put shade forward as a good adaptation measure. The selection of the shade type and shade density is a function of managing the competition for light, water and nutrients on the one hand and accounting for the benefits generated by the shade plants on the other hand. Competition can be reduced by applying nutrient inputs or irrigation. For this purpose, we developed site-specific fertilizer recommendations. Shade plants can also affect the incidence of specific pests and diseases. We observed that the incidence of Black Coffee Twig Borer would increase significantly under shade, particularly under *Albizia* spp where much higher incidence rates of twig borer damage was recorded. Although farmers recognize the constraints and opportunities of using shade as an adaptation strategy in their coffee systems, they explained the lack of access to existing knowledge but also to input markets that made it impossible for them to successfully adopt shade as a sustainable innovation. Furthermore, adopting new technologies like shade requires household members to prioritize their resource investments. Shade plants like bananas can provide food and income benefits in the short term (<1.5 years), whereas most shade trees would take 3-5 years before providing any benefits. Meanwhile, most private and public organizations are recommending this tree species through uncoordinated initiatives without taking into consideration that certain tree species can increase pest and disease incidence. Our work shows there is a strong need for an integrated approach to climate change adaptation, requiring improved understanding and linking of drivers and actors at household and institutional level.

Keywords: *climate change, coffee*

5.2 New tools and paradigms

OP5.2.1. New technologies to old problems: online Role Playing Games, farmers and coffee agroforestry in the Western Ghats

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Problems of natural resources management are often wicked problems. They involve multiple stakeholders with different worldviews, different needs and agendas, in a world with pervasive uncertainties. The answers to such problems are not technical fixes but political processes that engage the stakeholders in problem-solving iterative loops. However, new technologies, particularly IT, can help navigate the complexities of designing efficient natural resources management schemes. We present here an initiative to develop online participatory tools to contribute to an ongoing policy debate in the coffee agroforestry systems in the district of Kodagu (India). In this landscape, driven by market incentives and recently available technologies, farmers are intensifying the production system and replacing the complex and diverse canopy cover with the fast growing *Grevillea robusta*. In the background, farmers and foresters are fighting for the rights over the native tree species. The outcome

of this struggle has the potential to dramatically alter farmers' strategies and the distribution of biodiversity at the landscape level.

While earlier research quantified past dynamics and highlighted the main drivers of the present trends, tools are lacking for the decision makers to explore the long term, often unforeseen impacts of their proposed interventions. Based on a conceptual model developed through participatory workshops with local stakeholders, we developed a computerized agent-based model using a dedicated modelling platform, NetLogo. This online-enabled modular platform allows stakeholders to interact on a larger scale, to propose alternative futures and policy changes, and to explore the impacts of these proposed changes. We will use it as a springboard for discussion with local stakeholders and policy makers, to broadly disseminate the results of our research, and to encourage local farmers and outsiders alike to contribute meaningfully to the policy process, allowing for surprises and innovation to emerge from the interactions the platform will generate.

Keywords: *companion modelling, farmer strategies, Netlogo, wicked problems*

OP5.2.2. Agroforestry systems risk/revenue balance: an investor's point of view

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The Moringa fund is the world's first investment vehicle dedicated to agroforestry with high social and environmental impacts in Latin America and sub-Saharan Africa. While its final objective is to raise EUR 100 m, it has already gathered a blend of public and private investors for a total amount of EUR 51.4 m and is now ready to launch its first investments. The main objectives of the fund are (i) to develop sound agroforestry projects providing a commercial return to its investors; (ii) to have a positive environmental impact (climate change mitigation and adaptation, soil improvements, biodiversity conservation, etc.); and (iii) to increase the livelihoods of farmers and local communities. The main models targeted are sylvopastoralism, permanent crops under shade trees, and intertwined or mosaic agroforestry.

While numerous publications describe the economic, environmental and social benefits of agroforestry projects, few detail the advantages of agroforestry from an investor point of view. This article presents and discusses key arguments for agroforestry projects in comparison to conventional agriculture and forestry investments. Advantages can be summarized as follows: (i) diversified revenue and market sources (ii) increased yields thanks to synergies involved in agroforestry (iii) maximization of revenues for a given area of land (iv) reduced costs thanks to well designed partnerships and outgrower schemes with farmers (v) positive impacts on climate change, soil, water, biodiversity, etc. and reduced environmental risks (vi) better resilience of investments (vii) increased farmer and community livelihoods, less social risks (viii) reduced land grabbing issues (ix) potential for revenue from environmental services.

Keywords: *agroforestry systems, investment, revenue risks*

OP5.2.3. The end of the sun/shade dichotomy in AFS: mapping of plant light budgets in multistrata heterogeneous plots

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In many agroforestry systems (AFS) studies, shade is presented as being the opposite of full-sun condition. This simplification ignores light transmission through canopies or the role of diffuse light transmittance in crop light budgets. We argue here that a detailed and continuous assessment of light availability in AFS is a prerequisite to understand the impact of shade trees on the productivity of the associated crop. With this aim, we applied MAESTRA, a 3D light interception model, to a coffee AFS (CoffeeFlux Observatory) composed of two heterogeneous canopy layers to assess the level of competition for photosynthetic active radiation absorption (aPAR) between coffee and shade trees (*Erythrina poeppigiana*) with a spatial resolution from plant to plot and a temporal resolution from 30 min to a whole year. Model predictions were tested against field measurements. We mapped aPAR over the coffee layer. Large and low density shade trees (9% tree cover) reduced the aPAR in coffee by 14% on a yearly average. Shade trees increased the fraction of diffuse irradiance by 20% below their crown, suggesting some positive impacts on the efficiency of coffee photosynthesis. Seasonal variations in aPAR were mainly explained by changes in coffee leaf area index with the annual coffee pruning having the strongest impact. In the actual coffee density, 35% of the incident PAR was still absorbed by the soil due to inter-row spaces. This is a large amount of underexploited energy that could be used by a cover crop. We performed prospective simulations increasing shade tree density gradually. Coffee plantation aPAR displayed a negative exponential relationship with increasing shade tree density. The photosynthesis being non-linearly related to incident light, the decrease in coffee layer photosynthesis is expected to decrease less rapidly than the decrease of aPAR.

This modeling approach allows to assess the light available for individual plants as a continuous factor that can be used as a powerful covariable to study e.g. the determinants of crop yield, the incidence of diseases, etc. MAESTRA can be used to test some simple hypothesis prior to AFS field experiments such as the effects of slope, row orientation, pruning techniques, shade tree arrangement on light absorption. Once carefully verified and parameterized, MAESTRA can be used as a powerful tool to test some new AFS designed to optimize light absorption, canopy temperature, carbon assimilation and/or transpiration.

Keywords: 3D light models, coffee, agroforestry, shade tree density

OP5.2.4. Using ground penetrating radar in agroforestry systems: quantification of tree root distribution and biomass

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Within agroforestry systems, tree root architecture is a driver of important ecological processes such as nutrient cycling and carbon storage. Yet the below-ground component of trees remains largely

understudied due to methodological constraints. Conventional subsurface sampling can overlook the heterogeneity of root systems, while complete excavations are destructive and unrepeatable. Thus, there is a need to develop *in situ* non-intrusive technologies, such as ground penetrating radar (GPR), to measure root systems. Radar signals emitted from GPR into the subsurface are reflected at the coarse root-soil interface due to a contrast in dielectric properties. The returned radar signals can be interpreted to determine root biomass estimates and distribution. This technology was tested in two agroforestry systems: a tree-based intercropping (TBI) system in Canada and a cocoa-shade (CS) system in Ghana. Drawing on these tropical and temperate systems, we provide an overview of the methods used, the limitations of the technology, and the promising applications of GPR to study the ever-elusive tree root in order to answer important ecological questions pertinent to land management objectives. Using GPR image analysis, we successfully and non-destructively detected alley tree and shade tree plus cocoa tree-crop coarse root distributions in TBI and CS systems, respectively. We show strong root plasticity in agroforestry systems as: i) interspecies variability was detected in tree root stratification patterns and ii) coarse root distribution was modified in the presence of a secondary species and under contrasting edaphic conditions. In the TBI system, tree root biomass was accurately estimated for five tree species using GPR image processing when compared to the matched harvested root systems. This new application of GPR allows for the charting of tree root structure and a novel method for root biomass estimation, and therefore carbon storage, in agroforestry systems.

Keywords: *cocoa agroforestry systems, geo-imaging, carbon storage, tree root biomass, tree-based intercropping*

OP5.2.5. The talking toolkit for facilitating farmer groups on the role of trees for adaptation

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As agroforestry is gaining ground as a climate-smart practice, we discovered that very little scientific evidence was documented on the role of trees for farmers' coping and adaptation strategies particularly in Southeast Asia. Furthermore, 'participatory tools' for this purpose were missing or needed revamping.

Results from a survey of 660 households in northern and north-central Vietnam show 2/3 of women and 1/3 of men had never heard of 'climate change' although they were exposed to multiple hazards on an annual basis. This affected how we worked and talked about adaptation.

Here we present a selection of tools designed to encourage inclusive discussions, which were developed specifically to identify the role of agroforestry and trees as coping strategies during extreme weather events and for identifying adaptation options. Next we present key results from focus group discussions in 18 villages and how these are used for local land-use planning. The tools are available online as a 'living' document for further use by agroforesters.

Keywords: *adaptive capacity, focus group discussion, land-use planning, participatory methods*

OP5.2.6. Combining a numerical model with farmer participation for the design of sustainable and practical agroforestry systems

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The complexity and variability of multispecies perennial systems creates a challenge for the design of sustainable agroforestry systems that need to be applicable in practice. Combining numerical models with farmers' participation could help design systems that find optimal solutions for balancing different performance requirements, as well as being acceptable by the farmers who would be implementing these new systems. We used a working coffee/shade tree agroforestry model, CAF2007, to search for scenarios where farmers could increase shade tree density in order to decrease runoff and erosion, while maintaining coffee yields. 19 coffee farmers, divided into four groups according to their farming practices, were invited to attend five interactive work sessions. We evaluated the effect of introducing a numerical model on the scope and detail of a discussion around design of cropping systems for mitigating erosion at the plot scale. Participants in all groups actively engaged with the model, which served as a support for discussing the processes and parameters affecting soil erosion, including shade tree management. As the study area was located in a highly productive coffee zone, fertilization was also a topic of major interest. Farmers compared simulation outputs to their own observations in the field; feedback on model performance suggested that model sensitivity to certain parameters such as N input and shade tree density needed to be improved. Overall, 78% of participants identified at least one change in practice that they wished to try on their field; the majority were concerned with changes in the amount and frequency of fertilization applications and/or change in shade tree pruning levels. This study showed that a) numerical models can be a valuable tool for facilitating discussion of the function of complex systems and encouraging on-farm trial of new/modified practices; and b) feedback from such interactions yields valuable information on necessary improvements to the model.

Keywords: *coffee agroforestry system, Costa Rica, modelling, participative approach*

5.3 Biodiversity and agroforested habitats

OP5.3.1. Tree-soil interactions and the provision of soil-mediated ecosystem services

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Agroforestry is recognized to have the potential to guide the transition to a multifunctional agriculture that successfully addresses the challenge of optimizing crop productivity while maintaining the provision of multiple ecosystem services. The majority of ecosystem processes depend on the soil as the critical and dynamic regulatory centre. Soil organisms contribute to a wide range of ecosystem services that are essential to the sustainable function of natural and managed ecosystems. Recent evidence has shown that there is a strong linkage between above-ground biodiversity (vegetation/crops) and below-ground biodiversity (soil organisms). This finding supports the concept that the integration of trees in agriculture can have profound impacts on soil-mediated ecosystem services. Our study of tree-soil interactions is housed within a Land Health Surveillance Framework that involves standardized measurement protocols over sentinel sites (10 x 10 km blocks of land), within which a spatially stratified, randomized ground-sampling scheme is implemented. Tree and shrub density are measured and soil samples taken in 100-m² sub-plots, which are nested within 1000-m² plots, in turn nested within 1-km² diameter clusters. The position of the clusters within 2.5 x 2.5 km tiles is also randomized. Soil

samples from each plot are characterized using infrared spectroscopy as a front-line tool for screening soil properties. The strategic combination of a whole soil biota sampling protocol, molecular biology tools, and spectroscopic techniques within spatially-explicit sampling frameworks allows the systematic study of tree/soil biota interactions influencing soil-mediated ecosystem services in agricultural landscapes of east and southern Africa. Land Health Surveillance can provide a practical, evidence-based approach for considering soil biodiversity and other land health indicators when planning and evaluating land management interventions

Keywords: *trees, soil biodiversity, ecosystem services, agroforestry*

OP5.3.2. Shade, litter, nematodes, earthworms, termites and companion trees in coffee agroforestry in relation to climate resilience

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Coffee agroforestry systems are intermediate between forest and monoculture coffee in many aspects of above and below-ground biodiversity and related functions. For the farmer, however, the balance of positive and negative aspects of diversity needs to be understood in relation to key processes such as nutrient and water uptake, slope and topsoil integrity and harvestable yield. Climate variability affects water availability, modulated by the pattern of infiltration and water holding capacity of the soil, but also through pest and disease relationships that influence root functions in water uptake. In the Way Besai catchment (Sumberjaya, Lampung, Indonesia) that has seen a rapid transformation towards coffee in the past three decades, we surveyed earthworm, nematode and termite diversity profiles of forest, coffee agroforestry; simple shade-tree + coffee mixtures and coffee monocultures were combined with measurement of soil macroporosity, surface runoff and coffee yields. Four relatively large-bodied native earthworms were lost upon forest conversion, with six exotic and smaller-bodied worms replacing them. The nematode fauna shifted towards plant-parasitic genera, especially where a grass/weed understory was present. Shade trees depress ground vegetation through litter, reducing plant parasitic nematodes, but enhancing earthworms. *Gliricidia sepium*, a favourite N₂ fixing companion tree of coffee is toxic for earthworms as well as plant parasitic nematodes, while banana stimulates the nematodes but provides direct yield to the farmer. Termites can shift from beneficial to pest status depending on the availability of woody debris in the system. Overall, the multispecies coffee agroforestry systems are more robust to climate variability, partially through these biotic interactions with soil fauna. Farmer knowledge tends to focus on what is visible above-ground and rationalizes the benefits and negative impacts of various companion trees in terms of ‘hot’ or ‘cold’ soil properties. Although these terms do not directly relate to temperature, management towards ‘cold’ components can in fact buffer them from effects of global warming.

Keywords: *coffee agroforestry, nematodes, pests*

OP5.3.3. Impact of rubber tree plantations on soil functional biodiversity and soil organic carbon

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The Mekong sub-region faces an exceptional expansion of rubber tree plantations, which represent a potential problem in terms of soil sustainability. However, in comparison with intensive annual cropping, rubber tree plantation could also have a positive impact on soil functioning but data concerning its influence on soil environment remains scarce. To address this question, we investigated the impact of rubber tree plantations on soil organic carbon (SOC) and soil biological diversity (soil fauna and microorganisms) related to main soil functions such as OM mineralization and nutrient cycling. All the biologic and physical-chemical parameters were measured from the same sampling set along a rubber tree chronosequence in the eastern province of Thailand, and compared to the former crop cultivated (cassava). Compared to the cassava field, most of the variables measured (SOC, soil respiration, microbial activities and density, fauna density and diversity) showed significantly higher levels only in the old rubber plantations (23-25 years). However, the shift from cassava to young rubber plantations (< 7 years old) resulted first in a depletion of all these parameters. The soil ecosystem started to recover from the land use change after the closing of the canopy of the plantation. At this stage, above-ground and below-ground litter started to accumulate significantly in the system. Interestingly, soil fauna structure varied according to plantation age, while bacterial structure depended more on land use change (cassava vs. rubber). These increasing biological activities seemed to participate to a significant change in OM quality (Rock Eval results). These results suggest that planting rubber trees could be a better alternative than cassava crops in terms of soil sustainability. This first study needs to be generalized through an extension towards other crop systems and soil types.

Keywords: *Soil biodiversity, soil bacteria, soil fauna, soil organic matter, c stock*

OP5.3.4. The role of coffee agroforestry in the conservation of forest tree diversity and community composition

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Coffee agroforestry is considered a promising alternative to conventional agriculture that may conserve biodiversity while supporting local livelihoods. This study analyzed the capacity of coffee agroforestry to conserve the tree species diversity and community composition found in forests in La Sepultura Biosphere Reserve in Chiapas, Mexico. To meet this goal, we compared coffee agroforests to forest in terms of floristic richness estimated by tree species richness, Shannon and Simpson Reciprocal diversity indices, and accumulation curves; vegetative structure characterized by basal area, canopy closure, shade tree density, and coffee shrub density; tree community composition described by non-metric multidimensional scaling ordination and by traits of succession (pioneer, intermediate, and late successional); and the presence and abundance of tree species of conservation concern. We found that,

although at the landscape level the ensemble of coffee agroforests may conserve comparable species richness to forests, the species ensemble that is being conserved in coffee agroforests is different from that found in forests. Coffee agroforests were dominated by *Inga* spp, harboured lower tree species diversity at the plot level, a higher proportion of pioneer trees, lower proportion of trees of conservation concern, and were different in terms of community composition compared to forests. Due to these significant differences in tree diversity and community composition between coffee agroforests and forests, we suggested that conservation practitioners and policy makers seeking to promote coffee agroforestry as a conservation strategy should be mindful of whether coffee expansion is occurring in forests or land previously used for agriculture. Whenever appropriate, strategies and policies should impulse the conversion of crop monoculture and pastureland into coffee agroforests, thereby sparing forests and reforesting tree-less agricultural land. Conservation strategies should also discourage the replacement of diverse forest canopies by *Inga*-dominated coffee agroforests.

Keywords: *biodiversity, coffee agroforestry, conservation agriculture with trees tree and crop management*

OP5.3.5. Effects of local and landscape conditions on insect pollinator in forest–agricultural landscape of west Java, Indonesia

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In relation to the issue of pollination crisis and the importance of crop pollinations to ensure enough food in tropical developing countries, it is crucial to understand roles and effects of human-modified landscapes with fragmented forest remnants in maintaining pollinator diversity while fulfilling the demands of local residences and reducing poverty. To implement appropriate landscape management for maintaining pollination service, sufficient information is essential about parameters of habitat suitability among various human-modified habitats with a range of distances to forests and vegetation characteristics, but such information is scarce. We investigated differences in insect pollinator communities between a remnant forest, two types of mature plantations, two types of agroforests, upland crop fields, rice paddy fields, and human settlements in a forest–agricultural landscape of west Java, and we analyzed the effects of both local and landscape factors on various types of species richness in this landscape. Results of non-metric multidimensional scaling revealed almost no strong difference of insect pollinator species composition among habitat types, although the results also indicated that abundance of crop pollinators (bees and wasps) declined and their replacement with others (beetles, moths, butterflies, and flies) along a gradient of human disturbance. Generalized linear modelling results revealed that insect pollinators were more sensitive to vegetation cover rather than to distance to remnant forest. However, crop pollinators were more sensitive to different habitat types: species richness of bees was highest in the remnant forest. Mixed-tree agroforests were colonized by 93% of crop pollinators found in remnant forest, and maintained the highest richness of insect pollinators together with the remnant forest. We concluded that the protection of remnant forests as a source of crop pollinator diversity particularly bees has to be prioritized. However, as different environmental factors affected the richness values of different groups of insect pollinators, appropriate landscape design and habitat management could improve functional diversity in forest–agricultural landscapes in the tropics.

Keywords: *pollination, crop pollinator, generalized linear modelling, mixed-tree agroforest, landscape management*

OP5.3.6. The effects of shade, altitude and landscape composition on coffee pests in East Africa

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The diversity and abundance of natural enemies of insect pests is often higher in agroforestry plantations than in sun-exposed monocultures, and it is often assumed that this will result in improved pest suppression. However, the effect that incorporating trees in cropping systems will have on pest populations also depends on the habitat requirements of the pests themselves. We studied how the abundance of a range of coffee pests was influenced by agroforestry in East Africa. Along the slope of Mt Elgon in Uganda, we studied how shade level and altitude influenced the abundance of the white stem borer, *Monochamus leuconotus*, and the coffee berry borer, *Hypothenemus hampei*, and close to Kitale in western Kenya we investigated how various pests on coffee leaves, e.g., aphids and lacebugs were influenced by shade level and the amount of trees in the surrounding landscape. We found that the effect of shade trees differed between pest species. The coffee berry borer was more common on sun-exposed plantations, whereas the white stem borer was more common in shaded plantations. However, the effect of shade level on the white stem borer depended on altitude, with the differences between shade levels being most pronounced in plantations at low altitudes. For lacebugs, *Habrochila ghesquierei* and *Habrochila placida*, the effect of shade trees depended on the amount of trees present in the surrounding landscape, with a higher abundance of lacebugs in shaded plantations only in landscapes with a low tree cover. The results from this work show that the impact of agroforestry on pest regulation in coffee is highly context specific; it depends on the identity of the most important pests in the area, the altitude and landscape composition.

Keywords: *ecological context, insect pests, landscape complexity, shade tree*

5.4 The agroforestry of dry and degraded lands

OP5.4.1. The Spinal: a sustainable productive alternative for interior dryland development of Chilean Central Mediterranean area?

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The formations constituted by individuals of the native *Acacia caven* (Espino) in Chile can contribute to the development of dry land areas of the Central Zone of Chile in South America. Specifically Espino is a legume that fulfills important economic, social and environmental issues within this system such as maintaining and improving soil resources, creating better conditions for developing local prairie, and maintenance of livestock production. It also has the ability to generate products such as firewood and charcoal wood energy, contributing to improving the quality of life of rural residents.

However, this resource is highly degraded and as in the past, it is currently under strong human pressure to convert this system to agriculture and livestock, and for the extraction of biomass as fuelwood and coal.

This paper aims to describe the resource constituted by *Acacia caven* formations, Espino, existing in central Chile and provide a background to show the contribution that this resource is able to generate for a productive, environmental and economic central Chile.

In analyzing this information, it has been elucidated that *Acacia caven* formations can be one of the main sustainable development of dry land areas of Central Chile as a silvopastoral system, but progress is still required in new lines of inquiry and mainly in a systemic analysis that optimizes and gives this resource sustainability.

Keywords: *Acacia caven, agroforestry systems, dry lands, silvopastoral systems*

OP5.4.2. Trees and resilience in dryland agroforestry systems in Eastern African

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Vulnerability related to drought and climate change has led to considerable interest to enhance resilience in drylands. Woody species form an important part of the vegetation of drylands, yet there is scattered knowledge on the role that trees could play in achieving more resilient drylands development. The World Agroforestry Centre (ICRAF) organized a consultative assessment process to compile existing knowledge and best practice on trees and resilience to ensure that trees in dryland forests and agroforestry systems are managed to strengthen people's resilience to the shocks they encounter. Considering resilience from an ecosystem service perspective has advantages in agroforestry systems where trees have many indirect benefits. An ecosystem service approach was thus taken to assess existing knowledge of benefits that people derive from trees in the drylands of East Africa. The assessment further reviewed 15 project-based natural resource management interventions in African drylands in more detail and assessed whether experience gained could be upscaled throughout the region.

Keywords: *agroforestry, eastern Africa, ecosystem services, resilience*

OP5.4.3. Agroforestry for rehabilitation of degraded lands and poor quality waters: livelihood security and mitigating climate change

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About 2 billion ha in the world is affected by various forms of human-induced land degradation with erosion by water being the chief contributor (1.1 billion ha). In India, out of 120.8 million ha (Mh) degraded land, 82.6 Mh is estimated to suffer from water erosion, 24.7 Mh from chemical degradation, 12.4 Mh due to wind erosion and 1.1 Mh from physical (mainly due to stagnation of water) degradation. About 6.73 Mh is adjudged as salt-affected. With developing scenarios of severe water scarcity and competition from other sectors of the economy, it appears axiomatic that agriculture would have to increasingly depend upon marginal and poor quality waters. In most of the arid and semi-arid regions, the ground water aquifers are saline. The groundwater surveys indicate that poor quality water utilized in different states of India ranges between 32 and 84% of the total ground water development.

To meet various diverse needs of ever-increasing human and animal population, we need to rehabilitate all degraded lands. Many species of forest and fruit trees, shrubs, forbs, grasses and medicinal plants have been identified and evaluated for growing in problematic areas. Vast tracts of arid and semi-arid areas remain barren due to salinity or water scarcity. With use of appropriate planting techniques and salt-tolerant species, these could be brought under viable vegetation cover. Auger-hole technique for sodic soils, furrow technique of tree plantation for saline soils, and ridge plantation in waterlogged fields are found quite appropriate. By applying appropriate planting and management techniques (e.g. sub-surface planting and furrow irrigation), various species of forest and fruit trees, forage grasses, medicinal and aromatic and other high value crops have been found equally remunerative. Tree-based technologies have additional environmental benefits including huge amounts of carbon sequestration, biological reclamation and mitigating climate change.

Keywords: *degraded lands, livelihood security, rehabilitation, salty soils*

OP5.4.4. Using species distribution models to select climate change resistant species for the ecological restoration of bowé in west Benin

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'Bowalization' is a particular form of land degradation and leads to the lateral expansion of ferricrete horizons. The process occurs only in tropical regions. The term 'bowe' refers to edaphic deserts. The adapted and robust species towards climate change on bowe were identified by taking down the most common present-day bowe species in both climate zones. Then these species were submitted together with significant environmental variables (the elevation and 19 current bioclimatic variables and the digital soil map of Benin) at a spatial resolution of 30s to the ecological niche model of Maxent (Maxent 3.3.3, Phillips et al. 2004). Altogether 15 woody and herb species of the sub-humid and semi-arid climate zones were used. For future prediction of the spatial distribution of the most common bowe species, the IPCC4/CIAT climate data for 2050 were applied. In the semi-arid climate zone, *Asparagus africanus* presented a stable performance in the three phytogeographical districts (Atacora chain, Mekrou-Pendjari and North Borgou) while *Andropogon pseudapricus* and *Combretum nigricans* showed a wider potential distribution in 2050 than today. *Hoslundia opposita*, *Crotalaria macrocalyx*, *Schizachyrium sanguineum*, and *Detarium microcarpum* were modelled with a smaller potential distribution area in 2050 than today in the three phytogeographical districts of this climate zone (table 2). *Asparagus africanus*, *Andropogon pseudapricus* and *Combretum nigricans* species are the best for the restoration of bowé since the future climate will be suitable for them. In the phytogeographical district of sub-humid climate zone (South Borgou, Bassila and Zou) *Asparagus africanus* was modelled with a similar extension for today and 2050. *Detarium microcarpum* and *Lannea microcarpa* will potentially be distributed more widely except in Bassila while *Asystasia gangetica* is potentially encountering more favourable environmental conditions in the future (2050) in South Borgou and Bassila. *Combretum collinum*, *Combretum nigricans*, *Ctenium newtonii*, *Indigofera bracteolata* and *Schizachyrium sanguineum* will be potentially less distributed in Bassila and South Borgou while *Indigofera bracteolata* will be potentially less distributed according to the model in the three phytogeographical districts of the sub-humid zone. *Asparagus africanus*, *Detarium microcarpum* and *Lannea microcarpa* are the best species for restoration in the sub-humid climate zone as the future climate condition will be suitable for them.

Keywords: *Benin, bowé, ecological restoration, resistant species*

OP5.4.5. Arbuscular mycorrhizal association and growth response of *Faidherbia albida* (Del.) A. Chev. as influenced by land use type

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The distribution and density of mycorrhizal fungi is highly influenced by the type of vegetation and land use types. This study was carried out to study Arbuscular Mycorrhizal (AM) fungi status of *Faidherbia albida* trees grown at three different land use types (area enclosure, grazing and cultivated lands). Soil and live fine roots were collected from the rhizosphere soils of *F. albida* trees. AM root colonization percentage was determined using the grid line intersect method. Spores were extracted from 100 g of air-dried sub-samples by wet sieving and decanting method. Pot experiment was set up in a greenhouse using completely randomized design with four treatments and replicated three times. There was a significant difference on AM colonization among *F. albida* tree roots grown on different land use types ($P < 0.0086$). Colonization of *F. albida* roots were higher in area enclosure (71.1%) followed by grazing land (66.5%) and cultivated land (66.1%). Similarly, spore abundance count was significantly higher ($P < 0.0014$) in area enclosure (3041 100 g⁻¹ of dry soil), followed by cultivated land (2002 per 100 g⁻¹ of dry soil) and grazing land (1364 100 g⁻¹ of dry soil). Soil samples collected from cultivated land showed a higher number of spores with low AM colonization compared with grazing lands, which implies low level of infective AM populations in cultivated lands. *Glomus* was the dominant genus identified in all land use types. AM inoculated *F. albida* seedlings showed significant growth enhancement compared to the control treatments ($P < 0.05$). Growth enhancements of seedlings inoculated with AM fungal inoculums collected from area enclosure was, however, higher than those collected from grazing land and cultivated land. This emphasises the importance of native soil AM potentials in area enclosure and grazing land for better combinations of *F. albida* seedlings with AM fungi species to achieve optimum plant growth improvement and rehabilitation of degraded lands.

Keywords: spore abundance, AM colonization, soil disturbance, inoculum types, land use types, growth parameters

OP5.4.6. Physiological response of switchgrass for bioenergy alley cropping in soils of varying depths in central Missouri

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Sustainable biomass feedstock production systems involve biomass generation from non-agricultural or marginal lands with minimal external inputs. Switch grass based alley cropping systems have been proposed as biomass feedstock crop systems in marginal lands. In many areas in the midwest United States, shallow soils above the argillic horizon (claypansoil or often called depth to claypan –DTC) are susceptible to flooding and drought and thus hinder high economic returns from conventional agricultural production. The main purpose of this research was to assess differences between corn and switchgrass photosynthetic potential as influenced by the DTC. Research was initiated in 2009 in Columbia, MO on 160 plots with corn, soybean, and switchgrass grown on a range of DTC (0 to 80 cm). Biomass data from 2009 to present have revealed that corn yield was sensitive to DTC with greater yield as DTC increased ($p < 0.06$) while switchgrass yield proved to be insensitive to DTC for

all years except in 2012. To understand the fundamental mechanism driving this trend, we used a portable photosynthesis measurement unit (LiCor 6400) to measure the light response curves for corn and switchgrass at three different soil depths –shallow (2 cm), medium (22 cm), and deep (42 cm). Results suggest that soil depth was more important for corn to maintain a high rate of photosynthesis while switchgrass was able to maintain photosynthesis in a more uniform rate irrespective of soil depth. The significance of this research is that it establishes that switchgrass can be used as an alternative bioenergy crop in marginal lands degraded due to erosion such as commonly found in side-slope landscape positions of claypan soils.

Keywords: *alley cropping, biofuel feedstock, switchgrass*

5.5 Temperate agroforestry

OP5.5.1. Temperate agroforestry in the 21st century: a North American perspective

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The scientific foundation that has been laid over the past decade in particular has elevated agroforestry's role as an integral component of a multifunctional working landscape in North America. Recent trends in the agricultural sector necessitate farm diversification as an essential strategy for economic competitiveness in a global market. The realization that agroforestry systems are well suited for diversifying farm income while providing environmental services and ecosystem benefits has increased receptivity on the part of some landowners. Agroforestry systems offer great promise for the production of biomass for biofuel, specialty and organic crops, pasture-based dairy and beef, among others. Agroforestry also offers proven strategies for carbon sequestration, soil enrichment, biodiversity conservation, and air and water quality improvement for not only the landowners or farmers, but for the society at large. In an era of environmental sustainability and green business, the realization that agroforestry is an environmentally sound, ecologically sustainable, and economically viable alternative to traditional farming will propel its adoption to newer heights in the coming decades.

Keywords: *biodiversity conservation, carbon sequestration, temperate, water quality*

OP5.5.2. Evaluating nitrogen transfer from Caragana Shelterbelt and its effects on yield and nutrition of forage crops

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The overuse of synthetic nitrogen (N) fertilizer to meet the requirements of food and forage crops species contributes to environmental problems such as nitrate leaching to groundwater and enhanced greenhouse effects through N₂O emissions. Agricultural practices integrating legumes and food or forage crops can address this problem by reducing the reliance on industrial fertilizers through fixation and transfer of N by legumes to associated crops. Below-ground N transfers in various systems have been widely researched. However, within the prairies, there is dearth of information regarding N transfer in shelterbelt-based systems. The field experiment was conducted to determine the amount of N transferred from Caragana shelterbelt to forage crops (triticale and oats) using the ¹⁵N natural abundance technique and to assess effects of this transfer on forage biomass and quality. Plants close to the

shelterbelt row received significantly higher % N and actual N transferred compared to those further away. The range of the % N transfer spanned from 8-64% and 16-70% for the 2011 and 2012 seasons, respectively. This amount was equivalent to the transfer of 33-329 g N m⁻² and 67-228 g N m⁻² in triticale and oats, respectively, and it was within the optimum N application rates for these crops. The below-ground N transfer reached the optimum N rates even up to 20 m away from the shelterbelt. Total N and crude protein of the test crops improved significantly with the distance from the shelterbelt, signifying that the amount of N transferred enhanced forage crops nutrition. Biomass yield was, however, not affected suggesting that N may not be the main factor driving crop growth in the study site. This study suggests that the N requirements of the forage species can be met by N from the shelterbelt.

Keywords: *15N, natural abundance, N management, nutritive values, prairies*

OP5.5.3. Effects of silvopastoral practices on intensively-managed quality timber plantations in Spain

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Europe needs high quality wood. A number of several thousand hectares of hardwood plantations have been established in many regions of the Iberian Peninsula. To enhance tree growth, frequent harrowing and high levels of water, fertilizer and herbicide inputs are commonly applied. Silvopastoral management could reduce the economic costs and the negative environmental impact of these plantations.

We evaluate the response of intensive irrigated walnut (*Juglans major* var. 209 x *Juglans regia*) and wild cherry (*Prunus avium*) plantations to: (i) alternative methods of controlling the competing herbaceous understory (harrowing, brushcutting, and grazing), and (ii) the substitution of mineral N fertilization by sowing leguminous pastures (which would also reinforce the pastoral value of the system).

After 12 years of intensive management, the change to alternative management had a slight but significant effect on tree growth. Both fertilized and legume-intercropped trees grew similarly and faster than control trees and in spite of this the yield of herbaceous understory almost doubled in both cases in comparison to the control ones (3652, 3564 and 1978 kg DM ha⁻¹, respectively), and consequently soil moisture was reduced with both treatments. Nevertheless, this did not have any significant effect on water status and photosynthetic activity of walnut leaves. By contrast, both fertilized and legume-intercropped walnuts had leaf N content slightly higher than control trees.

Grazing did not significantly affect soil moisture, tree water status, soil nutrient availability or leaf nutrient content, but significantly reduced the growth of trees compared to brushcutting and harrowing. These results agree with the marginal decrease of CO₂ assimilation rate of walnut leaves in grazed plots. We expect that with more time a more regular grazing will reduce differences among grazed plots and mechanically managed ones.

Keywords: *hybrid walnut, intensive silviculture, legume intercrop, wild cherry*

OP5.5.4. Environmental and biological interactions on productivity of silvopastoral system with *Pinus contorta* Doug. ex. Loud.

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In a study conducted in the Aysen Region, located in the extreme south of Chile, we evaluated the effect of *Pinus contorta* plantation, managed under two designed silvopastoral systems, in altering climatic parameters under its influence such as wind speed, wind chill, relative humidity, ambient temperature and precipitation that reaches the ground, and its effect on livestock and prairie production. The silvopastoral treatments evaluated were a) strips of four lines of trees, 21 meters apart, and b) traditional silvopastoral systems with trees spaced in the land, both with 400 trees ha⁻¹, compared with c) animal production system without trees, as a control treatment. The results obtained show that the trees managed under silvopastoral systems modified some ambient climatic parameters. The main parameter that was modified by the effect of the trees was average wind speed. The trees reduced the average wind speed in relation to the control treatment by 200%. In relation to the wind chill, higher values were recorded between 22 and 26% for the forest strip and traditional silvopastoral systems respectively, compared to livestock treatment. On average there was no difference in the air temperature, relative humidity values were 0.2 to 0.6% higher in the silvopastoral treatments than the control. When analyzing the factors that influence pasture and livestock production, when tree density and arrangement were modified for silvopastoral purposes, positive correlations were obtained between canopy cover and wind speed of $r^2=0.95$; between canopy cover and productivity of prairie the correlation was $r^2=0.88$ and $r^2=0.69$ for traditional silvopastoral and strips treatment respectively; for animal productivity and wind velocity, it was $r^2=0.86$. On linear models of more than one variable, the forest crown coverage associated with wind was the variable most incident, which impacts positively the pasture productivity and consequently in animal production.

Keywords: *environmental and biological interactions, livestock and pasture productivity. silvopastoral systems, wind speed*

OP5.5.5. Introducing AGFORWARD –a project to advance agroforestry in Europe

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AGFORWARD is a major four-year research project funded by the European Commission starting in January 2014. The goal of the project is to promote **AGroFOREstry** that **Will Advance Rural Development** in Europe. This exciting initiative will involve over 20 European partners, two international institutions and about 960 person-months of paid input. It builds on the work of European research projects like SAFE, promotional work by ACTA and AGROOF in France, the establishment of the European Agroforestry Federation, and a recognised role for agroforestry in rural development programmes and the new EU strategy for forestry.

This paper will describe the development, the objectives and the broad methodology of the research project which comprises four main components. An initial component is focused on understanding the context and extent of agroforestry in Europe. A large participatory component will work with about 400 stakeholders to identify, develop and field-test innovations to improve the benefits and viability of agroforestry in specific agricultural sectors. There is an evaluation and modelling component that will examine the opportunities for uptake at field-, farm- and landscape scales, building on previous modelling research. The fourth component will promote the wider adoption of appropriate agroforestry systems in Europe through a range of policy development and dissemination activities.

Keywords: AGFORWARD, agroforestry promotion, Europe, methodological approach

5.6 The social science of agroforestry

OP5.6.1. Rural livelihoods, HIV/AIDS, and agroforestry interventions: social science methods for addressing complex problems

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Social science methodologies have been lacking in the field of agroforestry, and this was apparent and admitted at ICRAFs Science Week in 2010. However, the value and contribution of social science methods to agroforestry research are powerful. The interdependent nature of people's lives and livelihoods with forests and forest resources in developing countries cannot be adequately described and understood through the use of quantitative methods alone. Based on social science research I have been conducting in Malawi since 2010, I outline how the use of these methods have elucidated some of the key research questions I have been addressing within a broad field of study: the dependence of HIV/AIDS-affected households on forest resources, and agroforestry interventions and innovations for meeting their forest resource needs. I begin by summarising an exploratory study whose data were collected using focus groups and semi-structured interviews with local respondents in four Malawian study sites. This study characterised how household dependence on the most important forest resources (firewood, medicinal plants) changed through three phases: the period before HIV became a problem in the household, the period during HIV-related morbidity, and after AIDS-related mortality. It also identified a range of local forest-related coping strategies being used to alleviate the HIV/AIDS burden on their households, and agroforestry interventions that local people would like to try. I provide preliminary results from my current research assessing the socioeconomic impacts of several of these agroforestry interventions, and highlight potential social science research that could assess other interventions. Throughout the presentation, I will stress the key contributions that social science methods have made to this globally-relevant research domain.

Keywords: forests, HIV/AIDS, livelihoods, social science

OP5.6.2. The role of informal social networks in agroforestry adoption and management

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The diffusion of information on agroforestry management practices may rely heavily on social relationships and informal networks in the farming community. The structure of these networks can play a key role in advancing, or limiting, the adoption of agroforestry techniques. Of particular interest are the emergent networks in regions with weak institutional support but high technical necessity, such as the economically vital cocoa belt of West Africa. I draw on findings from a range of complementary but independent studies over the last five years in Ghana, and new data, to chart the role of social networks in agroforestry management. Producer-to-producer ties illustrated agrarian information networks where features of an individual network correlated strongly to agrobiodiversity (tree and crop species richness) as an estimate of agroforestry adoption. Pooled data showed a negative relationship between the density of ties in an individual's network and the number of reported species, suggesting that adding ties between community members did not forecast adoption of agroforestry. With increasing ties, information may become redundant or even conflicting; therefore I conducted a subsequent study that examined the role of other players in the agricultural landscape. Results demonstrate the significant position of local agricultural institutions on reshaping local networks and the role of migrant farmers as agroforestry information brokers between socially and geographically distant groups. More recently, we ask: do distinct agroforestry information network topologies coincide with predictable patterns of land use? Findings show that diverse, but not necessarily more, network ties correlate to land diversification and the emergence of agroforestry land use. Taking a social networks approach to elucidate the flow and coordination of information on suitable but innovative agroforestry management enables strategies for i) ecological resilience of the cocoa sector, which is key to rural livelihoods in the region, and ultimately ii) appropriate adoption of agroforestry.

Keywords: *cocoa, agroforestry systems, Ghana, information diffusion, social networks*

OP5.6.3. Transforming land and livelihoods: analysis of agriculture land abandonment in the mid-hills of Nepal

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Nepal continues to face exacerbating poverty, decreasing agricultural productivity and food insecurity. At a time when there is large-scale land grabbing taking place with the purpose to intensify agriculture for food security globally and scholarly debate to increase the extent and intensity of land use for agriculture, the mid-hills of Nepal seem to be witnessing an unprecedented degree of agriculture land abandonment in recent years. Therefore it is important to understand the extent, causes and consequences of land abandonment and its implication to food security and livelihoods. The aim of this paper is therefore to investigate the factors influencing the agricultural land abandonment in the middle hills of Nepal. This study employs mixed method approach to data collection in 4 mid-hill districts of Nepal, using both household survey and key informant interviews.

The results indicate that three key reasons relating to ecological, socioeconomic and cultural factors influence agriculture land abandonment in Nepal. Firstly, the highly fragile agroecology additionally

affected by the unprecedented climate change, forcing many smallholder and subsistence farmers either to change land-use patterns or abandon their agriculture lands altogether. Secondly, traditional small-scale subsistence agriculture in hills with its low returns on labour and other investment is not economically competitive with commercial agriculture. Thirdly, farming is no longer viewed as a prestigious or viable profession to maintain sustainable household economy. It is no longer a cool career that many young farmers aspire to pursue, forcing young villagers to urban areas and gulf countries, abandoning their farms. In conclusion, we highlight that the land abandonment presents some opportunities to bring agroforestry as the sustainable agroecological approach which can be successfully reintroduced to enhance an adaptive agricultural approach that can increase food security and livelihood options as well as address climate change threats.

Keywords: *agroforestry, food security, land abandonment, livelihoods*

OP5.6.4. Migrants and land markets in Jambi, Indonesia: the prospect of agroforestry development in peatland

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Policies designed to promote agroforestry development require a good understanding of the complex connections between state-sanctioned concessions, forest conversion, informal land markets and migrants. Our case study in the peat forests of the Tanjung Jabung Barat (TanJaBar) regency of Jambi aimed to explore relations between four key stakeholder groups: the state, local communities, migrants, and state-sanctioned concessions and how these relationships affect land-use patterns. We hypothesized that current land-use patterns are shaped by insecurity in formal forest tenure alongside informal land tenure arrangements with migrants.

In analyzing the six two-way relationships between the four stakeholder groups, we found that interactions between the stakeholders have changed local norms and practice, causing land conflicts and contested claims that need to be explicitly addressed in efforts to promote agroforestry development in TanJaBar. Relational concepts of land rights between migrants and local community are informed by social identity, expectations of investment opportunities, insecure customary forest tenure and competing land-use policies. These concepts in the end determine the land-use patterns. Migrants act as intermediaries in shaping the land tenure system and creating a new balance of power between local communities, government authorities and business concessions.

The Government of Indonesia (GoI) promotes national agroforestry development programs under different schemes of community-based forest management (CBFM). However, we conclude that effective and equitable implementation of national agroforestry development programs will need to recognize underlying land ownership dynamics, power struggles and strategic positioning among stakeholders across scales. It is increasingly important to consider migrants, migration and the emergence of land markets as part of agroforestry development programs.

Keywords: *community-based forest management, conflict, customary rights, power relations*

OP5.6.5. Management of Ghana's modified taungya system: challenges and strategies for improvement

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Ghana has since 2001 introduced a number of forest-based strategies for improving livelihoods of forest communities, restoring forest cover and addressing timber deficits; among these strategies is the modified taungya system (MTS). Through a mix of qualitative methods, field observations, and a household survey among 146 MTS farmers from eight villages in the Tano Offin, Tain II and Yaya forest reserves in the high forest zone, this paper addresses some challenges related to MTS management in Ghana. Results indicate that the quality of partnership (i.e. the actors involved) matters in the performance of the scheme. First, a co-management arrangement exclusively between the Forestry Commission and MTS farmer groups generates poorer results in terms of the quality of the timber stands, income-generating potential and motivation of the actors involved. Second, the lack of income from the MTS between tree canopy closure (when the growing of food crops is no longer possible) and timber harvesting demotivates farmers to invest labour in tree farm maintenance in the meantime. Thirdly, continued commitment of both participating farmer groups and coordinating agencies is key to tree farm establishment and maintenance and the quality of timber stocks. Lastly, the prospects for future income from timber revenues determine to a large extent farmers' commitment to tree maintenance. Linking up with theories on interactive governance and partnerships, the authors make several recommendations to overcome these challenges.

Keywords: *agroforestry management, livelihoods, modified taungya system, partnerships*

OP5.6.6. Understanding diversity of smallholder agroforestry and forestry systems in hilly and mountainous landscapes: regional comparisons in Asia

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Agroforestry systems and forests play an important role in providing or supplementing the livelihoods of smallholders living on sloping lands. Given this importance, smallholders manage these systems in ways that sustain their livelihoods and the biophysical and ecological integrity of these lands. These groups are also targets of various development interventions to promote forestry and agroforestry usually for the purpose of increasing ecosystem services and goods for people living elsewhere. While often sophisticated in terms of attention to the ecological characteristics of agroforestry systems, these policies are not sufficiently attentive to the sociocultural and political economic context within which smallholders operate. Furthermore, "smallholders" are not a unitary group. Rather, they are as diverse in terms of their needs, characteristics, motivations, and management practices as the agroforestry systems they depend upon. In more remote hilly and mountainous regions far from central authority, dominant national cultures and prime agricultural land, this diversity is even more pronounced. In this paper we draw on social science tools and methods to understand the diversity of smallholders and especially their agroforestry management practices. This understanding provides key insights to analyse incentives and restrictions governing projects targeting sloping lands for environmental interventions to improve, for example, soil and water management. We will draw on cases from overviews prepared by colleagues in seven Asian countries. In our synthesis of these cases we argue that the use of social science methods

and the inclusion of social scientists on multidisciplinary teams would allow policy interventions to be better adapted to the conditions and needs of heterogeneous populations.

OP5.6.7. Decentralization and forest restoration governance: a comparative study in upland communities of Southwest China

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The Chinese government is currently implementing the world's largest forest restoration program, the Sloping Land Conversion Program (SLCP), which uses public payments to convert marginal cropland in upper watersheds into forests, engaging millions of mountain-dwelling households. Apart from providing financial incentives, the state has also attempted to promote local autonomy and participation in the program. This promotion is a milestone shift in forest policy to grant more power to local communities and increase the involvement of local governance in decision-making. However, whether the SLCP has been effectively implemented, the extent of its ecological and socioeconomic outcomes and how its performance can be improved are still unclear in the absence of adequate biophysical and socioeconomic data. To gain a holistic understanding of the SLCP's implementation and impacts, this research examines the interplay between the governance of the policy implementation and local variations leading to the various ecological and socioeconomic outcomes observed based on a comparative case study. It provides a novel explanation of why SLCP succeeds in one place but fails in another although the program is generally implemented in a top-down approach, and it argues the significance of local institutions in shaping the policy's outcomes. This paper recommends institutional reform across the country's socioecological system with the national policy-maker allowing flexibility in policy implementation and developing mechanisms for accountability and local institutions.

Keywords: *governance, policy, institutional reform*

6.0 Sustaining development through agroforestry

6.1 Policy, governance and international frameworks

OP6.1.1. Revisiting debates on the role of gender in the governance of trees and forests in the context of climate change

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There exists a long-standing debate among researchers and practitioners on the role of gender in environmental governance including of trees and forests. While some point to the synergies between women's interests and the goals of good governance, others suggest that such relationships need to be examined in specific social and historical contexts and cannot be pre-determined. The importance of revisiting this debate is all the more important in light of recent attempts to integrate gender in climate change policies in the forestry and agroforestry sector. Informed by the aforementioned debate, women are portrayed as "victims" of climate change and "agents of change" in designing and implementing climate change policies while others see women as "perpetrators" and suggest including them might risk jeopardizing efforts to adapt to and mitigate against climate change. This presentation will critically review these debates and suggest that the role of gender in forestry and agroforestry in the changing

context of climate change needs to be understood from a relational and rights-based perspective, and it will highlight some of the implications for such a change in perspective for policies and practice.

Keywords: *gender, roles, climate change, policy*

OP6.1.2. Why has community forestry made limited contribution to agroforestry in Nepal?

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Nepal has one-fourth of its population living in absolute poverty. A major part of the poor population lives in rural areas and relies heavily on traditional agrarian economy with integrated forest-livestock-farm system. Ironically, the much-lauded success of community forestry (CF) institutions have posed restrictions on fodder production and grazing. As a result, the number of livestock per household has sharply declined over the past few decades. This is particularly so with the small and marginal farmers who rely on community forests to feed their livestock. It has two consequences. First, the livelihoods and food security of these poor farmers is seriously undermined. Second, the growing demand for meat and milk products in the country is met largely by imports. In this backdrop, this paper investigates why CF institutions are not adequately responsive to local livelihoods and national economic interests despite its huge potential through integrated and multiple use of forestry.

The paper is based on a critical review of policy documents, secondary information, key informant interviews and focus group discussions with community groups. In-depth cases of four Community Forest User Groups of Kavre and Lamjung districts on fodder production and grazing management is developed. It is found that the CF institutions have three major constraints. First, there is the strong influence of the conventional forestry science that conceptualizes forest management either for biodiversity and wildlife protection or commercial timber enterprises. Second, there are various regulatory barriers which restrict the use of community forests for fodder production and grazing. Third, the institutional fragmentation restricts the use of forest land for non-forestry species. We suggest an adaptive collaborative management approach building on the previous research conducted by ForestAction Nepal in collaboration with the Center for International Forestry Research (CIFOR) and International Development Research Center (IDRC) for multiple use forest management. The paper finally draws implications to CF policies and institutional architecture.

Keywords: *community forestry, fodder production, grazing management, livestock, livelihoods*

OP6.1.3. Engagement of private sector in REDD+: issues, opportunities and challenges

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REDD+ is rapidly evolving in several countries supported through the Forest Carbon Partnership Facility (FCPF) managed by the World Bank and the United Nations REDD Program (UN-REDD). Concomitant with national-level and government-led processes towards development of strategies for REDD+ and creating the legal and institutional enabling conditions for performance-based payments, several institutions including the voluntary and for-profit sectors are involved in REDD+ implementation at different scales and using different models.

The early engagement of private sector in climate change mitigation and adaptation efforts is fundamental for demonstrating how the sector can draw upon its market-based know-how and financing to take risks and venture into reducing emission endeavours as providers/suppliers, buyers, or simply investing capital in companies doing either. There is, however, debate about private sector engagement in REDD+ with some concerned about the robustness of the policy and legal systems for ‘investing’ in ecosystems service commodities such as carbon, tenure arrangements, benefit-sharing, undertaking of free, prior and informed consent processes for local buy-in and participation; the extent and tools used for addressing drivers of deforestation and forest degradation; and taxation of income from regulating services.

To help understand the scale of private sector engagement in REDD+ and analyse the issues, we constructed a database of 115 initiatives in Africa, Asia and Latin America. The paper starts with a brief analysis of the private sector players in REDD+, also focusing on who the developers and beneficiaries are, their geographical distribution (countries), and their motivations or objectives as well as the main activities being undertaken for reducing emissions. The paper then provides an analysis of rights to carbon and benefit-sharing. A case study of the Democratic Republic of Congo complements these analyses, providing further insights of a policy and institutional framework that is being used for engagement of the for-profit sector in REDD+.

Keywords: *benefit-sharing, carbon rights, performance-based payments, policy and institutional framework*

OP6.1.4. Security beyond the political forest: regulation, formalization, and timber production in northern central Java

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Forest Law Enforcement, Governance, and Trade (FLEGT) agreements between the EU and countries that grow tropical timber are set to complement, alter, or generate new regulatory mechanisms that seek to ensure the legality of timber products. These regulatory changes will affect specific policies and practices within timber production networks. Smallholder timber production (STP) in Indonesia will come under FLEGT regulation from January 2014. Using grower surveys conducted in the Jepara regency of central Java (n=204), we generate information on who Jeparanese smallholders are, what they are growing, and why. We draw upon Foucauldian governmentality to understand how STP operates and how Sistem Verifikasi Legalitas Kayu (SVLK), the Indonesian method for timber legality verification, might further affect networks of STP. We find that current methods of resource provision, in addition to increased oversight of source documentation, combine to increase formalization within STP to secure timber resources outside the political forests of Java. Attending to place-specific detail, we provide several potential insights for the optimal application of SVLK certification.

Keywords: *FLEGT, Governmentality, Indonesia Java*

6.2 The ecology and economics of rubber agroforestry

OP6.2.1. Factors influencing the adoption of improved rubber agroforestry systems by rubber smallholder farmers in Indonesia

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The use of clonal planting material is important to increase the latex productivity of traditional rubber agroforestry systems among smallholder rubber farmers in Indonesia. There are technical, economic and social challenges associated with conversion from traditional to improved system. Clone-based technology that has significant benefits for rubber systems has been widely promoted, but its adoption by farmers has been less than satisfactory. However, the underlying reasons for the limited adoption of improved system by farmers remain unclear. We studied the adoption of technology to improve rubber agroforestry systems in the two main sites for smallholder rubber systems in Indonesia: Jambi and West Kalimantan. The new technology includes a recommendation to use clone materials while other aspects of rubber management follow the traditional practice. We used logistic regression to analyze the relationship between socioeconomic variables (age, education, experience, labour, land size, incentives, income, jobs, farmer group, demonstration plots, training) with farmers' decision to adopt the new technology. The results showed that factors of availability of incentives, level of income, availability of demonstration plots, and land size influenced farmers' decisions to adopt or not adopt the technology. In Jambi the factors of incentives and demonstration plots are significant; meanwhile in West Kalimantan land, incentives and income are significant. Availability of incentives is an important factor also as an indicator of the available economic resources to start clonal rubber in both locations and the willingness to adopt a new technology. The reasons for different factors influencing adoption include differences in social, cultural and economic factors between these provinces which are also highlighted. The results provide important clues in motivation and limitation in adoption, and the information will be of importance to extension workers, researchers, and policy makers involved in promotion and interventions needed to accelerate the rate of adoption of improved rubber agroforestry system.

Keywords: *technology adoption, smallholder farmers, rubber agroforestry systems*

OP6.2.2. Ecosystem services trade-offs and synergies of rubber agroforestry under uncertainty

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Land use change is one of the major causes of global environmental change. In the case of Jambi province, Indonesia, where rapid replacement of agroforests by oil palm and other monoculture plantations leads to environmental degradation, we investigated economic incentives via payments for ecosystem services (PES) to establish rubber agroforestry for sustainable development. To explain farmers' land-use decisions and determine appropriate payments, it is necessary to focus on uncertainty in profits of land uses coming from the variability in yield, and prices of yield and input. Multi-period linear programming that combines Monte Carlo simulation was used to derive the range of conditions for determining payments required to guarantee that the environmentally preferred land use dominates. An empirical application to establish rubber agroforests in Jambi province shows that environmental payments for reduction in carbon emissions and biodiversity increase would substantially vary due to

the uncertainty in revenues, which in turn would affect negatively or positively the income of farmers. At the same time, maintaining rubber agroforestry would lead to land use diversification of farmers, and consequently allow mitigating revenue risks.

Keywords: Monte Carlo simulation, payment for ecosystem services, revenue uncertainty

OP6.2.3. Rapidly increasing demand for rubber drives plantations into ecological margins and threatens biodiversity

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The global consumption of natural rubber is expected to grow by 3.7% per year to 13.8 million tonnes in 2018. Soaring rubber prices have led to rapid land use conversion to rubber in mainland SE Asia and although prices have fallen since 2010, rubber farming continues to be lucrative. An ability to predict where rubber is likely to be planted next is key to targeted policy. We show that the environmental space where rubber plantations have traditionally been established matches the environmental conditions of the natural South American range of *Hevea brasiliensis*. As much of this ‘traditionally suitable’ environmental space for plantations in SE Asia is now occupied, we have investigated the more recent spread of plantations into new environments and whether this expansion follows a spatially predictable pattern (using MODIS NDVI 250m derived maps for 2004/05 and 2009/10*). The spread of rubber 2004/05 – 2009/10 was strongly related to proximity to the nearest neighbour plantation (70% explanatory power). Of these new plantations, 96% were established in non-traditionally suitable environments. Novel environments may not *per se* be suboptimal for specifically bred rubber clones, but 23% of the plantations were found in areas where temperature seasonality differed by >50% from the native rubber range, and almost a quarter of these replaced areas that prior to 2000 were under forest. Sudden weather extremes in areas with greater climate variability may push even adapted clones to their tolerance margins. Our results suggest that there is a rapid and partly predictable spread of plantations into marginal and potentially risky environments, often at the expense of high-biodiversity value land. We highlight areas that may be next in line for conversion to facilitate targeted policy interventions that prevent “loss-loss” scenarios, e.g. the conversion of high-biodiversity land in areas where environmental stresses may render rubber farming ultimately difficult.

* Li Z and Fox JM. 2012. Mapping rubber tree growth in mainland Southeast Asia using time series MODIS 250 m NDVI and statistical data. *Applied Geography* 32(2): 420-432.

Keywords: biodiversity, loss climate, risk, rubber expansion, tropical deforestation

OP6.2.4. The planter's bet. Can family-owned rubber farms match global challenges?

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Natural rubber links global industry to millions of family farms. To ensure the sustainability of plantations, conditions should remain favourable during one or two decades. How can such conditions be ensured when the environment is changing? From farm surveys, ecological studies and experiments, a multi-disciplinary methodology was developed in Thailand to identify significant indicators to assess the long-term adaptation and sustainability of smallholder's plantation systems.

Risks and adaptations related to climate. The increase in global temperature will directly affect agriculture, particularly in the tropical area (IPCC 2007). Drought is the more likely climatic risk due to the more irregular rain patterns and as rubber plantations expand towards drier areas. The hydraulic properties of rubber clones are considered a key for their adaptability to drought. It is also relevant to assess the effects of drought on soil biology, which maintains soil fertility. Extreme events, like flooding, are likely to increase as well but their actual occurrence and effects on rubber trees and farms is not well documented. As rainfall is becoming more erratic, farmers tend to adopt irregular tapping patterns. Assessing the resulting physiological status of trees will help identify adaptive strategies.

Changes in socioeconomic context. Rubber price fluctuations have greatly affected the sector recently. This is a risk for farmers' budgets but also an incentive for flexible production systems. Plantations are extending towards new areas where their sustainability is questioned, whereas new investors get involved. These changes will affect the functioning of both the field-plant system and the production system. There is a need to identify the way socioeconomic factors interact with biophysical factors to determine farmers' strategies regarding risks induced by global changes.

Environmental issues. The impact of rubber plantations on natural resources and associated environmental services has been poorly studied. Environmental impacts affect the plantation in terms of soil sustainability (soil fertility preservation related to soil functional diversity) and generate externalities. We consider the risk linked to the extension of rubber plantations in sub-optimal regions and the risk of soil degradation in the traditional area of cultivation after 50 years of continuous rubber cropping.

Keywords: *climate change adaptation, Hevea brasiliensis, land use change*

OP6.2.5. Measuring the impact of rubber agroforestry –an integrative ecosystem service assessment framework

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With today's need of a project to meet inter-, multi- and trans-disciplinary standards as well as integrating stakeholder-based decision-making processes into a research framework, project management staff and project proposal writers face quite difficult tasks. Not only do the scientists need to meet their own disciplinary standards, but also it is expected that from the fruitful interdisciplinary interaction something bigger is born.

Within the SURUMER project we have established a working framework that allows for an integrative Ecosystem Service Assessment (ESA) aiming at bringing together both the needs of disciplinary data acquisition and high quality research with interdisciplinary modelling approaches under the umbrella of a stakeholder-based steering mechanism.

A continuous stakeholder process focusing on three different groups of decision-makers (village heads and innovative farmers, regional planners as well as politics) in our project region develops key questions related to ESS to be addressed by the project scientists. Based on these questions, scenarios are designed in an iterative process during the stakeholder process. One of the major aspects of these scenarios is the integration of different management methods for various agroforestry-based intercropping approaches. These scenarios are analyzed by multiple disciplinary and interdisciplinary modelling and assessment approaches, leading first to a biophysical assessment of the scenario. This assessment is, in a second step, supplemented with socioeconomic appraisals on expected changes in household income and economic welfare. Finally, these assessments are combined and adapted to be returned into the continuous stakeholder process for information exchange and possible adaption of key scenario questions.

For this World Congress on Agroforestry, the authors present the established framework as well as first results of the ESA. In addition, we want to share our experiences from the stakeholder integration processes and discuss possible adaptation strategies for other agroforestry systems and other (inter-) national settings.

Keywords: *Ecosystem Service Assessment, ecosystem services, interdisciplinary methods, rubber intercropping*

OP6.2.6. Rubber monoculture or rubber agroforestry: are there implementable policy supports based on results from spatially explicit models?

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Xishuangbanna, SE China, like most of SE Asia regions, has been largely transformed from biodiverse natural forests and mixed-use farms into monoculture rubber plantations in just twenty years. This conversion has expanded into forests previously protected by the community and onto marginal sites at high elevation. Market-based ecosystem payments, especially carbon financing, water and recreation market are potential tools to prevent further forest loss. Here, we compare rubber net present value (NPV), market value of carbon sequestration, non-timber forest products (NTFPs), other land-use and biodiversity, labour force needs for Xishuangbanna given seven land-use scenarios based on the 2010 land-use map: Non-Rubber Scenario, agroforestry 2010, Conservation Oriented Scenario (CES), agroforestry CES, Business-As-Usual Scenario (BAU), agroforestry BAU, Economic Oriented Scenario (EOS), and agroforestry EOS using our previously published spatial map of rubber profitability. The spatially explicit models on carbon, NTFPs, and land use market price in our study will help us to answer: 1) which is more cost-efficient between rubber monoculture and rubber agroforestry? 2) Which has better ecological functions/values? 3) Is there a balance between economic cost-efficiency and ecological functions/values? Which can perform better between rubber monoculture and rubber agroforestry? 3) Which is more implementable based on existing policy supports?

The results from our study are not only important for China, but also to the SE Asian countries where rubber monoculture is expanding rapidly. Our methodology provides a direct and spatially explicit approach to identify where market-based payment for ecosystem services and implementable policy-supports could be successfully introduced for sustainable land-use management. Our results are novel and provide a significant insight into the development of sustainable rubber agroforestry through the application of appropriate policy.

6.3 The science of scaling up and the trajectory beyond subsistence

OP6.3.1. Determinants of farm households' agroforestry technology adoption in Ethiopia: empirical evidence from selected districts

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As one of the strategies for alleviating the current environmental degradation problem of Ethiopia, the government has been taking different measures. The forest policy approved in 2007 clearly indicates agroforestry development as one of the strategies designed to foster private forest development and conservation. Despite the efforts made to understand the role and determinants of adoption of such technologies, there is still little empirical evidence on the link between farmers' behaviour and other community level variables and the adoption of various types of agroforestry technologies in Africa in general and Ethiopia in particular. Therefore, the purpose of this research is to analyze and understand why agroforestry technologies are not being taken up by examining factors that influence the adoption of agroforestry practices using data collected from different parts of rural Ethiopia. We employ econometric models to address the objective of the paper. The findings show that different factors do have different effects on the different agroforestry technologies. For example, tenure security is important for the adoption decision of some types of agroforestry technologies. Other factors such as improving the access of distant and more marginal villages to infrastructural facilities such as market and biomass availability seem to affect the decision to adopt both multipurpose and fodder positively and significantly. The paper also discusses the effect of other socioeconomic variables and identifies important measures needed to be taken in order to promote different types of agroforestry technologies in rural Ethiopia. The findings of this research may also provide scientific evidence for other similar countries whose livelihood depends mainly on agriculture and natural resources such as forests.

Keywords: *adoption, agroforestry, Ethiopia multivariate probit*

OP6.3.2. Farmer-to-farmer extension: a viable option to enhance agricultural dissemination? Evidence from Cameroon

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The past decade has seen a renewed interest in investment in agriculture and particularly extension. However, donors and policy makers would like to see agricultural extension systems that are more participatory, demand-driven, cost-effective, efficient and sustainable. Farmer-to-farmer extension is such a bottom-up approach in which farmers share knowledge on agricultural innovations within their communities. However, for these new extension approaches to be institutionalized, they must demonstrate their superiority over old approaches. Unfortunately, such evidence is hardly available and there are concerns in the literature on the capability of farmers to take up extension.

This paper therefore examines the experience of 34 organisations (i.e. government, international and national/local NGOs and farmer organisations) with the farmer-to-farmer extension approach in Cameroon. Topics covered in the semi-structured surveys with extension managers include selection of

lead farmers; their terms of reference; motivation and incentives; training programmes and other capacity development for lead farmers; dropout rates; challenges and lessons for successful implementation of farmer-to-farmer extension under varying circumstances.

The results from this study are of use to decision makers in search of low-cost, community-based dissemination approaches. Information is provided on opportunities that could be explored to improve the motivation and effectiveness of lead farmers and sustainability of farmer-led extension programmes.

Keywords: *adoption farmer trainers, rural advisory services, sustainability*

OP6.3.3. Why volunteer? Insights from farmer to farmer extension in Kenya and Uganda

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This paper assesses the motivation behind the decisions of smallholder farmers to volunteer as farmer trainers despite the fact that they are not paid for their services. The farmer trainers are volunteers selected by the community on the basis of being good communicators and having an interest in sharing knowledge on fodder innovations. They are trained in livestock feeds and feeding methods by extension officers. They in turn share the knowledge with other farmers in a participatory manner through demonstrations and interactive learning. A study was carried out to understand the motivations of smallholder farmers to volunteer their time to train and share their knowledge with other farmers without pay. Collection of data was through a combination of focus group discussions and individual interviews with 99 and 190 volunteer farmer trainers (VFTs) in Kenya and Uganda respectively. Findings of the study showed that VFTs were motivated by a combination of intrinsic and extrinsic factors. Knowledge and altruism were found to be the most important motivating factors for becoming trainers. Other factors are social and project benefits. Three years after becoming trainers, income earned from selling inputs and specialized services was a more motivating factor for VFTs in Kenya than Uganda. Reasons are explored in the paper. Demand for training also emerged as a motivating factor after VFTs started sharing their knowledge. The findings point to the fact that the general reasons that motivate volunteers irrespective of context are personal and community interests. However, certain motivations are context specific.

Keywords: *farmer-to-farmer extension, volunteer farmer trainers, fodder innovations, motivation*

OP6.3.4. Taking tree-based ecosystem approaches to scale: impacts, drivers and mechanisms

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Tree-Based Ecosystem Approaches (TBEAs), which include a variety of land and forestry management systems and practices that combine trees with agricultural production to seek to sustain or increase productivity and enhance ecosystem services supply, are widely documented. Their potential for

economic development, poverty reduction and climate resilience has inspired growing interest and investment. However, processes that underpin the scaling up of TBEAs are poorly identified and described, and evidence of the impacts of TBEAs on livelihood improvement is lacking. We conducted a review of peer-reviewed and gray literature on TBEAs to gain insight on: (1) the impacts of TBEAs specifically on food security, resilience to climate change, carbon sequestration, and income generation, and (2) drivers that explain the adoption of TBEAs. Of the 292 documents identified, the 93 containing relevant data for our analysis reported on 40 different tree-based practices across 111 sites in 53 countries where TBEAs are in some stage of scaling up. The most commonly reported drivers leading to the adoption of TBEAs were soil quality improvement, income, and subsistence production of food and fodder. External NGOs and local or collaborative mechanisms were frequently reported mechanisms for supporting TBEA implementation or maintenance. We found a wide variety of quantitative and qualitative descriptions for TBEA impacts and a poor description of the actual levels of adoption and extent of TBEAs suggesting the need to: 1) develop a shared conceptual framework and assessment strategy to inform cross-site comparative impact analysis; 2) conduct spatial analyses to determine geographic distribution and extent of TBEAs; and 3) conduct comprehensive case studies of TBEAs to better understand scaling processes and dynamics at landscape scale.

Keywords: *drivers, landscape approach, scaling up, tree-based ecosystem approaches*

OP6.3.5. What is the influence of extension methods and approaches on adoption of agroforestry practices in Zambia

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Improving agricultural productivity among smallholder farmers is a goal of much tropical agricultural research. Smallholder farmers are often faced with poor soil fertility. Researchers have developed agroforestry technologies including improved fallows and biomass transfer to address these problems. These technologies have been promoted for nearly thirty years through the public extension system, international and national research institutions. However, levels of adoption of agroforestry practices are low and impacts on smallholder farmers' livelihood negligible. This study examines particularly the role of extension technologies and practices on trialling and adoption of agroforestry in four districts of eastern Zambia. A survey was completed of 388 smallholder farmers. Data analysis shows that trialling of agroforestry technologies is generally low, 44.9 percent of farmers trialled improved fallow technology and 21.4 percent trialled biomass transfers. Logistic regression analysis is completed to establish the roles of main sources of information, the work of extension officers and researchers, farmer training in how to practice agroforestry, and farmer visits to extension. Despite low trialling rates, retention among farmers who had trialled these agroforestry practices was high (over 70%). Understanding the factors influencing trialling of agroforestry technologies is crucial to ensuring that many farmers take up agroforestry technologies.

Keywords: *agroforestry adoption, extension, small-scale farmers, Zambia*

OP6.3.6. Agricultural research for development: implications for policy, practice and investment

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There has been a semantic shift from agricultural research “**and** development” to agricultural research “**for** development” (AR4D) or “**in** development”. This change reflects the need for agricultural research to become more focused on and accountable for its impacts on people’s livelihoods and health, and on the environment. In practice, this new paradigm recognizes that research takes place and is scaled up within complex adaptive systems. Approaches to agricultural research have been dominated by conventional linear research and development models, where scientific advances are assumed to drive the developments that result in changes that impact on people’s lives. Complex systems-based research, of the sort that dominates agroforestry, does not fit this simple model. Scholars have shown that most economic change in society does not often derive from single scientific breakthroughs, but frequently from the re-working of existing knowledge. Scientific-led change takes place in social contexts that are typified by complex interactions among a range of actors, and agroforestry presents a clear example of these complex interactions. Change in these systems is not linear, but consists of many feedback loops whereby knowledge and information flow through the system in different directions.

Many of the implications of understanding how to operate in complex adaptive systems are behavioural, and will require scientists to work with a broader range of partners and through different working relationships than previously. Other necessary changes are institutional, and include how scientific institutions partner with others, what incentives are provided to scientists to work within complex adaptive systems and how the funders of science allocate funds to allow the merging of science and development. Major changes are needed in monitoring methodologies to allow more rapid learning from experience and the shortening of feedback loops. Better systems for tracking investment in Ar4D are needed.

Keywords: *agricultural research for development, agricultural research in development, complex adaptive systems, research policy*

6.4 Landscape approaches

OP6.4.1. Landscape approaches from concept to action: insights from 191 landscape initiatives in Africa and Latin America

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Landscape approaches are becoming increasingly common as scientists, policymakers, and local stakeholders recognize the need to increase the multi-functionality of rural landscapes for food production, livelihood improvement, and ecosystem conservation. To date, however, there has been no systematic assessment of the practice or outcomes of landscape approaches. To fill this gap, we

surveyed participants and managers in integrated landscape initiatives throughout Latin America and the Caribbean (LAC) and Africa to assess these initiatives' contexts, objectives, participants, activities and investments, outcomes, and major successes and shortcomings. Results from 104 initiatives in 21 countries in LAC and 87 initiatives in 33 countries in Africa indicate that landscape approaches are being applied to address a variety of challenges in diverse contexts, and that use of this paradigm is expanding. On both continents, initiatives reported investing across four key 'domains' of landscape multifunctionality: agricultural production, ecosystem conservation, human livelihoods, and institutional planning and coordination. Initiatives reported positive outcomes across all four domains, but particularly with respect to institutional planning and coordination. These results suggest that landscape approaches have aided in building local foundations for adaptive management and resource governance, including platforms for stakeholder coordination and negotiation, improved inter-sectoral alignment, and empowerment of women and local communities. In Africa, landscape approaches were most commonly rooted in conservation objectives, underwritten by external funding, and often engaged local governments in a superficial way. In Latin America, we found a wider range of entry points and objectives, more robust local participation, and greater evidence of supportive policies and platforms. Key challenges identified by survey respondents—including the long time horizon required to achieve results at scale, unsupportive policy frameworks, and difficulty in engaging the private sector and other important stakeholders—offer insights for improving the future effectiveness of landscape approaches.

Keywords: *agriculture, biodiversity, landscape multifunctionality*

OP6.4.2. Environmental services as binding pillars to synergize climate change mitigation and adaptation in rural landscapes

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Recently there is an emerging concept that addressing climate change mitigation and adaptation in an integrated manner improves the ineffectiveness and inefficiency resulting from the dichotomized approaches of addressing the two measures. Such arguments base on the fact that addressing adaptation and mitigation as separate policy streams in different institutions increases the cost of climate policy. In tropical and subtropical landscapes, adaptation and mitigation share common resources such as land, natural resource management skills and institutions. Moreover, the two measures strongly complement one another. For example, failure to adapt among rural households may strongly affect the mitigation efforts in the forestry sector. Despite the envisaged positive benefits of synergizing adaptation and mitigation in the land use sector, there is limited knowledge as to what could be the appropriate basis for synergy to happen. This study explores the extent of the interdependence between climate change mitigation and adaptation in tropical and subtropical landscapes and how the interdependence can help designing a holistic approach of addressing both measures using environmental services as platforms. Four landscapes—Menagesha Suba area from central highlands of Ethiopia, Bamendjing and Bankim landscapes from Cameroon, and Ngitili-dominated landscape from Shinyanga region of Tanzania—were used for the analysis. Two key lessons are learnt from the study: 1) at landscape level, there is a strong interdependence between adaptation and mitigation; 2) most of the networks of interdependences between adaptation and mitigation are through one or more environmental services. Hence, proper emphasis should be given to practices, functions and processes that promote the provision of environmental services which concurrently facilitate the move to address climate change effectively.

Keywords: *adaptation, environmental services, landscapes, mitigation*

OP6.4.3. Are innovation platforms possible institutions for integrated natural resource management practices at landscape level?

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The success of any sustainable integrated natural resource management (INRM) initiatives is determined largely by local level solutions derived from community involvement. This is because community members are more cognizant of processes that bind them and therefore have effective possible solutions to their challenges. However, most community members lack the capacity and ability to individually address these challenges. There is need to enhance their capacity and ability so as to gain access to combined knowledge and to leverage complementary assets to address their underlying challenges. This study examines in detail the contributions of innovation platforms towards integrated natural resource management using a case study of Kapchorwa District Landcare Chapter (KADLACC) in Uganda. Emerging studies from KADLACC have shown that addressing complex INRM challenges requires an expanded multistakeholder process, otherwise known as innovation platforms. The platforms link local level decision making to various levels of governance, and provides for the institutional capacity to improve livelihoods and landscapes. KADLACC has achieved successful experiences by capturing existing social capital through strategic support of farmer groups, community-based organizations and institutions in higher levels of governance like the local government units and technical service providers from government line agencies. Bringing together the various actors across all the levels has enabled farmers to build their capacity to formulate and express their needs and concerns thereby being able to connect between individual issues and possible solutions.

Keywords: *innovation platforms, integrated natural resource management, multi-stakeholder process*

OP6.4.4. Freeing the land of the tea legacy - the case of Wild Flower Holdings

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The restoration of Wild Flower Holdings (WFHL) is currently under way in the Deltota Valley in Sri Lanka. This biodiversity-rich montane forest area is the watershed of the Maha Oya where tea was first planted. The Valley is extremely windswept and dry for much of the year. More than a century later it has lost most of its forest cover, soil and is an unproductive environment.

One and a half years ago, Neo Synthesis Research Centre partnered with WFHL to carry out the ambitious rehabilitation of this landholding. They adopted a landscape approach to rehabilitation. Since this was a commercial land holding the landscape design had to address ecological needs and be economically viable.

The Loolecondera forest, the closest natural forest in the area, was first visited to understand its architectural structure and species composition. This information provided the blueprint for rehabilitation. Thereafter, the WFHL landholding was surveyed and sectioned into zones for rehabilitation based on the ecological function they played in the landscape. GIS mapping was undertaken and special emphasis was placed on hydrology since water drained into a large wetland area.

The landscape design adopted a different ‘treatment’ for each of these zones. Areas that had once been planted with tea and were severely eroded were first planted with hedgerows along the contours. In

between the hedgerows cinnamon and coffee were inter-planted with native species. The design varied depending on the wind direction and intensity. In the lower parts of the property subject to less wind damage, other tree crops were planted.

Native shrubs and small and large trees were planted in the riparian zone around the lake and alongside the streams. Bamboo *sp.* was used in areas prone to erosion.

The land around the house was planted with several ornamental species and an extensive organic vegetable garden.

This experiment may offer the solution to restore vast areas of unproductive tea land.

Keywords: *tea, restoration, watershed*

OP6.4.5. The Model Forest landscape approach: innovative territorial governance

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As a name, a brand and a practice, Model Forests are intriguing and counterintuitive. They are an original concept and a unique platform of territorial governance that creates conditions for grassroots cross-sector integration tightly linked to progressive public policies. This is because:

Model Forests are not just about forests. Rather, they embrace all forms of land use and activities in a large landscape such as agriculture, livestock, fisheries, mining, water, energy and health, as well as forests, whether natural or planted, rich or degraded. Even cities can be part of a Model Forest.

A Model Forest is not just a place. It is primarily a voluntary and inclusive partnership among all relevant actors, big and small, in order to ensure the sustainable development of the territory. The partners do this through joint activities, projects and programs of work.

A Model Forest is not a project; it is a life project. It is both an approach and a process by which the partners work together through dialogue, experimentation and innovation to find long term, cooperative solutions to their problems, and to give concrete shape to their aspirations. Each Model Forest is unique, but all are based on the same core principles (partnership, landscape, sustainability, governance, program of work and networking).

A Model Forest belongs to the local partners; they set it up and run it. However, while autonomous and rooted in locally established priorities, a Model Forest is sponsored by its government to join the International Network. This global community of vision and practice has been gaining ground around the world over the last twenty years.

In Africa, the concept emerged from research on Adaptive Collaborative Management. Today, the Model Forests initiative is in its tenth year of development in Africa.

Keywords: *landscape approach, Model Forest Multi-actor Process Territorial governance*

OP6.4.6. Is agroforestry feasible towards conservation in protected areas? An ongoing case study in rural Mexico

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In situ conservation in Mexico is based in natural protected areas with different categories. They now cover ca. 12% of the territory, from which 8% is covered by biosphere reserves. National parks have the most and oldest protected areas in Mexico, with the first decree in 1917. They cover 1.3% of the territory and represent spaces of high species and ecosystem biodiversity where management activities are restricted. Nevado de Toluca is a forested volcano of 53 000 hectares that used to be a national park from 1936 up to 2013. In this time 5500 hectares of forest have been fragmented and degraded, 10 000 people established inside the protected area polygon, and maize, potatoes, wheat and cattle are extensively cultivate—most of these activities are illegal according to the national park status. An initiative by some society individuals from the academy and NGOs, the Mexican National Commission on Protected Areas (CONANP), and local stakeholders proposed a change of status in Nevado de Toluca protected area. From September 2013 it became a “Flora and Fauna Conservation Area”, a less strict status that allows management and agroforestry activities. We propose a zonification and management plan that includes a strong link between the local stakeholders and the academy, with preservation areas (strict conservation) and agroforestry actions that do not compromise the sustainability of this volcano. From this background the question is which are the best agroforestry practices involved in the policies in order to get the best natural resources management?

Keywords: *agroforestry, conservation, ecosystem services, protected areas*

6.5 Agroforestry, water quality and nutrient export

OP6.5.1. Innovative technology for water quality protection in agroforestry systems

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Phosphorus saturation ratio (PSR) and soil phosphorus storage capacity (SPSC) are two concepts that have become popular in relation to phosphorus (P) chemistry and management of many agricultural soils in the United States and other parts of the world during the past two decades. The PSR is the molar ratio of phosphorus to iron and aluminum in an oxalate or a soil test solution such as Mehlich 3, and SPSC signifies the amount of P that can safely be stored within a soil prior to it becoming an environmental risk. The SPSC can be calculated based on a threshold PSR value, above which P release from the soil will increase substantially. In this study we evaluated the potential for using the PSR/SPSC concept to agroforestry and related land-use systems for identifying soils where P could pose a potential environmental threat. Studies were conducted on tree-based agricultural systems on different soil types: Alfisols (*Quercus suber* silvopasture; Extremadura Spain), Inceptisols (*Pinus radiata* and *Betula alba* silvopasture; Galicia, Spain), Spodosols (*Pinus elliottii* silvopasture; Manatee county, Florida), Oxisols (Uganda; *Coffea canephora* and *Coffea arabica* plantations), and Ultisols (*Pinus elliottii* silvopasture; Suwannee county, Florida). At all locations, PSR and SPSC were calculated for soils sampled by depth; up to one-metre depth in most cases. Results showed that irrespective of soil

type, P release from the soil increased once the threshold PSR value was reached. The P release generally decreased down a soil profile with the P storage capacity increasing deeper in a soil profile in a tree-based system compared to adjacent treeless plots. This is attributed to the ability of trees to remove excess P (and other nutrients) from agricultural soils. The study suggests that the threshold PSR and SPSC could be used to predict P storage and loss from agricultural and agroforestry systems.

Keywords: *phosphorus saturation ratio, soil phosphorus storage capacity, silvopasture, treeless pasture*

OP6.5.2. Shade level and tree species composition affect water dynamics in coffee agroforestry systems of Western Ghats, India

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Over the last 30 years, coffee expanded tremendously in the region to the detriment of the forest. Still, robusta (80%) and arabica (20%) are grown under the shade of multi-strata agroforestry systems (AFS) and hence play a major role in biodiversity conservation and provision of goods and services to local communities. Water is a critical service since the main rivers providing water for urban centres and agriculture all over Southern India originate from these coffee areas of the Western Ghats.

The tree composition of this coffee AFS landscape has been affected by important changes in management practices such as irrigation to stimulate coffee mass flowering and introduction of fast-growing tree species (mainly *Grevillea robusta*) for timber production and a stand for pepper. Consequently, we studied for 3 years how the change in tree cover from predominantly native tree species to exotic species affected the water dynamics in coffee AFS of the Kavery watershed of Kodagu district, the most important coffee district of the region.

Conclusions of this study are 1) coffee canopy and shade trees intercept 15-25% of the rainfall, 2) coffee trees intercept the largest part of the rainfall (9-21%), 3) coffee under shade of native trees transpires more than coffee under shade of exotic trees, particularly during the dry season, 4) native trees transpire more than exotic ones, especially during the dry season, 5) runoff was comparable (in the range of 3-6%) in native and exotic plots, 6) the amount of rain infiltrating into the soil was greater in native than in exotic plots, and 7) the amount of water drained below the root zone was lower in native than in exotic plots, and hence less water from native plots was going to rivers and recharging the aquifers than from the exotic plots.

Keywords: *agroforestry, coffee, native and exotic trees, water, India*

OP6.5.3. Modelling the effects of adopting agroforestry on basin scale surface runoff and sediment yield in the Philippines

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The Carood watershed incorporates a heavily degraded, mosaic landscape covering 21 407 hectares in the province of Bohol, Philippines. The area is home to around 60 000 people whose principal livelihood activities of subsistence agriculture—particularly rice and maize production—as well as livestock management and aquaculture are closely bound to the ecosystem services provided by the

watershed. The degraded nature of the watershed, which has been largely deforested and replaced with extensive agriculture and grasslands over the last half century, has disrupted the evenness of river flow resulting in alternate flooding and drought episodes, an accelerated level of soil erosion as well as downstream sedimentation. The degradation of the landscape has impacted the economic activities of local communities and alternative land-use practices that continue to offer livelihood benefits are required to tackle the associated environmental problems. However, reported problems remain largely anecdotal with limited available hydrological data. This study therefore uses Soil and Water Assessment Tool (SWAT) to simulate the effects on watershed hydrology of different land use practices under two scenarios: current land-use practices, and improved land management using agroforestry in strategic locations. Using a combination of observed climatic and soil data, land cover and geomorphological data derived from high resolution satellite imagery, the results reveal the effects of different land-use practices on the quality (sediment load), quantity (surface runoff) and seasonal availability (evenness of flow) of water in the Carood watershed. The simulations demonstrate that the adoption of agroforestry in strategic locations represents an effective land-use option to address the reported water quality and quantity issues. In particular, the use of carefully located or restored riparian buffers in addition to contour planting in grasslands appear to be the most effective techniques to reduce sediment transfer to the watershed river network.

Keywords: *land use, sediment transfer, water quality, watershed hydrology*

OP6.5.4. Chemical attributes of a silvopastoral system with a legume tree and signal grass in the Brazilian savanna

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Brazil is the world's biggest meat exporter; more than 40% of the beef production takes place in the Brazilian savanna pastures. The research site was located in southeastern Brazil (20°18'16.71"S; 44°55'28.57" W) and had 35.3 ha of silvopasture (SP) with signal grass (*Urochloa brizantha*) and native legume tree *Pterodon emarginatus*, with a density of 156 trees ha⁻¹ established more than 30 years ago as cattle pasture was never fertilized. The control (CT) had 26.5 ha traditional signal grass pasture. Soil collection profiles were made randomly at both areas at 0-10, 10-20, 20-40, 40-100 and 100-140 cm deep, in order to study the chemical attributes and the influence of a stabilized silvopasture. Calcium (Ca⁺²) was higher (P<0.05) in the CT, compared to SP area at 0-10, 10-20 cm profiles, but no difference was found in other layers. Inside SP, Ca⁺² in 0-10 cm was higher (P<0.05) than 10-20 and 100-140 cm, while intermediate values were found at 20-100 cm profiles. Variables P M1, K⁺, S-SO₄⁻, Zn, B and Sum of Bases (SB) did not show differences between systems (P>0.05), but Organic Carbon (OC), Cu and Fe were higher at SP, while Water pH had superior values in the CT (P<0.05). OC, Fe e P showed decreasing differences (P<0.05) with increasing of depth for both systems. Al, Cu and B were higher (P<0.05) down to 40 cm deep and reduced from this layer. Levels of Zn and SB were higher (P<0.05) at 0-10 cm and kept the same values in other depths. Sulfur was higher in 0-10 cm in comparison to 100-140 cm depth (P<0.05), but the other profiles were intermediate. Non-fertilized silvopastoral system with native legume trees adapted to poor acid soil had higher carbon content than traditional pasture, however, there was extraction of most of the nutrients.

Keywords: *agroforestry systems, animal production, soil profiles, sustainability*

OP6.5.5. Performance of herbal medicinal crops under Sapota-Jatropha-based three-tier agroforestry system

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Newly established forest plantations can be intercropped with medicinal plants similar to food crops until the trees cover the ground. The participation of the local people with the right to share benefits of the plantations, especially ownership to crops, has helped government to establish plantations without conflict with the local people in many Asian countries. The same approach can be employed for the cultivation of medicinal plants in the new plantations. In the rehabilitation of degraded forest lands, participating, planning and implementation with local communities and economic benefits from an early stage onwards will ensure commitment of the people. The intensity of shade experienced by the under storey medicinal plants growing in forests and tree plantation affects their growth and chemical composition. In recent years, attention has focused on the diversified medicinal plant production system for maximizing utilization of resources as compared to the monoculture cropping systems. The improved use of resources results in greater total intercrop yields as compared to sole crops of the same species grown on the same area.

Field experiments were conducted to find out performance of herbal medicinal crops (basil, kalmegh & mint) under Sapota-Jatropha-based three-tier agroforestry system at the Agronomy Farm (Block-E), ASPEE College of Horticulture and Forestry, Navsari Agricultural University, Navsari (Gujarat) during the rainy season of 2011 and 2012. The experiments were laid out in randomized block design with six treatments and four replications. Three medicinal plants viz. basil (*Ocimum sanctum* L.), kalmegh (*Andrographis paniculata* Well.) and mint (*Mentha arvensis* L) were selected for the present study. The observation on the fresh weight of plant/plot (kg), dry weight of plant/plot (kg) and economic yield (q/ha) was recorded higher under sole crop of basil, kalmegh and mint as compared to intercrop with Sapota-Jatropha in both the years. While basil (1.67), kalmegh (1.46) and mint (1.40) when grown as intercrop gave higher economic returns as compared to sole crop in 2011 and 2012.

Keywords: *agroforestry, intercrop, basil, kalmegh, mint, economics*

OP6.5.6. Restoring riparian vegetation – a promising means to ensure clean water

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Forest cover in Sri Lanka has declined of which riverine forests form a substantial part. Aside from stabilizing stream banks, controlling soil erosion, providing shade and habitat for surface and aquatic biodiversity, their importance as riparian buffers to mediate the inflow of polluted surface water or in bio-remediating ground water must not be underestimated.

The most serious loss was experienced in the upper watersheds where montane forests were cut to plant tea. Current land use in these areas is dominated by tea and vegetable cultivation that use massive amounts of agrochemicals. Many agrochemicals produce and disseminate xenobiotics and their metabolites that may result in dangerous health issues both in the area of application and downstream. Current research suggests that the use of reservoir water might be a cause for acute chronic kidney disease in downstream communities.

Parallel to their impact on surface water quality, the impact of agrochemical leaching into ground water is equally serious. The experience in Kalpitiya where nitrogen-based fertilisers have contaminated the prevailing Gyben Herzberg type aquifer is well known.

The Neo Synthesis Research Centre (NSRC) has from 2001 to date been engaged in the restoration of riparian vegetation alongside banks and gullies in the upper reaches of the Mathatilla Oya, Maragala Oya, Bolgoda Ganga, Hulu Ganga, Rakwana Ganga, Lemastote Oya and Maha Oya as well as around Lake Richmond in Haputale. The vegetation used in the landscape design of the riparian buffer zone mimicked the natural forest vegetation of the area. If the buffer zone was inhabited with people who had tea, home or vegetable gardens, efforts were made to induce trees in the area adjacent to the water body and convert cultivation to adopt organic regimes. However, most of these areas also suffer from a lack of sanitation. Hence issues include the intrusion of faecal coliform bacteria into surface water bodies, further compounding water quality. Toilets have been constructed although many more are required. Restoration has, in all instances, been undertaken with the participation of the community.

Restoration of riparian vegetation around and along surface and ground water bodies may be a promising and low cost solution to averting the contamination of water resources.

Keywords: *riparian zone, restoration, agrochemicals*

6.6 Successful and scalable business models for agroforestry with quantified mitigation and adaptation co-benefits

OP6.6.1. Agribusinesses reducing climate, water and community risks: Landscape approaches in agroforestry systems

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Agribusinesses that depend on tree-based products—particularly coffee, cocoa, and increasingly oil palm—are experiencing water, climate, and community risks that are urgent and well-suited to landscape approaches to mitigate risks while addressing long-term profitability. The agribusiness sector is experiencing a shift to marginal and unconventional production in the face of scarcity and conflicts over natural resources leading to lower productive potentials and susceptibility to sourcing disruptions (Lee et al 2012). Agribusinesses dependent on tree-based agricultural systems are increasingly piloting landscape approaches in business models, which can provide important insights for other production systems such as annual crops to mitigate sourcing and supply risks (Kissinger et al 2013).

Olam, Starbucks, Mars, Natura, and Guyakí Yerba Mate are piloting landscape approaches for cocoa, coffee, oil palm and tea in agroforestry systems. Commonly identified models that agribusinesses use to apply landscape approaches, often motivated by certification, include a) producer support programs implemented at a regional scale that often combine certification or management objectives with livelihood improvements while simultaneously combating sourcing risks (examples: cocoa in Ghana and tea/charcoal in Kenya), and b) value chain interventions with landscape approach elements added on in order to secure inputs, yields, supply quality, and long-term sourcing security (examples: coffee in Indonesia and Mexico). In Mexico, interventions at one project site have already resulted in 5042 tonnes of CO₂ sold at an average price of \$9/tCO₂e. This investigation explores the motivations, risks and opportunities that companies identify in these agroforestry landscape approaches in order to address climate, water and community risks.

Lee B, Preston F, Kooroshy J, Bailey R, Lahn G. 2012. *Resources Futures*. London: Chatham House.

Kissinger G, Brasser A, and Gross L. 2013. *Synthesis Report. Reducing Risk: Landscape Approaches to Sustainable Sourcing*. Washington, DC: Landscapes for People, Food and Nature Initiative.

Keywords: *business model, GHG mitigation, landscape approach, sourcing risk*

OP6.6.2. Potential role of exotic poplar in increasing tree cover as an alternative for forest restoration in India

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Forest-based industries in India show significant deficits between wood requirements and supply. Therefore, plantation forestry and imported wood would be the means to fill the gap. Poplar (*Populus deltoides*), a native tree of USA introduced in India around 1950, is widely grown on a rotation of six to eight years all over northern India as an agroforestry tree because of its desirable characters and multiple uses. Commercial scale plantations of poplar have been expanding since the introduction of buy back guarantee schemes in 1984. Maximum production potential of poplar plantation is up to 65 m³/ha/year and average potential is 35-40 m³/ha/year. The deciduous nature of poplar allows agricultural crops to grow under poplar without adversely affecting crop production much. Poplar-based agroforestry has been very profitable since the beginning. Poplar wood prices were reduced drastically during 2000-2004. Farmers were compelled to cut their young poplar trees because of market insecurity. The poplar plantations are again rising with the increase in the price of poplar wood from 2005. Poplar-based agroforestry plantations are increasing at a very fast rate with an average density of 400-500 trees per ha. Presently, six to eight-year-old poplar trees with girths measuring 1 m at breast height (1.37 m), fetch about INR 4000 per tree and the net income from poplar plantations can be expected to be INR 200 000 per hectare. In this way a poplar plantation is the economically excellent alternative in increasing tree cover. Production potential, market trend and economic return of exotic poplar in India have been reviewed.

Keywords: *poplar, populus deltoides, agroforestry, tree cover, commercial plantation*

OP6.6.3. Oil palm and agroforestry systems: coupling yields with environmental services, an experiment in the Brazilian Amazon

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Over the last few decades, oil palm has been grown commercially throughout the world in monoculture production systems, becoming a main driver of deforestation in the top producing countries—Indonesia and Malaysia. Meanwhile, low carbon and bioagriculture have emerged as promising solutions for tackling climate change stemming from agriculture; however, very little research has been done on oil palm and agroforestry systems. In order to test the feasibility of adopting such intercropped systems, in 2007 a partnership between NATURA, a major Brazilian cosmetics company that relies heavily on palm oil; Embrapa, the national agricultural research agency; and CAMTA, a farmers' cooperative; began experiments on demonstration plots in Tomé Açu, Pará State, and the Brazilian Amazon. Oil palm was

planted in double rows between wider rows of agroforestry systems on three six-hectare plots, using slash and mulch, leguminous species and organic fertilization to build up soil fertility. The goal of this paper is to analyze the effectiveness of these management practices and environmental services provided, including nutrient cycling by specific crops, and soil carbon storage. Overall, these systems have shown high yields of oil palm, surpassing conventional monoculture systems at the same age, as well as high cacao yields in the first harvests, and high nutrient cycling by certain key species most notably *Tithonia Diversifolia*. The spatial variation of C stocks in young (3-yr-old) oil palm-based agroforestry systems was quantified according to different species diversity (high vs. low) and land preparation techniques (manual vs. mechanized) on one of three plots. According to preliminary findings, soil C storage (71 to 76 Mg C ha⁻¹) was significantly higher than on both an adjacent 13-yr-old secondary growth forest (60 Mg C ha⁻¹) and a conventional 9-yr-old agroforestry system (57 Mg C ha⁻¹), thus suggesting the feasibility of these systems as a climate change mitigation strategy.

Keywords: *agroforestry, Brazil, environmental services, oil palm*

OP6.6.4. From a demonstration plot to an integrated resource and agricultural tourism centre: Case of MIFACIG, Belo, Cameroon

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In this paper, we showcase the experience and reveal the key to success of the Twantoh Mixed Farmer Common initiative as a viable Agroforestry Resource Centre, and also as a self-sustaining business in the North West region of Cameroon. The paper begins by narrating the history of the group as an on-farm tree domestication and vegetative propagation demonstration site for the Cercle Internationale pour la Promotion de la Création (CIPCRE) and later the World Agroforestry Centre (ICRAF-WCA). The paper discusses the reasons and strategies for its successes and its frustration of not succeeding to gain direct financial benefits from its research partners and other donors. Key success factors include: members' commitment to take advantage of agroforestry and vegetative propagation knowledge learned from its partners; dedicated leadership; progressive visibility; and increased demand for improved planting materials and their integration into existing and new farms both from small-scale and elite farmers. We further demonstrate how the group has split into more than five satellite branches yet they maintain a strong network which permits them to respond to a huge demand for planting materials that reach 20 000 plants in some cases worth about XAF 25 million a year. From an agroforestry trial plot in the early nineties, we also exemplify how and why MIFACIG has now diversified its activities into animal rearing, bee-keeping, horticulture, organic gardening and agricultural tourism. As farmers we suppose that our model can be replicated by other producer groups around the world.

Keywords: *agroforestry, Cameroon, farmer groups, self-sustaining business*

Posters

South Asia Day: Agroforestry systems, income and environmental benefits

1.1 Policy agroforestry and tree-based farming systems

PP1.1.1. Institutional analysis of natural honeybee collection in West Nusa Tenggara province

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The province of West Nusa Tenggara or Nusa Tenggara Barat (NTB), in particular the Sumbawa Island, has a high potential for natural honeybees. It is well known in the national trade. The Ministry of Forestry has been trying to support the development of this natural honey collection by launching the province as a cluster for natural honeybee development through the Ministry of Forestry regulation or *Peraturan Menteri Kehutanan* No. P 19/2009. This study aims to assess the effectiveness of this regulation. The study applied institutional analysis through the identification of biophysical factors and actors involved in natural honeybee collection activities. The study also reviewed the regulations and policies that affect overall performance of management systems of natural honeybee collection. The study found that the development cluster policy on the one hand has increased concerns and supports of various parties in encouraging the natural honeybee collection activities. However, the policy has not effectively increased the production of honey collected from the forests. Honey production is more affected by the carrying capacity of the ecosystem and the seasonal conditions that determine the amount of honey that can be harvested from the forests. This study recommends the local government to undertake wider dissemination of this cluster development policy. Dissemination efforts can be applied in the form of strengthening community rights to access the state forests for collecting natural honey, conducting enrichment planting of Boan (*Ziziphus mauritiana*) to provide natural bee habitat, strengthening the marketing network of Jaringan Madu Hutan Sumbawa (JMHS), and preventing deforestation that could threaten the existence of natural bee populations. Through the development of good institutions, local government has potential to earn revenue from forest provision fee (PSDH), while supporting community on their natural honey collection activities.

Keywords: *actor, cluster development, honeybee, institution*

PP1.1.2. Agroforestry policies and raising money for rural people in Turkey

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The increasing world population decreases the resources people need. Desertification and decrease in soil fertility result in decline in forestry, agriculture, stockbreeding and a fall in the fertility of farmlands. As a result of these unfavourable consequences, rural development experts searched for new ways for rural people to produce food and generate income. Soil is the main input for both forestry production and agricultural production, but it is also scarce. Because of this we have to use the same piece of land for agriculture, forestry and stockbreeding. This type of combined usage of land is called agroforestry.

In this study, we examined the policies about agroforestry systems in Turkey, and then we had case studies about implementation of different agroforestry practices. In order to have maximum outputs

from the soil, we had land classifications, which we have not yet finished in Turkey. The results of the study showed that the classic way of agriculture and forestry is not generating enough food or income for rural people anymore. As people living inside or near forested areas use agrosilvicultural, silvopastoral and agrosilvopastoral practices, we will need to find new ways of agroforestry practices in order to provide rural people with food and income security.

Keywords: *forestry, agroforestry, agriculture, rural development*

1.2 Agroforestry for rural employment and income generation

PPI.2.1 Multipurpose trees in traditional agroforestry systems of Western Himalyas—growth and ecological impacts

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Large-scale land use transactions for maximizing the benefits to meet the rising demand for fuel, fodder and other ecosystem services for the well being of society has been the main problem confronting sustainable development in the mountains. This paper analyses the role of multipurpose agroforestry trees in settled farms on terraced slopes by traditional farmers in Western Himalyas, India. Information about growth rates and ecological impact of these species is lacking. Ten locally valued tree species viz *Albizia sptipulata*, *Alnus nepalensis*, *Bauhinia varigata*, *Celtis australis*, *Dalbergia sissoo*, *Ficus palmata*, *Grewia optiva*, *Prunus pardus*, *Pyrus pashia* *Sapim sebiferum* were established as mixed plantation at a degraded community forest land site and an abandoned agricultural land site in a village at 1200 m altitude in District Kangra, Himachal Pradesh, India. At the abandoned agricultural land site, annual food crops were grown along with planted trees, providing supplemental irrigation and organic manure following traditional practices. Survival, height, stem circumference, crown depth and width, number of branches, above ground biomass and soil physico-chemical characteristics were monitored up to five years. Above-ground tree biomass accumulation at the abandoned agricultural land site was 3.9 tonnes/ha/year compared with 1.1 tonnes/ha/year at a degraded forest land site. *Bauhinia varigata*, *Celtis australis*, *Ficus glomerata*, *Grewia optiva*, *Prunus pardus* and *Sapim sebiferum* showed more prominent differences in growth at the two sites compared with *Albizia stipulata*, *Acacia nepalensis*, *Dalbergia sissoo* and *Pyrus pashia* which showed best growth performance at both sites. A significant improvement in physico-chemical charaterstics was observed after five years at both sites. Carbon sequestration in soil was higher than that in bole biomass.

Keywords: *biomass, multipurpose trees, degraded lands, carbon sequestration*

PPI.2.2 Poplar (Populus deltoides) based agroforestry system: A case study of southern Haryana

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Haryana is a small state in the Gangetic plains of India meeting Shiwalik foothills in the north, Aravallis in the southwest and arid plains in the west. It has a geographic area of 4 412 square km., of which only 6.8 percent is under forest (3.6%) and tree cover (3.2%) as reported in forest survey of

India report (2011). The forest area in the state is far below the targeted goal of 20 percent area under forest and tree cover. To fulfill this goal and to replace paddy-wheat rotation, the policy makers are encouraging farmers to adopt agroforestry. Among different agroforestry tree species, the farmers give prime importance to poplar and eucalypts due to their short rotation. A case study of poplar-based agroforestry system was conducted to ascertain the economics of poplar-based agroforestry system vis-à-vis sole agriculture at farmer fields of Manjhawali village in Faridabad district of Haryana, India. The farmer planted *Populus deltoides* (G-48) in February 1999 at a spacing of 5x4 m in 4 ha area. No intercrop was undertaken during the rainy season and wheat was intercropped with poplar during the winter season. The farmer after six years of plantation from poplar earned a gross income of INR 4.5 lakhs (\$7258)/ha. The gross income from wheat intercropped with poplar worked out to INR 225 000(\$3629)/ha. The net income from agroforestry (poplar + wheat) after deducting the expenditure incurred on wheat and poplar worked out to INR 6.0 lakhs (\$9677)/ha. The net returns on year basis worked out to INR 1.0 lakh (\$1613)/ha/year from agroforestry against INR 44 000(\$710)/ha/year from sorghum-wheat crop rotation and INR 53 750 (\$867)/ha/year from paddy-wheat crop rotation. Thus the farmers earned 46 percent more income from poplar-based agroforestry compared to paddy-wheat crop rotation.

Keywords: agroforestry, economic-return, paddy-wheat, poplar

PP1.2.3. Buchanania lanzan: a threatened minor fruit tree suitable for agroforestry under Vindhyan region of Uttar Pradesh, India

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Buchanania lanzan commonly known as 'Cuddaph almond', 'Char', 'Chironji' or Pyar is a valuable tree species found in deciduous forests throughout the greater part of India, excluding eastern Himalayan forests and arid regions of North India. It is a main species of the southern and northern tropical dry deciduous and northern dry mixed deciduous forest. It belongs to the Anacardiaceae family and is a small to medium size evergreen tree with a straight, cylindrical trunk up to 15 meters high. *Buchanania lanzan* is known for its high value kernel, which is a rich source of fat, protein and minerals. Its leaves, bark, fruit and gum have medicinal value. It grows well on clayey and laterite soil, but it does not withstand waterlogging. It prefers red soil which is neutral in reaction and medium to deep in depth. The species was in abundance before 1970. At that time it was the backbone of the rural economy of tribals particularly in Bundelkhand, Chattishgarh and Vindhyan region of Uttar Pradesh. But due to rapid deforestation, mishandling of trees during fruit collection, and lack of care, the species population is depleting very fast from its natural habitat. Poor seed viability, slow growth rate and very poor capacity of rooting by vegetative means the species has not so far been raised in plantations, despite the recent high market price. In order to augment depletion, the species needs to be brought under large-scale plantation in its natural habitat under domestication on farmers' fields. Keeping these points in mind, a study was conducted to know the system profitability. Under this study a survey was conducted in Ghorawal, Chopan and Duddhi blocks of district Sonbhadra and Patehra block of district Mirzapur by selecting agricultural fields having *Buchanania lanzan* trees. On average 7-10 trees were found scattered on these fields. The height range of trees was 4.5 to 16 metres. Rainfed crops viz. gram, pea, lentil, mustard, sesamum, sorghum and pearl millet were generally preferred to grow in combination with the Chiroji trees. By adding the fruit yield from the tree component, the present system of Chiroji-based

agroforestry was found 8 to 12 percent more profitable than the sole crop system. Therefore, adoption of systematic Chironji-based agroforestry system with sufficient number of trees will be more beneficial towards the conservation of this species.

Keywords: *Buchnanian lanzan, Chironji, Vindhyan region, profitability*

PP1.2.4. Productivity and financial viability of potential agroforestry systems in North Western India

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The growing of agricultural crops with commercial timber tree species can be one of the promising and viable options to achieve diversification as well as assured income for farmers. However, to make the agroforestry systems more productive and economically more profitable, five potential agroforestry tree species namely, eucalypt (*Eucalyptus* hybrid), maharukh (*Ailanthus excelsa*), toon (*Toona ciliata*), dek (*Melia azadirach*) and poplar (*Populus deltoides*) were evaluated with possible *rabi* and *kharif* crop combinations. Trees were planted in 2005 at the forestry research area of PAU Ludhiana and different *rabi* (wheat, barley, oats, berseem, fenugreek, celery, fennel, dillseed and coriander), *kharif* (pearlmillet, cowpea, mentha, arvi) and annual turmeric crops were inter-cultivated in these tree species. Amongst these the better performing crop rotations viz. arvi-potato, pearlmillet-wheat, pearlmillet-potato, moong-berseem, mentha-fenugreek and turmeric were evaluated on the basis of the system productivity and economics under all these agroforestry tree species. Various understorey crops performed better with poplar and dek than the rest of the tree species in terms of their productivity after a period of six years. The reduction in yield of turmeric, potato, wheat and berseem under poplar trees was less as turmeric is a shade-tolerant crop while the growth season of potato, wheat and berseem coincided with the leafless stage of poplar trees. The yield of turmeric, potato and wheat ranged between 19.8 to 9.6 Mg ha⁻¹, 21.5 to 11.9 Mg ha⁻¹ and 5.14 to 2.45 Mg ha⁻¹, the highest and the lowest being in the first and sixth year of poplar plantation, respectively. The yield of pearlmillet and moong reduced from 43.0 to 6.5 Mg ha⁻¹ and 1.03 to 0.21 Mg ha⁻¹, respectively from the first to the sixth year of tree growth. After six years, turmeric cultivation under poplars gave an additional net income of INR 388 200 ha⁻¹ (USD 6470); the corresponding figures for pearlmillet-wheat, pearlmillet-potato and moong-berseem cropping systems were INR 276 471 (USD 4,608), INR 269 740 (USD 4496) and INR 225 250 (USD 3754) ha⁻¹. Hence, turmeric intercropping proved to be the most remunerative followed by intercropping of pearlmillet-wheat rotation with poplar.

Keywords: *intercropping, poplar, profitability, system productivity*

PP1.2.5. Causes of deforestation and conservation strategy in Teknaf Peninsula of Bangladesh

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Teknaf peninsula is situated in the southeast region of Bangladesh where both hill and coastal ecosystems are found within a narrow space. This area was once rich in various resources particularly forest and marine resources. However, due to natural and anthropogenic activities, the resources are

being depleted at an alarming rate. Increasing temperature, patchy rainfall and frequent cyclones are some common natural events that are responsible for resource depletion. Recent data showed that settlements became almost double in 2006 as compared to the base year of 1972, while the forest area decreased by 29% in the said time period. Surprisingly, there was no agricultural activity in 1972 as most of the local people were dependent on marine and forest resources for their livelihood. At present, land use change due to huge settlements is one of the major causes of forest resource degradation. Rice was the main crop during the inception of agriculture, but betel leaf (*Piper betle*) has become the most profitable crop and the area coverage has been increased by 40% in 2012 compared to five years back. Shading is a must for betel leaf cultivation, which ensures high production and quality. Farmers used to go to the forest to collect shading materials, which is one of the major causes of deforestation. It is urgent to address the problem and take necessary steps to conserve the forest as well as the environment. Agroforestry could help to reduce deforestation and restore the resources by establishing various timber and fruit tree orchards and cultivating suitable high value crops, which would ensure income generation and provide multiple products. Moreover, social forestry programs may be strengthened with adequate public awareness.

Keywords: *agroforestry, conservation, deforestation, resource*

PP1.2.6. Improving agroforestry contributions to the rural livelihood through value chain analysis: a case study in West and East Thailand

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Agroforestry has been an important alternative in land management systems to improve rural livelihood due to its capability to generate employment and income. The success story of In-Peng Community Group in Thailand in restoring their agroforestry system after the dark period of monoculture agricultural practices and tree production provide an example of the critical roles of agroforestry (Muktasam 2004). The local community livelihood was deteriorated by the government's decision to grow export-oriented crops through a monoculture system. Putting the critical roles of agroforestry in perspective at the community level, the role of agroforestry can be improved through a systematic value chain analysis of agroforestry products, both timber and non-timber. The analysis provides comprehensive information with regards to chain actors, activities, added value, employment, profit distributions, and gaps in knowledge and skills. Through better understanding of the agroforestry product value chains, various interventions can be taken to promote a more strategic contribution of agroforestry system. A study of existing agroforestry practices in west and east Nusa Tenggara, Indonesia provides an illustration on how value chain analysis supports effective interventions to improve local community livelihood particularly in generating employment opportunities and income. The preliminary data presents the limited activity of the local community, the first level actor in the value chain, in processing products such as fruits, coffee, bamboo, candlenut and honey, due to lack of knowledge and skills. Consequently, the existing agroforestry management has made a limited contribution to employment and income generation. The analysis suggests the need to improve the existing agroforestry system to grow more profitable agroforestry products and increase the capacity of local communities not only in agroforestry management but also in processing and marketing of agroforestry products.

Keywords: *agroforestry, contribution, rural, livelihood*

PP1.2.7. Agroforestry-based crop diversification for income and environmental services on reclaimed ravine lands: a case study

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Socioeconomic and environmental problems arising from mono-cropping influence the policy environment in favour of agroforestry-based crop diversification due to various dynamic and sustainability factors such as soil health, soil degradation and nutrient loss prevention. This is an effective strategy for food and nutrition security, income growth, poverty alleviation, employment generation, as well as for the judicious use of natural resources. Indian agriculture is preoccupied with the second generation problem debate including lowering of the water table, nutrient imbalance, soil degradation, salinity, environmental pollution and decline in farm profit. Shifting from a mono-cropping system to a tree-based system holds a lot of promise in alleviating these problems apart from fulfilling other objectives. The present case study draws from a research project on drumstick (*Moringa oleifera* Linn.) and aonla (*Emblia officinalis* Gaertn.) based agrihorticultural systems to replace tobacco (*Nicotiana tabacum* L.) crop on the reclaimed ravine lands of Mahi River in the Gujarat state of India.

Among the two agrihorticultural systems, the drumstick-based cropping system was not only found to be as remunerative as tobacco but also provided environmental services in terms of higher soil carbon built up and nutrient saving in the soil. Besides saving in irrigation water, the cropping systems enhanced returns over variable cost, saving in soil nutrients valued at INR 657 ha⁻¹ and sustained soil carbon built up valued at INR 3696 ha⁻¹. This holds promise for the agroecosystems of central Gujarat, which has a predominant tobacco mono-cropping system that is averse to soil conservation. The environmental benefits provided by drumstick-based agrihorticulture system has implications for resource conservation and environmental security, thus making it legitimate in view of the national action framework to find alternative crop after signing the Framework Convention on Tobacco Control of World Health Organization.

Keywords: *crop diversification, income, environmental service, Agrihorticulture*

PP1.2.8. Transformation of a fruit tree orchard into a multistoried agroforestry system: a way for higher production and income

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Fruit tree based agroforestry systems have been expanding to farmland ecosystems as crop farming is becoming risky and farmers are losing concern. Jackfruit orchards having sporadic understoried crops predominantly found upland of the terrace ecosystem were transformed into multistoried agroforestry systems for maximizing production through utilizing resources. The jackfruit tree was kept as an upper-storied crop; while papaya and lemon were established as middle-storied; and brinjal as lower-storied crops. The system was managed scientifically to ensure maximum resource utilization. Light availability, land equivalent ratio (LER) and benefit cost ratio (BCR) were determined to justify the advantages of this system. Light availability at middle- and lower-storied crops was reduced by 26.56

and 32.34%, respectively. Middle-storied crop did not cut much light due to pruning of the lemon tree and the nature of the papaya plant. The jackfruit yield increased by 33.66%, while yields of papaya and brinjal decreased by 17.86% and 24.73% respectively. Yield advantage in jackfruit might be due to judicious use of water and nutrients for middle- and lower-storied crops. Yields of middle- and lower-storied crops were reduced due to competition for resources. LER was appreciably higher in multistoried agroforestry systems (3.11) because of increased production. BCR was good in multistoried agroforestry systems and income from this system was 182% higher than the sole jackfruit system. Microclimate seemed to improve as the new system kept the farm greenish all the time. These are the results of two years' study. Benefits will be much higher when the lemon tree yield is received.

Keywords: *higher income, higher production, multistoried agroforestry system*

PP1.2.9. Assessment of growing stock of bamboo under agroforestry systems in central India

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Bamboo under agroforestry system provides higher economic returns than monocropping system, conserves and improves soil, as well as provides raw material to industry and for domestic use. The assessment of the growing stock of bamboo (*Dendrocalamus strictus* and *Bambusa vulgaris*) was done during 2012 in an ongoing bamboo-based agroforestry experiment initiated under National Bamboo Mission during 2007 at Jhansi. Bamboo plants were spaced at 10 m × 10 m having 100 clumps ha⁻¹. Blackgram and chickpea were grown sequentially. Assessment was done through a random sampling method, where 10 clumps of each species were selected. Thinning was done through culm selection during winter. Based on size and diameter at base, bamboo were segregated into class I: 7- 8 m, class II: 6 -7 m and class III: 3-6 m (*Bambusa vulgaris*); and class I: 2- 4 m and class II: 1.5 – 2 m (*D. strictus*). *Bambusa vulgaris* gained average height of 5.64 m, 3.28 m, 2.64 m with an average dry weight of 3.56, 1.40 and 0.94 kg culm⁻¹, respectively in class I, II and III. In *D. strictus* average height gained was 3.24 m, 2.04 m with an average dry weight of 1.93 and 0.76 kg culm⁻¹ in class I and II respectively. Average number of culms clump⁻¹, internodes culm⁻¹, internodal length and DBH were observed to be 20, 14.9, 24.6 cm and 4.66 cm (*B. vulgaris*) and 32, 10.5, 19.14 cm and 3.75 cm (*D. strictus*), respectively. Total growing stock on dry weight basis was assessed to be 5.19 t ha⁻¹ (*B. vulgaris*) and 4.35 ha⁻¹ (*D. strictus*). On an average 515 kg ha⁻¹ (blackgram) and 1853 kg ha⁻¹ (chickpea) yields were obtained under bamboo-based agroforestry system. Therefore, it can be concluded that bamboo-based agroforestry system gives additional income and livelihood opportunities to farmers.

Keywords: *agroforestry, bamboo, growing stock, livelihood*

PP1.2.10. Performance of gum yielding trees based agroforestry models from Central India

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Agroforestry has potential to contribute to the improvement of rural livelihood as it offers multiple alternatives and opportunities to enhance farm production and income. Agroforestry systems which integrate gum yielding trees offer a unique livelihood option to small and marginal farmers. However, systematic information is not available on agroforestry systems based on gum yielding trees. In order to generate such information and to provide an option to improve the economic status of farmers through gum production, studies have been undertaken at the National Research Centre for Agroforestry, Jhansi to develop agroforestry models for gum yielding trees. Six agroforestry models (4 at the research farm and 2 at the farmer's field) were planted in the year 2009. The developed models represent agri-horti-silviculture and horti-silviculture system of agroforestry. The tree species planted for gum production are *Acacia senegal* (Kumat) and *Acacia nilotica* (Babul), and horticulture species *Embolia officinalis* (Anola), *Citrus limon* (Lemon), *Aegle marmelos* (Beal) and *Carrissa carandus* (Karonda). On farmers' field, horticulture species were planted as per choice of farmers. Initial results after four years of planting indicated that in general, survival and growth in terms of plant height and collar diameter of planted gum yielding trees and horticultural plants was better in models developed at the research farm than the models on farmers' fields. Out of the two gum yielding tree species, better performance has been shown by *A. nilotica* than *A. senegal*. Among horticultural plants, *E. officinalis* gave maximum growth while *C. carandus* the least. *Acacia nilotica* planted at farm started exuding gum, whereas, no gummosis has been observed either in *A. senegal* or *A. nilotica* on farmers' fields. The main reason for poor survival and growth of the planted species on farmers' fields was uncontrolled grazing due to the practice of 'annapratha' in this region.

Keywords: agroforestry models, Bundelkhand, gum yielding trees, livelihood options

PP1.2.11. Opportunities and challenges of large cardamom-based agroforestry (a high value cash crop) in the Eastern Himalayas

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Large cardamom (*Amomum subulatum*) is socially accepted, ecologically adaptive (600-2500 m), high-value, low input, and a not labour-intensive perennial cash crop endemic to the Eastern Himalayas cultivated under shade trees. This study analyses socioeconomic/socioecological opportunities and challenges of cardamom-based agroforestry systems across the four districts (18 sites) of Sikkim during 1997-2013.

Sikkim was the largest producer of cardamom (5000 t fetching USD 15-20 million year⁻¹) in the world until 2000. Climate change had devastating impacts on cardamom reducing the socioecological resilience while threatening the socioeconomic security of smallholders. People's perception revealed that emergence of new diseases/pests (37%), long dry-spells (29%), altered seasons (10%), erratic/scanty/unseasonal rainfall patterns (17%), and decreased (7%) abundance of pollinators attributed to the decline of plantation area (26-60%) and productivity (30-60%). Regression analysis showed negative correlation of production area ($P < 0.01$, $r^2 = 0.54$) and production ($P < 0.01$, $r^2 = 0.44$) over the last twelve years. Around 16 037 (14.34%) smallholders out of 111 830 households in Sikkim cultivate cardamom. It contributed 40-80% of household economy

before 2000, while it still contributes 29% followed by livestock (12%), other cash crop/labour (6%), and service/remittances (53%). Annual cash earning was highest (USD 2450 ha⁻¹) from cardamom-based agroforestry, 11, 3, and 1.7 times that of forest-based, farm-based, and mandarin-based agroforestry systems, respectively. Production efficiency (ha⁻¹), soil nutrient availability, N-fixation, agronomic yield, and ecological suitability increased with age until 15 years and decreased significantly thereafter. Thus, a rotation cycle of 15-20 years is recommended with phase-wise agroforestry re-establishment for climate change adaptation, ecological resilience and higher economic return. In addition to an average earning of USD 1962 ha⁻¹ year⁻¹ (3rd year), the timber/fuelwood harvest at 20 years would bring around USD 8088 ha⁻¹. Cardamom-based agroforestry bestows ecosystem services such as habitat/biological corridor for wild animals, recharge catchments for springs/streams and basic resources (timber/fuelwood, fodder, NTFPs). Its appropriate management can bring opportunities for sustainable development in the region.

Keywords: *cardamom-based agroforestry, climate change, adaptive management, Eastern Himalayas*

PP1.2.12. Economic viability of *Andrographis* in agroforestry

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The field experiment was conducted at AICRP on Agroforestry, ANGRAU, Rajendranagar, Hyderabad during 'Kharif' seasons of 2008 and 2009 under rainfed conditions to assess the performance and economic feasibility of medicinal plant namely *Andrographis paniculata* (Kalmegh) intercropped in existing plantations of amla and terminalia. The treatments consisted of three cropping situations (C₁- intercropping andrographis in amla-based cropping system, C₂- intercropping andrographis in terminalia-based cropping system, C₃- sole cropping of andrographis and six integrated nutrient management practices (M₁-control, M₂- 20 kg, Nha⁻¹ alone (through Urea), M₃- Vermicompost@2t, M₄-FYM @ 5t ha⁻¹, -20kgNha⁻¹, M₅ through urea+Vermicompost@2tha⁻¹, M₆20 kg N ha⁻¹ through urea + FYM @ 5t ha⁻¹) laid in split plot design with three replications. The results indicated that intercropping of andrographis + terminalia proved more economical with maximum total net returns of INR 241 823ha⁻¹ over intercropping with amla and sole cropping of andrographis. Among the nutrient management treatments, the INM treatment with 20 kg Nha⁻¹ through urea + Vermicompost @ 2 tha⁻¹ resulted in maximum net profit over inorganic fertilizers or organic manuring alone in all the three cropping situations.

Keywords: *andrographis, cropping situation, integrated nutrient management, intercropping*

PP1.2.13. Evaluation of agri-horti-silvicultural agroforestry systems in rainfed uplands of coastal Odisha, India

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Introduction of fruit trees into agroforestry systems proves remunerative to the farmers as it imparts stability to their income. Mango (*Mangifera indica*) being an income-generating fruit tree, its

integration with timber species and field crops would provide useful information to develop a remunerative agri-horti-silvicultural system for the rainfed uplands.

A field experiment was conducted at Bhubaneswar, Odisha, India during 2009-12 to study the performance of three medicinal crops *Andrographis paniculata*, *Aloe vera* and *Curcuma amda* and one short duration fruit crop, pineapple (*Ananas comosus*), in the alleys of nine-year-old trees *Acacia mangium*, *Dalbergia sissoo* or *Gmelina arborea* planted in east-west direction at a spacing of 6 m x 6 m. The mango grafts were planted during 2000 at 6 m x 6 m spacing along the tree rows leaving 3 m on either side of a tree.

Pineapple as an intercrop recorded maximum yield recovery as compared to sole crop in association with *Gmelina arborea*. Among the tree species, yield recovery for all the crops were higher with *Gmelina arborea* followed by *Acacia mangium* and *Dalbergia sissoo*. Highest fruit yield in mango was recorded with *Gmelina arborea* + *Andrographis paniculata*. Pineapple was the most suitable crop in the system with mean net returns of INR 87 348, 77 110 and 75 954/ha/year with B:C ratios 2.12, 1.98 and 1.97 when intercropped with *Acacia mangium*, *Dalbergia sissoo* and *Gmelina arborea*, respectively; as against a net return of INR 56 000 with B:C ratio 1.82 when grown as a sole crop. *Curcuma amda* and *Andrographis paniculata* recorded higher B:C ratios when grown as sole crops than in the system. *Acacia mangium* had higher annual increment in height, diameter and volume as compared to the other two tree species. However, the return from the tree component was not considered for the economics analysis.

Keywords: *Acacia mangium*, agri-horti-silvicultural system, *Curcuma amda*, *Mangifera indica*

PP1.2.14. Economic returns from major agroforestry species in Haryana State of India

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Agroforestry is an area where Haryana has taken long strides. With more than 80% of the total area under agriculture and less than four percent under forests, agroforestry is the only option left in Haryana to increase tree cover. Although forest deficient, a farmer-friendly agroforestry atmosphere has turned it into a wood surplus State and has enabled it to support a large number of wood-based industries based on farm-grown wood. The policy of not putting any restriction on felling of agroforestry trees and not having any restrictions on transit of wood has also helped in expanding agroforestry, timber trade and wood-based industries. A minimum support price of the agroforestry produce offered by Haryana Forest Development Corporation (HFDC) ensures economic security to the farmers and they have taken agroforestry as their way of life. Haryana Forest Department had been distributing twenty million seedlings every year to the farmers and other tree growers to promote agroforestry. The department is also carrying out plantations on farmers' fields and maintaining them for one year. Later on these trees are maintained by the farmers themselves. While poplar is the main agroforestry species in the northern part along Yamuna river basin, *Eucalyptus* is grown almost throughout the State except sandy and dry areas. *Ailanthus excelsa* is performing well in semi-arid conditions. Haryana's model of successful agroforestry is the most economical, sustainable and stable alternative for ecological security of land production system and efforts made in this direction in the State are the best in the country. This model has made Haryana a national leader in agroforestry and needs to be replicated elsewhere in the country or world. Economics of major agroforestry species

namely eucalyptus, poplar, *Media dubia* and *Ailanthus excelsa* on farmers' fields will be discussed in the paper.

Keywords: *poplar, eucalyptus, Melia dubia, Ailanthus excelsa, HFDC, Yamunanagar*

PPI.2.15. Identification of elite genotypes of fruit trees for arid zone agroforestry

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Arid zones all over the world are climatically constrained and edaphically impoverished areas that support specialized and adapted plants. Farmers in these areas have perfected through the ages agroforestry systems inculcating trees and shrubs in a variety of ways for improving their livelihood and sustainability. The tree components of traditional agroforestry systems in Indian arid zones comprise mainly *Prosopis cineraria*, *Tecomela undulata*, *Ziziphus mauritiana* var. *rotundifolia*, *Ziziphus nummularia*, *Salvadora oleoides* and *Capparis decidua*, etc. Such agroforestry systems need diversification in woody perennial components by including elite fruit trees and shrubs. Of the different horticultural species, *Cordia myxa*, *Carissa carandas* and budded 'khejri' (*Prosopis cineraria*) have been investigated in the last ten years at CAZRI, Jodhpur before trying them on farmland. It was imperative as a first step to select the desirable types and standardize their clonal propagation methods. In *Cordia myxa*, four elite genotypes viz. CAZRI-G-2011, CAZRI-G-2012, CAZRI-G-2021 and CAZRI-G-2025 were selected out of a diverse germplasm collection from different parts of India and their clonal propagation method standardized. These genotypes expressed higher fruit yield potential up to 100 kg per plant. In the case of *Carissa carandas*, three improved genotypes viz CZK2011, CZK2022 and CZK2031 were found high yielding and with bold fruit size. These were found suitable as live fence for creating favourable microclimate besides enhancing income from fruits. Similarly in khejri, desirable pod types for vegetable purpose were identified from naturally growing trees. *In situ* budding technique and their management for obtaining fodder as well as pods have been perfected to fit in the arid zone agroforestry. Thus, instead of using nondescript plants, use of improved types propagated by vegetative method in arid agroforestry systems will definitely enhance the productivity and sustainability of farming systems.

Keywords: *arid zone agroforestry, cordia myxa, Elite genotype, prosopis cineraria*

PPI.2.16. Performance of potato varieties and their time of sowing under Poplar plantation

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Poplar-based agroforestry system is considered one of the viable alternatives for crop diversification. Wheat is the main rabi crop sown under poplar. However, other rabi crops such as oats, mustard and berseem can also be grown. In the northern parts of the Punjab state, farmers grow potatoes along boundary/block plantations of poplar. Introduction of this high value, short duration and highly productive crop in a poplar-based system could play a significant role in improving the economic status of farmers. Therefore, to find out the best variety and optimum sowing time, early (Kufri Pukhraj), mid (Kufri Badshah) and late-season (Kufri Jyoti) potato varieties were sown at four times (mid October, mid November, mid December and mid January) under poplar plantation. Based on various growth

(emergence, plant height, days to maturity) and yield parameters (number of tubers/plant, average tuber weight, yield/ plant, fresh and dry weight of plant and tubers), the maximum tuber yield (24.73 t/ha) was recorded in potato variety Kufri Badshah sown during mid-November. This combination also gave the highest total dry matter content (21.24 %) of tubers, the most important character required for processing. Amongst the different sowing times, maximum average tuber yield (21.96 t/ha) was observed in the mid-November sown crop. Maximum average tuber yield (14.32 t/ha) was recorded in Kufri Badshah, whereas the tuber yield of other two varieties was at par. When the yield of potato varieties sown under block plantation of poplar were compared with those sown in open plantations, yield reduction ranging from 24.88 to 34.37 percent was observed during different times of sowing. Total dry matter (%) recorded in potato varieties, sown under poplar plantation was also less compared to that in open. This may be attributed to differences in soil (0.2-1.8°C) and air temperatures (5-6°C) inside and outside plantation.

Keywords: *agroforestry interventions, high value crops, growth parameters, yield parameters*

PP1.2.17. Pinus gerardiana for agroforestry systems: an opportunity for rural development

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Pinus gerardiana (Chilgoza pine) is an important economic and ecological species in the dry temperate forests of India's Himalaya. There are large numbers of biotic and abiotic factors affecting *P. gerardiana* regeneration, so there is a need to understand the regeneration process in this pine. This research was conducted in Kinnaur region, Himachal Pradesh, India. The regeneration success in this pine is lower than the requirement of sustainable forest, but varies widely among sites. Results suggest that in different forests regeneration success is influenced by the collection of cones (nut) by tribal people, grazing and browsing, soil sand and nutrient content. Regeneration varied from 15% - 25% at different sites and it was observed that the sites with more regeneration have less biotic interference, soil sand and litter depth, but more soil nutrient availability. Among all these factors, the most important factors affecting regeneration of this pine is the collection of cones (nut) by the tribal people, harvesting almost all the cones except for 5% of the trees located in inaccessible and remote areas. The decline in regeneration of this pine has led researchers to develop chilgoza pine-based agroforestry system which could improve economic conditions and maintain ecological sustainability. It has been classified as a social forestry species and could be considered for growing in horticultural/agroforestry settings. This nut producing pines could become a suitable agroforestry species, only if suitable varieties are developed that are a) well adapted, b) fast growing, c) precocious, d) produce heavy cones, e) and multipurpose. Chilgoza pines exhibit a wide variation in most of the characters and have high heritability and genetic gain. So there is scope to domesticate and improve it through establishment of clonal seed orchard and control breeding.

Keywords: *Pinus gerardiana, regeneration, economic, ecological*

PP1.2.18. Tree-crop association for livelihood security of small and marginal farmers of coastal Odisha

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Growing of traditional food crops with multipurpose tree species on the farmland has been the general practice of the small and marginal farmers in India. Alternate land management systems involving multipurpose trees have proved to provide higher net returns compared to monocropping. Therefore it is necessary to work on economically viable, socially acceptable, and sustainable land management systems to ensure sustained production by optimising utilization of resources. Agrisilvicultural system can be one such promising option to achieve diversification as well as assured income. It reduces the risks of monoculture; sequesters more carbon besides efficiently cycling nutrients through multiple land use activities. Coastal Orissa characterized by high and uneven rainfall provides ample scope for agroforestry systems in the rainfed uplands. Ragi, sesamum and groundnut were raised in the alleys (8 m x 2 m) of timber tree species *Acacia mangium* and *Gmelina arborea* in acidic sandy loam soil during the rainy season of 2001-2004. Thereafter, from 2005 to 2008, shade-loving crops turmeric, arrowroot and colocassia and from 2009-2012 pineapple, aloe vera, kalmegh and mango ginger were grown. There was a gradual decrease in grain yield of all the associated crops with increase in age of the tree species. Grain yield decreased to the extent of 45% to 55% irrespective of the tree species from 2002 to 2004. During 2005-2008, colocassia, arrowroot and turmeric performed well in association with the timber trees with higher economic returns. Similarly during 2009-2012, pineapple performed better with reasonably good yields and returns. After 138 months of growth, *A.mangium* and *G.arborea* recorded plant height and collar diameter growth of 19.06 m and 24.28 cm and 13.92 m and 17.45 cm respectively.

Keywords: *Acacia mangium*, coastal Odisha, livelihood security, multipurpose trees

PP1.2.19. Abelmoschus esculentus, a potential intercrop under Grewia-based agroforestry system of mid hill of Himachal Pradesh

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The study was carried out in the experimental farm of the Department of Silviculture and Agroforestry, Dr. Y. S. Parmar University of Horticulture and Forestry, Nauni, Solan (H.P.) during 2012-2013, where an agroforestry system comprising *Grewia optiva* + bhindi (*Abelmoschus esculentus*) was developed. The study was conducted to evaluate the effect of different tree spacing, direction and distance from tree row on yield parameters of bhindi (*Abelmoschus esculentus*). The *Grewia optiva*, an important fodder tree, was planted in a row using three different spacing viz. 1 m, 2 m and 3 m apart. Bhindi was intercropped as a field crop in between two tree rows spaced at 8 m apart during June 2012. The data was recorded in two directions i.e. north and south and at two distances from tree rows viz. 1 m and 2 m on various yield parameters of field crop (bhindi). The data was analyzed using Randomized Block Design (RBD). The study revealed that tree spacing, interaction between tree spacing and distance from tree row, control and agroforestry system significantly influence all the yield parameters of field crop under *Grewia optiva*-based agroforestry system. The maximum fruit yield (45.83 q/ha) was recorded in open, whereas under tree canopy the yield recorded was 26.63 q/ha. The reduction in the yield of field crop is

compensated by tree crop and the system offers an excellent opportunity for diversification and more income generation than monoculture.

Keywords: *bhindi, Grewia optiva, spacing and direction*

PP1.2.20. Critical issues in poplar-based different agroforestry system in India

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Poplar has become a lifeline not only to the adopting farmers but also to the dependent plywood industry in northern India. Poplars have become significant resources in plantation forestry in India, which are ideally suited for supporting rural livelihoods, enhancing food security, alleviating poverty and contributing to sustainable development. They provide raw material supplies for industrial processing and valuable non-wood products. Poplar plantations intercropped with agricultural crops have better growth than those without intercrops and the growth of trees is variable under different intercrops. The preferred agroforestry production was intercropping poplars with agricultural crops such as wheat, maize, mustard, turmeric and aromatic crops in order to provide scope for essential food production. Poplar-based agroforestry system has privileged productivity, if they are associated with agricultural crops. Keeping in mind the present status of the poplar-based agroforestry system, this paper emphasized the critical issues that emerged in the past which may endanger the system productivity and thereby may revolutionize the economics of the above said system.

Keywords: *agroforestry system, critical issue, intercropping, Poplar*

PP1.2.21. Development of agroforestry models for the semi-arid tropics of Andhra Pradesh

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The shortage of raw materials of *Gmelina arborea* R.Br. and *Wrightia tinctoria* Roxb., augmenting the income of farmers of rainfed agriculture and to suffice the demand of artisans necessitated the on-farm trial at Chelmeda village of Ramayampet mandal, Dist- Medak (Andhra Pradesh, India) to study the interactions of tree and crop combination of the agroforestry system. Trials were laid out in randomized block design with Nine treatments replicated thrice comprising Sorghum (*Sorghum bicolor* L.Moench.) and Red gram (*Cajanus cajan* Milsp) (Five rows of Sorghum alternated by One row of Red Gram) as intercrops with *W. tinctoria* and *G. arborea* as tree crops. The spacings adopted are i) 3m x 9m and ii) 3m x 12m in case of *G. arborea* and i) 3m x 10m and ii) 5m x 12m in case of *W.tinctoria*. The results so far revealed significantly higher grain and fodder yield. Grain and fodder yield of Sorghum were 500 and 2104 kg/ha and that of Red gram were 101 and 1700 kg/ha respectively in case of *G.arborea* with spacing of 3m x 12m. In the case of *W. tinctoria* with spacing 5m x 12m, the grain and fodder yield of Sorghum were 176 and 742 kg/ha and that of Red gram were 79 and 1021 kg/ha respectively. As the espacement increased from tree row there was significant increase in grain and fodder yield. The percent reduction in the yield of Red gram and Sorghum with lesser espacements was attributed to the shading effect of trees which in turn had reduced the availability of light. Soil fertility increased significantly by the association of trees. The

land equivalent ratios (LER) and economic analysis were carried out. The cost benefit ratio is in favour of intercropping as against controls.

Keywords: agroforestry, interactions, LER's, cost benefit ratio

PP1.2.22. Performance of Dendrocalamus strictus and Bambusa nutan-based silvi-agri system in tropical region of Madhya Pradesh

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Bamboo has been recognized as an important wood for furniture and as a substitute for timber worldwide. At present, bamboo can be obtained from wastelands to farm bund plantations as most important source of raw materials for paper industries, besides improving soil condition of eroded river bank soil. Although, some farmers are reluctant to adopt the bamboo in their farmland due to its vigorous and fibrous root growth but even then due to its high remunerative price, recently they are ready to adopt this species in their idle land.

An experiment was conducted in the experimental area of Agroforestry division of Tropical Forest Research Institute, Jabalpur (MP) during the year 2007-2010 with two bamboo species (*Dendrocalamus strictus* Roxb. Nees & *Bambusa nutans* Wall ex. Munro at 6x5m spacing intercropped with *Triticum aestivum* L. (Wheat) to standardize the Bamboo based Silvi-agri system. Performance of growth data indicates that both the species performed better from 51.48-463.24cm in *D. strictus* whereas in *B. nutans* i.e. 0.67-575cm during the first to fourth year of its growth. The yield of wheat shown marginal reduction from 18.82 to 17.33q^{ha-1} with *B. nutans* and 16.06 to 14.89q^{ha-1} with *D. strictus* as compared to sole i.e. 24.45 to 22.50q^{ha-1} under the system. Below ground parameters like nutrient status of soil revealed the increasing trend in pH – 6.8 to 7.01, EC – 0.3 to 0.49 m/mhos, Nitrogen – 229 to 355.9kg^{ha-1}, Phosphorus- 13.55 to 30.73Kg^{ha-1} and Potassium - 345.2 to 585.17kg^{ha-1} under the system.

Standardized package of practices of bamboo-wheat silvi-agri system for tropical region of Jabalpur, MP which has potential to provide additional income of Rs. 1,08,703^{ha-1} as compared to Rs. 51,148.8^{ha-1} and Rs.14,485^{ha-1} from monoculture of *B. nutans* and *D. strictus* and Rs.35,218.2^{ha-1} from wheat sole at the end of 4th year of the experiment.

Keywords: *Dendrocalamus strictus*, *Bambusa nutans*, Jabalpur

PP1.2.23. Influence of climatic factors on Lac cultivation on Flemingia macrophylla in understored plantations of Dalbergia Sissoo

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Lac is a resinous exudation from the body of female scale insect *Kerria lacca* Kerr. (Tachardiidae: Homoptera). The study was conducted to elucidate the influence of climatic factors viz. temperature, humidity and light intensity in the process of exploring the possibility of lac cultivation on non-traditional host *Flemingia macrophylla* (Willd.) Kuntze and its possibilities in understories of *Dalbergia sissoo* Roxb. ex DC. plantation. Experiment was conducted in shade of *Dalbergia sissoo* plantation and open condition with single shrubby host *Flemingia macrophylla* and two lac strains Kusumi & Rangeeni. Two lac crops Aghani (winter) & Jetwi (summer) of Kusumi strain and two lac crops Katki

(rainy) and Baisaki (summer) of Rangeeni strain were tried on shrubby host *Flemingia macrophylla*. The climatic factors recorded during the study period of three years reveals that, in understories of *D. sissoo* plantation during lac cultivation period temperature was 1° to 1.5°C lower than control/open condition. In experimental/shade condition the humidity was more and light intensity was almost ten times lesser than control/open condition. Mean performance for height in *F. macrophylla* for different biometric traits revealed that height growth in control/open condition (229.94 cm) was nearly double than the experiment/shade condition (132.98 cm). The average ‘scrap lac’ yield in control/open condition for Aghani, Jethwi & Katki crop was 166.64g/plant, 105.36g/plant, 81.47g/plant which is 2.6, 3.8 and 4.7 times to that in under-storey (63.63g/plant, 27.58g/plant, 17 g/plant) respectively for these lac crop. However, Baisaki crop failed because of high temperatures (38°C) and higher number of male insects 80:3 (M:F) per sq. cm.

Keywords: *Dalbergia sissoo*, *Flemingia macrophylla*, *Kerria lacca*

PP1.2.24. Trees on Farmland: composition, abundance and role of trees on farmland in rural communities

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Farm trees are increasingly viewed as an integral part of rural farming system, agro- biodiversity conservation and improved food security in developing countries. Farm trees often possess competitive advantages to rural households and are integrated into farming system for a variety of purposes, including fodder, firewood and fruit production. In some communities, the economic contribution of farmland trees to households is comparable to, or greater than, the contribution of the forest. In order to improve our understanding of farmland tree population (spatial, temporal, structural and use), a survey was conducted in middle hill (Kaski) and lowland (Chitwan) of Nepal to generate empirical data on farmland trees. Households were randomly selected at each site and the number of trees owned by each sample household was counted and measured. Species were identified and diameter at breast height (dbh), crown width, tree height and lopping intensity were measured and/or estimated for characterizing the structure, use and dynamics of the tree population. Each tree was grouped according to its dominant use as fodder, fruit, timber, firewood and ornamental purposes. The survey revealed that the average number of trees owned by households in Kaski and Chitwan was 45 and 51 respectively. Out of the total tree species recorded, majority were used for fodder and fruit production. Fruit and ornamental trees were mostly confined around home-yard whereas fodder trees were grown along the roadside, farm boundaries and fallow lands. The choice of species and its abundance in farmland was largely associated with land and livestock holding, the market value of the production and nutritional requirement of the household. The current composition and abundance of farm trees has ushered towards the potential agroforestry systems towards contributing to food security by improving livestock and fruit production in rural communities.

Keywords: *agro-biodiversity, agroforestry, farm trees, food security*

PP1.2.25. Contribution of Agroforestry based NTFPs as Livelihood options in Rural Areas of Jharkhand State of India

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There is an inextricable link between forest resources and livelihood of rural people. A study to evaluate the benefits of agroforestry tree-products especially NTFPs was conducted in twenty villages of East Singhbhum(Jamshedpur), West Singhbhum(Chaibasa), Saraikela-Kharsawan, Ranchi, Gumla, Simdega and Dhanbad districts of Jharkhand. It was found that NTFPs play an important role in rural livelihood in the shape of medicine, food, fruits, fibre, firewood, oil, lac, silk etc. Of these NTFPs, Lac and Silk occupy an important place in rural economy. Jharkhand has abundance of Lac and Silk host trees. Lac, which is a natural resin secreted by an insect, *Kerria lacca* (Kerr.), cultivated on host trees like Palas [*Butea monosperma* (Lam.) Taub], Kusum [*Schleichera oleosa* (Lour.) Oken] and Ber [*Zizyphus mauritiana* Lam.]. In Jharkhand mostly Tassar Silk is reared which is an important vanya variety produced by a wild silkworm of *Antheraea mylitta* Drury. *Antheraea mylitta* Drury feeds primarily on Asan [*Terminalia tomentosa* (DC) Wt. & Arn], Arjun [*Terminalia Arjuna* (Roxb.exDC.)Wt. & Arn.] and Sal [*Shorea robusta* (Gaertn.f.)] and secondarily on *Lagerstroemia parviflora* Roxb., *Zizyphus mauritiana* Lamk. Their production and applicability have been growing in different sectors. Lac is much in demand in the sector of printing ink, furniture polishing, handicrafts, cosmetics, dyeing sector and pharmaceuticals sector. Similarly Silk is much in demand in textile sector which involves many subsidiary operations. Hence livelihood options based on lac and silk cultivation and their subsidiary operation have occupied a sizeable space in rural economy. The paper critically examines various facets of Lac and Silk cultivation and their contribution in improving earnings of rural people.

Keywords: NTFP, Jharkhand, lac, silk

PP1.2.26. Linking Native Perennial Fruit Tree Species to Livelihood Security and Poverty Reduction: Lessons from Tribal Areas of Chhattisgarh, India

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The Chhattisgarh State is bestowed with a vast area of forests covering about 44% of the geographical area. The area is also inhabited mostly by tribals constituting 32% of the population of the State. The judicious development and exploitation of the minor perennial fruit species may be one of the most crucial livelihood options for the disadvantaged segment of the tribal population of the Chhattisgarh. Out of the hundreds of wild domesticated species, seven most commonly used species for various purposes were selected for detailed analysis. They are: Chiraunjee (*Buchanania lanzan*), Bael (*Aegle marmelos*), Jamun (*Syzygium cumini*), Tamarind (*Tamarindus indica*), Custard apple (*Annona squamosa*), Tendu (*Diospyros spp.*) and Rose apple (*Syzygium jambos*). Wild fruit tree species are either becoming extinct or under the threat of over-exploitation due to biotic and abiotic factors.

This paper centered around the following technical and institutional arrangements: Survey and identification of elite genotypes; finding of suitability of a particular indigenous fruit species for its importance and potential as source of livelihood security; importance and prioritization of indigenous perennial fruit tree species in micro-ecological zones; standardization of agro-techniques including promotion of these techniques amongst growers by skill enhancement programme; market support to minimize price risk and standardization of practices of value addition.

Keywords: *minor perennial indigenous fruit plant, livelihood options, Chhattisgarh forest trees*

PPI.2.27. Variation among poplar clones for morphological and physiological parameters

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The poplar clones were evaluated for two years for various growth, leaf traits, stomata number, physiological parameters, insect-pest incidence and wood traits under nursery conditions. Significant variation was present among the clones for all parameter except fiber width. Clones 22-N, L-290/84, L-50/88 for tree height and L-290/84, L-50/88, 22-N, WSL-22, Ranikhet and S₇C₈ were superior for collar diameter during 1st year study. In 2nd year Clones L-7/87, and L-34/82 for height and L-7/87, L-48/89 and L-247/84 for collar diameter were promising. Clones L-7/87, L-48/89, 22-N and clones L-7/87, L-247/84, S₇C₈, L-48/89, WSL-22, 22-N were superior for shoot and root biomass. Clones L-48/89, 40-N, 22-N and L-7/87 recorded higher leaf area. Clone L-34/82 recorded maximum transpiration rate. Clone 22-N had top rank for photosynthesis rate and G-48 was at the bottom. On basis of wood traits, clones WSL-29 (0.936 mm) recorded the statistically highest value for fiber length whereas minimum value was noticed in clone S₇C₈. Wood specific gravity varied from 0.383 to 0.498) with top rank of clone L-290 and lowest value in case of clone S₇C₂₀. During 1st year, clones L-290/84, 40-N and WSL-29 experienced lower disease incidence, and clones L-17/92, WSL-29, Ranikhet, L-290/84, 22-N, 40-N, S₇C₈, L-247/84 and L-48/89 were relatively tolerant clones during 2nd year study. There was no significant difference among clones for defoliators and leaf webber. Growth traits were positively and significantly correlated with all leaf traits except stomata number but non significant and negatively correlated with stomatal density and chlorophyll content respectively. Height showed the highest value for broad sense heritability and maximum value for phenotypic coefficient, genotypic coefficient of variation and genetic advance. On basis of index score based on growth, biomass and disease incidence, clones 20-N, L-7/87, L-247/84, WSL-22, S₇C₈ and L-48/89 were superior clones.

Keywords: *Populus deltoides*

PPI.2.28. Standardization of macropropagation protocol of Eucalyptus clones under sub-tropical condition of Punjab

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Eucalyptus is used for agroforestry/social forestry/urban forestry and plantations and has been planted extensively owing to its fast growth and short rotation for various end uses. Macro-propagation has the potential to provide very high multiplication rates of selected tree genotypes, with resulting short-term silvicultural gains. The poor root growth of certain clones by using conventional cuttings is a major constraint to cloning, and has been attributed to the maturation degree of the plant material; therefore, the present study has been planned to standardize the macro-propagation protocol of few commercial clones in sub-tropical condition of Punjab. The cuttings of three genotypes (C-316, C-413 and C-288) were treated three hormones viz., IBA, IAA and NAA at different concentrations viz., 1000 ppm, 1500 ppm, 2000 ppm. IBA @ 4000 ppm and 5000 ppm were also used to evaluate the effect of different

hormones on the root growth of cuttings at Department of Forestry and Natural Resources at Punjab Agricultural University, Ludhiana (India). Significant differences were found among the clones and hormonal treatments for rooting percentage, number of roots and total root length. Rooting percentage was significantly higher in C-316, whereas, number of roots and total root length were higher in C-413. Rooting success in C-288 was 33 per cent, whereas, number of roots and total root length was approximately 1/3rd of the C-413. Highest rooting percentage was recorded in IBA @ 4000 ppm, whereas, highest number of roots and total root length were recorded in IBA @ 5000 ppm in all clones. Rooting success was lesser in untreated cuttings than treated cuttings. These differences were more noticeable in clones with low rooting ability in C-288, possibly due to the effect of “rejuvenation” of the clones with the use of macro-cuttings techniques.

Keywords: *Eucalyptus clones, growth hormones, macropropagation, root growth*

PP1.2.29. Performance of tuber medicinal crops under Sapota-Jatropha based three-tier agroforestry system

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Newly established forest plantations can be intercropped with medicinal plants similar to food crops until the trees cover the ground. The participation of the local people with the right to share benefits of the plantations, especially ownership to crops, has helped governments establish plantations without conflict with the local people in many Asian countries. The same approach can be employed for the cultivation of medicinal plants in the new plantations. In the rehabilitation of degraded forest lands, participating, planning and implementation with local communities and economic benefits from an early stage onwards will ensure the commitment of the people. The intensity of shade experienced by the under storey medicinal plants growing in forests and tree plantation affects their growth and chemical composition. In recent years attention has focused on the diversified medicinal plant production system for maximizing utilization of resources as compared to the monoculture cropping systems. The improved use of resources results in greater total intercrop yields as compared to sole crops of the same species grown on the same area. Field experiments were conducted to find out performance of tuber medicinal crops (kalihari, kali musli & safed musli) under Sapota-Jatropha based three-tier agroforestry system at the Agronomy Farm (Block-E), ASPEE College of Horticulture and Forestry, Navsari Agricultural University, Navsari (Gujarat) during rainy season of year 2011 and 2012. The experiments were laid out in randomized block design with six treatments and four replications. Three medicinal plants viz., Kalihari (*Gloriosa superba* L.), Kali musli (*Curculigo orchoides* Gaertn) and Safed musli (*Chlorophytum borivillianum* Ker.) were selected for the present study. The observation on economic yield (q/ha) was recorded higher under sole crop of kalihari, kali musli and safed musli as compared to intercrop with Sapota-Jatropha in both the years. While, Kalihari (1.79), Kali musli (1.38) and Safed musli (1.81) when grown as intercrop gave higher economic returns as compared to sole crop in 2011 and 2012.

Keywords: *tuber, medicinal, economics*

1.3 Land reclamation: biodrainage and salinity control

PP1.3.1. Salt-affected lands threats, opportunities and technologies for production of biomass and bioenergy

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Globally increasing salinization of the environment and salinity is affecting an area of 851 million hectare responsible for as much as 10% of all agricultural output as per FAO estimates. In India, salt-affected soils occupy about 6.73 million hectare; of which 3.60 million hectare are sodic soils and this area is progressively expanding due to secondary salinization. Longterm field studies over 10-15 year periods in highly degraded alkaline and saline soils at five locations in Haryana and UP in Indo-Gangetic plains of north-west India concluded that *Acacia nilotica*, *Eucalyptus tereticornis*, *Prosopis juliflora* and *Casuarina equisetifolia* produced higher biomass, whereas *Acacia nilotica* and *Terminalia arjuna* help in better soil reclamation in terms of reduction in soil pH and electrical conductivity. These species being high biomass producing as well as salt-tolerant hold the key for successful energy plantation in barren sodic soils of Indo-Gangetic plains with possible applications in similar situations globally. Highly significant regression relationships of biomass were observed with shoot girth and stem height and the developed equations are useful in making non-destructive and accurate estimates for biomass production in soils and plant species in similar situations in other parts of world. These studies provide useful data to establish the relationship between growth and biomass using these tolerant species with potential sustainable and long-term benefits in terms of C-sequestration and improving soil, water and climate. Estimates show that slightly and moderately salt-affected areas have large potential in terms of biomass and bioenergy production as compared to highly and extremely salt areas. Use of proper species, planting techniques and agromanagement in an integrated manner can optimize the productivity and economic contributions with additional environmental and climate benefits.

Keywords: *bioenergy, biomass production, Prosopis, salt-affected lands*

PP1.3.2. Transforming mined out degraded lands to silvopastures through ecological restoration: an attempt by a coal mining industry

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Much of the coal mining in Jharia Coalfield is done by Bharat Coking Coal Limited (BCCL), a subsidiary company of Coal India Limited (CIL), a public sector enterprise. Jharia coalfield (JCF) is located in Dhanbad district of Jharkhand state. Mining was carried out by the erstwhile private mine owners for more than 100 years with the sole motto of profit-making without any regard to safety, conservation and environment. Such a type of ‘slaughter mining’ in the JCF over a long period resulted in severe land degradation, subsidence, mine fires and other socioenvironmental problems. This led to the nationalization of coal mines in 1971-1973.

BCCL has been carrying out monoculture, single-tier afforestation over large tracts of degraded lands through the forest department for more than 30 years. Now with the guidance of Forest Research Institute (FRI), Dehradun and Centre for Environmental Management of Degraded Ecosystems (CEMDE) at University of Delhi, BCCL has started ecological restoration of all mined out and degraded lands. The

restoration work consists of 3-tier plantations by introducing native species and grasses to cater to the needs of the local community and bring back the degraded landscape to its original forest cover, focusing on biodiversity of flora and fauna as well. One of the main objectives being covering the ground with different grasses that can be used as fodder for the livestock of the surrounding villagers, thereby transforming the mined out and severely degraded coal mining areas into silvopastures. Grass species like *Heteropogon*, *Chrysopogon*, *Dichanthium*, *Eragrostis*, *Cenchrus*, etc and native tree species like *Albizia*, *Butea*, *Bamboos*, *Dalbergia*, *Zizyphus*, *Emblica*, *Cassia*, *Vitex*, *Adhatoda*, etc. have been introduced in the mined out and severely degraded coal mining areas. This is a challenging and unique attempt to restore degraded mining areas by any coal mining industry and the results are encouraging.

Keywords: *land degradation, ecological restoration, silvopastures*

PP1.3.3. Bioreclamation of salt-affected soil through Terminalia arjuna and Dendrocalamus strictus plantation model

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Plantation on salt-affected degraded lands is one of most desired strategies for rehabilitation and restoration of wastelands in productive land use system. With this approach, arjuna (*Terminalia arjuna*) and bamboo (*Dendrocalamus strictus*) were established in a R B D trial on degraded sodic barren land at Banthra Research Station of CSIR-NBRI, Lucknow. Bioreclamation through afforestation is a slow process and therefore it was assessed at 15, 30 and 45 years of tree growth with a comparison from the adjacent unplanted barren control site. It is observed that bamboo has ameliorated the sodic soil more efficiently compared to arjuna as evidenced by more reduction in (pH, EC and exchangeable Na⁺) and enrichment in soil fertility components (OC, N, P & K contents). The total CaCO₃ has decreased whereas active CaCO₃ proportion increased in the soil under plantation simultaneously from control, correspondingly as a result of afforestation by both the species. Similarly bulk density has decreased and water holding capacity and porosity increased in the soil of a planted site compared to the control (unplanted) site. Micronutrients (Cu, Fe, Zn & Mn) have also showed elevated concentration in planted soil from the unplanted soil. Overall, soil amelioration index was greater in surface soil (0-15 cm) compared to deeper depth (15-30 cm). Both arjuna and bamboo are suitable for bioreclamation of sodic soils, but arjuna may be preferred for waterlogged soils due to its relatively good adaptability to survive in temporary waterlogged conditions.

Keywords: *sodic soil, degraded lands, plantation, afforestation, terminalia, bamboo, fertility index*

PP1.3.4. Response of selected indigenous dryland agroforestry tree species to salinity and their implication to soil fertility management

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Salt-tolerant indigenous plants are known for salinity mitigation and removal of soluble salts from salt-affected soils. The research was conducted to study the response of *Acacia tortilis*, *Balanites aegyptiaca* and *Tamarindus indica* to salinity and their implication to soil fertility management. Three experiments were conducted: germination test in laboratory, seedling performances in a Lath house, and multipurpose trees' effect on soil productivity index at field condition. A mixture of salts composed of chlorides and sulfates of Na, K, Ca, and Mg were prepared at a ratio of 3:3:1:1 for chlorides and 1:1:1:1 for sulphates in order to maintain five treatment levels and five replicates of 4.1, 6.2, 8.1, 10.2 and 12.2 dS/m for the germination and lath house experiments. A randomized complete block experimental design was used. Seedling root collar diameter and height were measured at two weeks interval. Soil samples were collected from randomly selected pots to examine the effect of salinity on soil properties. The tree species contribution to soil productivity enhancement were studied by collecting 72 soil samples at different radii and soil depth. The soil productivity index was computed. There was a significant decrease in the final germination percent and germination rate with increased salt concentration ($p < 0.05$). The effects of the three species on soil properties were significantly different at 12 dS/m salinity level than control soil. The tree species had a significant effect on soil productivity enhancement. *Acacia tortilis* was the least salt sensitive followed by *Balanites aegyptiaca* and *Tamarindus indica*. The tree species could be integrated as a parkland agroforestry system or in irrigated fields to mitigate the problem of salinization and increase productivity of salt-affected soils.

Keywords: Germination, productivity index, *Balanites aegyptiaca*, *Acacia tortilis*,

PP1.3.5. Transforming mined out degraded lands to silvopastures through ecological restoration: attempt by a coal mining industry

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Keywords: land degradation, ecological restoration, silvopastures

1.4 Drylands agroforestry

PP1.4.1. Effect of NPK fertilizers on Cymbopogon flexuosus under Dalbergia sissoo based agroforestry system in Entisols

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In Chhattisgarh almost each block has 20 percent uplands of entisols and classified marginal wasteland. This upland was used to cultivate *Dalbergia sissoo* at 5 x 5 m spacing with intercrop of *Cymbopogon flexuosus* (Lemon grass) as rainfed farming. The application of 30 kg N, 20 kg P & K per ha in two equal split doses in form of eight treatments viz; T₁-N₀P₀K₀, T₂-N₃₀P₀K₀, T₃-N₀P₂₀K₀, T₄-N₀P₀K₂₀, T₅-N₃₀P₂₀K₀, T₆-N₃₀P₀K₂₀, T₇-N₀P₂₀K₂₀ and T₈-N₃₀P₂₀K₂₀. *C.flexuosus* was cut in September, December and February in two consequent years.

Application of NPK enhanced the performance of *C.flexuosus*, but application of single fertilizer was not as effective as combinations. The presence of Potash was more significant. Effect of fertilizers on *C.flexuosus* for proliferation of clump, biomass and oil yield were found statistically significant at all the three cut in both years with variations in order of T₈ > T₆ > T₅ > T₇ > T₂ > T₄ > T₃ > T₁.

The dry matter yield was more during the 2nd year than the 1st year, where it was recorded at 1st cut which gradually decreased in 2nd and 3rd cut. A similar trend was observed for oil production with statistical significant variations, where it ranged from 112 to 156; 31.3 to 54; and 13.1 to 32.3kg ha⁻¹ for 1st, 2nd and 3rd cut respectively in the 1st year, while 48.4 to 67.6; 50.1 to 62.9 and 36.8 to 46.9kg ha⁻¹ for 1st, 2nd and 3rd cut respectively in the 2nd year.

Application of fertilizers also played a statistically significant role in the growth performance of *D.sissoo* as well as improvement of the soil.

Keywords: *Cymbopogon flexuosus*, *Dalbergia sissoo*, entisols

PP1.4.2. Agroforestry and energy security: corporate, NGO and academic collaborative initiatives

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Fuelwood production and energy security of the nation are closely interlinked, since majority of the rural Indian population is still dependent on fuelwood as a major source of energy. The annual consumption of fuelwood in India is estimated to be around 306.50 million m³. Growing trees on farmlands, which combines food production and wood production, could be the best option to meet the fuelwood requirement of farming communities. To promote agroforestry in the Mysore region of Karnataka, India, to meet the energy requirement of the farming community, ITC Limited, in collaboration with MYRADA, an NGO and the College of Forestry, Ponnampet (University of Agricultural Sciences, Bangalore), initiated the process of developing suitable agroforestry models for

different cropping situations through identification of best performing clones of fast growing fuelwood-yielding tree species and development of appropriate agroforestry models with the selected species. A preliminary survey with some of the progressive farmers in the region was carried out and based on the discussion, eucalyptus was the preferred species from the point of growth and its ability to withstand drought and harsh conditions. To identify best performing clones of eucalypts for the region, clonal trial was established and growth performances of different clones are being monitored. To identify the suitable spacing for introduction of trees on farmland for different agricultural crops in the region, spacing trials of 8.5 m x 1.5 m, 8.5 m x 1 m, 6.5 m x 1.5 m, 6.5 m x 1 m, and 3 m x 1 m spacing have been established at two locations. To understand tree-crop interaction, important soil parameters and agricultural crops are being assessed annually along with the growth performance of the tree species.

Keywords: *energy security, clonal trial, spacing, soil property and growth*

PP1.4.3. Performance of some intercrops under *Dendrocalamus strictus*-based agroforestry system in rainfed upland

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The performance of some intercrops under the *Dendrocalamus strictus* (male bamboo) based agroforestry system in rainfed upland was studied during 2008-2011 at Orissa University of Agriculture and Technology, Bhubaneswar, India. The bamboo clumps were grown at two spacings e.g. 10 m x 10 m and 12 m x 10 m. Different intercrops were raised with bamboo and without bamboo such as sesamum, cowpea, blackgram and greengram in 'kharif' and 'toria', sunflower, blackgram, greengram and horsegram in 'rabi' season. In such rainfed upland situation, rabi crops suffered from moisture stress during flowering and fruiting time and were found not suitable. However, the kharif crops were found remunerative under bamboo-based agroforestry system although the yield reduced gradually with increase in the age of bamboo clumps under bamboo than pure crop. The yield of intercrops under 10 m x 10 m spacing were at par with 12 m x 10 m spacing. In the 1st year kharif and sesamum recorded a seed yield of 5.35 q/ha in sole crop; and 5.20 q/ha and 5.30 q/ha as intercrop under 10 m x 10 m and 12 m x 10 m spacing of bamboo, respectively. In the 2nd year kharif, cowpea resulted in a green pod yield of 18.92 q/ha in pure crop while 17.21-17.48 q/ha with bamboo. Blackgram recorded maximum grain yield of 5.62q/ha in pure crop while greengram recorded minimum grain yield of 3.99 q/ha with bamboo having spacing 10 m x 10 m. In the 3rd year kharif, the cowpea as pure crop yielded maximum seed yield (5.81 q/ha) and greengram yielded the minimum (3.88 q/ha) under bamboo 10 m x 10 m spacing. The highest net return (INR 9787/ha) was obtained under blackgram with bamboo 10 m x 10 m spacing and minimum net return (INR 3248/ha) was found under greengram as pure crop. The growth and development of bamboo clumps were significantly higher with intercrops than pure plantations. *Dendrocalamus strictus* with blackgram in kharif was found to be the best agroforestry system among the systems studied followed by bamboo+greengram, bamboo+sesamum and bamboo+cowpea under 10 mx10 m spacing.

Keywords: *Dendrocalamus, agroforestry, bamboo, blackgram*

PP1.4.4. Soil improvement by organic inputs of an agroforestry system in an arid zone of India

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Extensive agroforestry is a traditional way of farming in Thar Desert of Western Rajasthan. It is time-tested to sustain human and animal populations albeit marginally against harsh climate and impoverished soil conditions. Use of purchased chemicals is negligible in existing system and farmers mainly use local natural resources for various purposes including soil fertility buildup. Recent studies have however revealed weakening of a woody component in the system due to redundant exploitation and indicated need to strengthen it. We at CAZRI, Jodhpur, established in an experimental farm (26°18'N and 73.01'E) an agroforestry system with objectives to improve soil, productivity and woody component using organic inputs only. Some relevant experimental details are: soil—sandy loam belonging to Pal series; woody MPTs—*Ziziphus rotundifolia* and *Azadirachta indica* in rows; crop rotation—pearlmillet-cluster bean in the inter-space of tree rows; organic inputs—0, 2.5 & 5.0 t compost⁻¹ ha⁻¹ yr⁻¹ in crop, and 0.0 & 5.0 kg compost in 1.0 m diameter pit yr⁻¹ in trees. Varied quantities of neem cake were also applied in soil, primarily to control termites. At the end of the sixth crop cycle, various soil parameters were measured in surface soil. Crop and tree productivity parameters were also observed.

Results have revealed that organic inputs benefited the soil and enhanced the productivity of the crops and trees. The magnitude of these benefits, however, varied with the rate of inputs and vegetation. For example, for 0, 2.5 & 5.0 t compost ha⁻¹ yr⁻¹ soil organic carbon was 0.15, 0.17 & 0.21%, and hydraulic conductivity 3.34, 3.54 & 5.44 cm hr⁻¹ respectively. Organic carbon for control and compost application was 0.16 and 0.23% under *Ziziphus rotundifolia*, and 0.15 and 0.23% under *Azadirachta indica*, respectively. Successful establishment of *Ziziphus rotundifolia* and *Azadirachta indica* indicated that these MPTs can be used for intensification of woody component in the region.

Keywords: agroforestry, soil, inputs

PP1.4.5. *Ailanthus excelsa* Roxb: a potential tree species for short rotation agroforestry in semi-arid tropics

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A field experiment was initiated in 1999 to study the growth performance of few multipurpose tree species for studying their suitability under short rotation agroforestry in semi-arid tropics. Accordingly four fast-growing tree species namely *Ailanthus excelsa* (Maharukh), *Azadirachta indica* (kaduneem), *Acacia alida* and *Tectona grandis* (teak) were planted at 5 x 5 meter spacing under agrisilviculture system. Investigations have revealed that *Ailanthus excelsa* has attained maximum growth compared to other tree species under study. The height of *Ailanthus excelsa* was maximum (8.27 m) and diameter at breast height was maximum (18.69 cm) among other tree species under study. *Ailanthus excelsa* has produced maximum total wood (0.169 cum/tree) and industrial wood (0.1014 cum/tree). In all respects *Ailanthus excelsa* has proved superior among other tree species under study. The benefit cost ratio of *A. excelsa* based-agroforestry system was worked out to be 1: 4.77 beside intangible ecological benefits.

Keywords: agrisilviculture, *Ailanthus excelsa*, short rotation, forestry, wood volume

PP1.4.6. Anna Pratha and agroforestry development in Bundelkhand and Diara land of Indo-Gangetic plains of India

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Anna Pratha refers to a cattle rearing custom in which cattle are let loose during the rainy season (July-October) for free grazing. This system is common in the Bundelkhand region of India and Diara lands of Indo-Gangetic plains where rainy crop is either restricted to small well-protected areas or uncommon. Such areas are mostly single cropped during the winter season. Developing agroforestry in such lands holds great promise for drought proofing, risk partitioning, restoring ecobalance and enhancing biomass productivity. But cattle menace poses the greatest threat. Early efforts to develop agrihorticulture landuse on such lands registered meagre success. However, plants like *Tectona grandis*, *Bambusa vulgaris* and *Acacia senegal* which can withstand high biotic pressure showed high success under agroforestry system on farmers' fields in the Bundelkhand region. *Dalbergia sissoo*, *Butea monosperma* and *Acacia nilotica* are other promising species that need to be promoted on such lands on account of their non-browsable nature, high coppicing ability and hardiness to moisture stress. They are medium fast in growth, good coppicer and quite hardy. The sapling grows over a year to form visible juvenile plants. All these species have a high demand in the local market for fuelwood, timber, housing, small agricultural equipment and gum extraction. However, fruit plants showed high survival in home gardens of small and marginal farmers while those on crop lands could not survive beyond two years due to lack of protection. The study concludes that small and marginal farmers and farm labourers should be encouraged for fruit plantation in their homestead for nutritional security while small to big land holding farmers should be encouraged to plant above species on boundaries and field bunds. Average tree density of 11.0 trees/ha in Bundelkhand region where *Zizyphus mauritiana* and *Butea monosperma* dominate, inclusion of the above suggested species can potentially increase the area under agroforestry.

Keywords: Anna Pratha, biotic pressure, Bundelkhand, Diara lands

PP1.4.7. Biochar derived from crop and tree residues can revitalize drylands in India

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Thermo-chemical conversion of residues to biochar, a carbonaceous solid, is a valuable input for enhancing moisture retention and carbon sequestration which have potential to enhance crop yields in drylands. Field experiments were conducted over three years to study the multiyear application of castor (*Ricinus communis*), cotton (*Gossypium herbaceum*), pigeonpea (*Cajanus cajan*), biochar on pigeonpea crop (PRG 158) and soil water retention in a dryland Alfisol. Three biochar amendments (castor, cotton and pigeonpea biochar) were evaluated @ 0.0 t/ha, 3.0 t/ha and 6.0 t/ha in combination with the recommended dose of fertilizer (RDF) at every year and alternate year application schedule. On-farm portable kiln was developed and residues were subjected to thermo-chemical conversion at different loading rates and holding time. Volatile matter content decreased, whereas fixed carbon and ash content increased in biochar with increase in temperature. Biochar yield decreased with increasing temperature. The highest conversion efficiency of 29, 24, 27 and 35% with total carbon of 51, 56, 65 and 71% were obtained for maize, castor, cotton and pigeonpea residues, respectively.

Alternate year application of pigeonpea biochar @ 6.0 t/ha supplemented with RDF produced significantly higher pigeonpea grain yield (3.0 t/ha) compared to control (0.6 t/ha). Biochar of pigeonpea, cotton and castor applied @ 6.0 t/ha supplemented with RDF increased soil water holding capacity by 36, 35 and 29%, respectively over control. It can be concluded that biochar production is a feasible option to promote reutilization of crop and tree residues even by smallholders to enhance carbon sink and yields of dryland crops.

Crop (maize, castor, cotton and pigeonpea) and tree residues generation from drylands is estimated to be 0.36 Pg yr^{-1} . Indian paper industry in the last five years has promoted 300 000 ha of *Eucalyptus*, *Leucaena*, *Acacia* and *Casuarina* plantations which could generate logging residues to the tune of 0.001 Pg C at the felling cycle of four years. A total of 0.079 Pg yr^{-1} amount of biochar C from harvestable crop and logging residues could potentially be sequestered in soils.

Keywords: Biochar production, crop and tree residues, moisture retention and crop yield, portable kiln

PP1.4.8. Soil moisture dynamics and nutrient depletion pattern in agrisilvicultural systems

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Soil productivity can be improved by integration of tree species with intercrops because trees can take up nutrients and water from the deeper layers which otherwise cannot be utilized by intercrops. Thus a field experiment was done during 2009 to 2012 to study the soil moisture dynamics and nutrient depletion pattern of agrisilvicultural systems in rainfed uplands at an agroforestry research farm, Bhubaneswar, Odisha, India. The soil of the experimental site was sandy loam, mixed isohyperthermic forms of Typic Haplustult (Alfisol) with pH varying from 5.15 to 4.36, organic carbon 4.16 to 4.0 g kg⁻¹, bulk density 1.52 to 1.63 g cm⁻³, CEC 3.6 to 4.4 me 100g⁻¹ and base saturation 35-43%. Available N, P and K vary from 150.4 to 175.8, 9.11 to 48.27 and 92.2 to 211.9 kg ha⁻¹ respectively. After cessation of monsoon rainfall during October, available soil moisture content at different depth of soil profile was found to be lower with *Acacia mangium* and higher with *Gmelina arborea* based systems. This corroborates competitiveness of *Acacia mangium* as it drew more water from the profile due to its elongated root system and maintained its rapid growth compared to *Gmelina arborea*. Among intercrops, minimum soil moisture content was observed with kalmegh and maximum with pineapple. Pineapple was found to be more exhaustive for N, aloe vera for P and kalmegh for K and this trend was similar with both the tree species grown. Organic carbon in this system varied from 3.1 g kg⁻¹ in *Gmelina arborea* + mango ginger to 5.7 g kg⁻¹ in *Acacia mangium* + aloe vera systems. Soil fertility was either maintained or improved due to agroforestry intervention.

Keywords: agrisilvicultural systems, nutrient depletion, rainfed uplands, soil moisture

PP1.4.9. Traditional agroforestry is a basis of sustainability in arid zones: examples from western Rajasthan

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The hot arid regions of India cover an area of 31.70 million ha of which 61% is located in the state of Rajasthan. There are sparsely distributed trees and undergrowth of arable crops and grasses in between shrubby vegetation in long stretches interspersed with distantly distributed village settlements and *dhanis* (a settlement pattern of the arid western Rajasthan intended for the life of agriculturists' families during the active cropping period away from the village, but nearby their fields) are unique features of western Rajasthan. In fragile ecosystems of hot arid regions of Rajasthan, agriculture alone cannot be a dependable enterprise, hence desert dwellers with their traditional wisdom have integrated forestry into their farming since ages in order to confer stability and generate assured income. These combined protective-productive systems of integration of trees into farming systems are rooted in the principles of ecology, productivity, economics and sustainability of the region. In fact, traditional agroforestry providing basic needs of rural folk is the way of life in arid western Rajasthan which appears to evolve on the basis of rainfall gradient. There are four major kinds of traditional agroforestry systems namely *Zizyphus mauritiana* - *Prosopis cineraria* - *Acacia senegal* - *Salvadora* spp. based in areas of <200 mm rainfall; *Zizyphus mauritiana* - *P. cineraria* based in areas of 200-300 mm rainfall; *P. cineraria* based in areas of 300-400 mm rainfall and *P. cineraria* - *A. nilotica* based in areas of >400 mm rainfall. All these trees scattered on agricultural fields in arid regions of western Rajasthan are multipurpose in nature (particularly *P. cineraria*) and they have the ability to satisfy the expectations and aspirations of rural folk providing options for improvement in livelihoods through simultaneous production of food, fodder and firewood as well as maintaining microclimate in current situation of climate change. There are many more pathways through which agroforestry qualifies to be the basis of sustainability in the region since time immemorial.

Keywords: *Acacia senegal*, *Prosopis cineraria*, traditional agroforestry systems, *Zizyphus mauritiana*

PP1.4.10. Response of pruning and nutrient application on fruit and fodder yields of *Zizyphus mauritiana* Lamk. in hot arid India

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Ber (*Zizyphus mauritiana* Lamk.) belongs to family Rhamnaceae and is an important fruit species suitable for rainfed areas due to its adaptation to hot arid environment. It is cultivated for fresh fruits, rich in vitamins A, B complex and C. This makes it the poor man's fruit. During lean periods (April-May), it provides fodder (pala) containing 12 percent crude protein. It is suitable for making hay and silage for small ruminants and also used as fuelwood. A field experiment was carried out in the Farmer Participatory Research Programme for three years during 2008-2009 to 2010-2011 to assess the effects of different times of pruning (P₁:15th May, P₂:30th May, P₃:15th June and P₄:30th June) and nutrient management treatments (N₁:control; N₂:500 g N + 500 g P₂O₅ + 250 g K₂O; N₃:1000 g N + 750 g P₂O₅ + 500 g K₂O; and N₄:1500 g N + 1000 g P₂O₅ + 750 g K₂O per tree) on fruit and fodder yield of 10 year established orchard of *Ber* cv Gola at Geegasar village of Bikaner district.

The pruning at 30th May and 15th June recorded 30.9 and 39.6% higher fruit yield compared to pruning at 15th May, respectively.

Nutrient management treatments N₁, N₃ and N₄ recorded 27.7, 43.2 and 52.7% higher fruit yield than control (N₁). The combination of 15th June pruning with N₂ gave highest fruit yield. The fodder yields

decreased with delaying pruning *i.e.* at 30th May, 15th June and 30th June yielded 13.4, 23.1 and 34.9% less than 15th May's pruning. The application of N₂, N₃ and N₄ recorded 15.7, 41.9 and 48.9% higher fodder yields than control (N₁). Treatment comprised 15th May's pruning and application of N₁ gave the 8-150 percent higher fodder yield in comparison to other treatment combinations. Early pruning and high dose of nutrient provides more vegetative growth which resulted in higher fodder yield.

Keywords: *pruning, nutrient, fodder, Ber*

PP1.4.11. Enhancing forage production through silvipastoral system in arid regions

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Livestock-based farming system makes significant contribution for livelihood security of farmers in the arid zones of India. However, availability of fodder for livestock is not sufficient due to water scarcity and land degradation leading to low productivity of grazing land. The arid zones are less suitable for crop production due to inherent soil constraints like low water retentivity, sandy texture, shallow depth, and occurrence of rocks and stones. However some grasses and tree species of forage value and economic importance can grow well and help in augmenting forage production. Silviculture offers a sustainable land use system which increases overall productivity of land and makes efficient utilisation of natural resources. Participatory on farm trial was conducted from 2011 to 2013 at Harsolav village of Nagaur district, Rajasthan to assess suitability and production potential of pasture grasses viz. *Cenchrus ciliaris* and *Cenchrus setigerus* in association with different fodder trees. The intervention was undertaken on 6 ha common grazing land of Gaushala at Harsolav village in collaboration with Gramin Vikas Trust. Trees saplings of *Zizyphus nummularia*, *Acacia tortilis*, *Azadirachta indica* and *Prosopis cineraria* were planted at 5 x 4 m, 6 x 6 m, 8 x 5 m, 3 x 4 m, spacing respectively and grasses were sown in inter space between tree rows and in pastureland without trees. The growth and survival of tree species varied. The maximum plant height (165 cm) and survival percent (87%) was recorded in *Acacia tortilis* while plant height (49 cm) and survival percent (40%) of *Prosopis cineraria* was the lowest. The growth and yield of grasses did not vary with trees species at initial stages of tree growth. Dry forage yield of grasses in silvipasture (1.41 t/ha) was higher compared to natural pasture (0.65 t/ha) but less than pure pasture of *C. ciliaris* (2.12 t/ha) and *C. setigerus* (1.98 t/ha). The differences in forage yield of *C. ciliaris* and *C. setigerus* was found more or less similar. The developed model is used as a demonstration unit for training of farmers and upscaling the technology in the surrounding area.

Keywords: *trees, grasses, arid region*

PP1.4.12. Potential of biodiesel plantations in drylands of South India: experiences

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The on-farm experiments involving *Jatropha curcas* were conducted in farmers' fields during 2005-2010 in 69 acres in three districts of Andhra Pradesh, India. Mostly degraded/wastelands belonging to small, medium and large farmers with and without irrigation facilities were selected for field trials. The major criterion for selection of the farmers was their willingness to stay with the project at least for five years (duration of the project). The study was conducted with three levels each of irrigation,

nutrition, and pruning; and four levels of spacings. The soils of these sites are shallow, gravelly and marginal in fertility with low water holding capacity. The average annual rainfall of Nalgonda and Mahabubnagar is around 650 mm while that of Anantapur is 510 mm. In all the three districts the programme was implemented with the support of the District Water Management Agency/NGOs. The wider spacing (3 x 2 m or 4 x 2 m) enabled intercropping, partial mechanization, and response to irrigation in jatropha. Irrigation at 30% of evapo-transpiration level in combination with N and P at 45 g and 100 g per plant gave better results. The capsule-bearing bunches were more when the plants were pruned at 45 cm or 60 cm height. In order to provide immediate income to the farmer besides improving soil fertility, legume intercropping with pigeonpea, blackgram and horsegram was successfully taken up. Farmers were disappointed with the low levels of yields of jatropha seed (0.5 – 0.8 t/ha) even after five years because of non-availability of promising variety/selection and no immediate buyers for the harvested seed in the vicinity. As a result most of the farmers uprooted biodiesel plantations and went for traditional crops which they cultivated earlier or other profitable horticultural species.

Keywords: *degraded lands, intercropping, Jatropha curcas, on-farm*

PP1.4.13. Agroforestry for sustaining rural livelihoods in hot arid areas in India

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Agroforestry is of paramount importance in arid regions where crop production is very insecure due to variable and harsh climatic conditions. It offers security to inhabitants and their animals during famines and droughts which occur frequently in arid areas, in addition to providing food, fodder, fuel, timber and various other products of daily use. Agroforestry can mitigate the impact and consequences of the harsh climatic conditions of arid areas. It provides support to the farming system by conferring stability and generating assured income since agriculture alone is not a secure activity in the famine-prone fragile arid ecosystem. Agroforestry assumes significance in maximising production on the basis of sustained land management. Some existing agroforestry models in arid areas of Rajasthan state in India are described and suggested methods of improvement are presented in this contribution. Further, soil enrichment, nutrients from tree species, and the crop yield in various agroforestry models are also discussed.

Keywords: *agroforestry, arid land, livelihood, Rajasthan, India*

PP1.4.14. Soil quality under Grewia optiva-based agroforestry system in Doon Valley of Western Himalayas

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Grewia optiva Drummond is an important agroforestry tree species widely grown in north western Himalayas for fodder, fuelwood and fibre. To assess the impact of *G. optiva*-based agroforestry system on soil quality, a study was conducted in a five-year experimental plot on 4% slope in Doon valley of Himalayan foothills. The experiment comprised six treatments viz. sole *G. optiva*, *G. optiva* + barnyard

millet, *G. optiva* + finger millet, barnyard millet, finger millet and fallow plot. Five functional categories (water entry to soil, water retention and transportation, resistance to physical degradation, biochemical degradation and plant growth sustenance) were assessed using seven soil parameters viz., organic carbon, Total N, Extractable P, Available K, saturated hydraulic conductivity, bulk density and water stable aggregates in the top soil (0-15cm). Weights were assigned to each parameter depending on their relative importance. Mean values of original soil properties were converted into standard scores using the appropriate scoring functions. Results revealed that different soil properties showed significant difference among the various treatments. Sole *Grewia* and *G. optiva*-based agroforestry systems resulted in significantly higher OC, saturated hydraulic conductivity, total nitrogen, water stable aggregates as compared to agriculture crops (barnyard millet and finger millet) and fallow land. These soil properties when combined to assess the performance of soil functionality revealed that sole *G. optiva* had maximum score (0.50) followed by + barnyard millet and *G. optiva* + finger millet (0.47 for both treatments), barnyard millet (0.42), finger millet (0.39). Lowest value of 0.32 was observed in fallow plot. As compared to sole *G. optiva* treatment, there was 17% loss in soil quality in barnyard millet, 23% in finger millet and 34% in fallow land. Inclusion of *G. optiva* with agriculture crops checked the soil deterioration and the loss in soil quality was 7% only.

Keywords: *Grewia optiva*, soil quality, bulk density, total nitrogen, hydraulic conductivity

PP1.4.15. Effect of row spacing and mulching on production potential of maize (Zea mays L.) in guava (Psidium guajava L.) based agrihorti system under rainfed condition

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A field trial on maize with various mulches and different row spacing in guava based agrihorti system was conducted at the Agriculture Research Farm of Rajiv Gandhi South Campus, Banaras Hindu University, Barkachha Mirzapur, Uttar Pradesh (India) during kharif season of 2012-13 to find out its effect on the yield of maize. The experimental field is situated at 25° 10' North latitude, 82 ° 37' East longitudes, 427 meters above mean sea level in the semi-arid eastern plain zone. The field trial was conducted in the seven-year-old guava based agrihorti system under split plot design having three levels of row spacing (30cm, 45cm and 60cm) and four levels of mulching (no mulch, paddy straw mulch, green weed mulch and dust mulch). The height, girth and canopy of the tree in the seven year old guava were up to 3.15m, 21.50cm and 5.90m, respectively. The plant height of maize was found to increase with decreasing row spacing. The maximum plant height (215.06cm) was found with the application of paddy straw mulch. 60 cm row spacing produced the maximum number (2.33) of cobs plant⁻¹ which was followed by 45 cm (1.90) and 30 cm row spacing respectively. Mulching also had significant influence on the performance of maize. Maximum number of cobs plant⁻¹ and the highest cob length were found under paddy straw mulch among all the mulches. Paddy straw mulch at 60 cm row spacing produced the highest number of grains cob⁻¹ (358.07) and grain weight plant⁻¹ (64.13 g). However, the highest grain yield was obtained at 45 cm row spacing (52.21q ha⁻¹). Finally, grain yield was found to be significantly improved by mulching and the highest grain yield of maize (52.32 q ha⁻¹) was recorded with the application of paddy straw mulch and this was followed by green weed mulch (50.11 q ha⁻¹) and dust mulch (49.38 q ha⁻¹) respectively.

Keywords: agrihorti systems, guava, maize, row spacing and mulching

PP1.4.16. Agroforestry and Energy security: Corporate, NGO and Academic collaborative initiatives

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Fuel wood production and energy security of the nation are closely interlinked since majority of rural Indian population is still dependent on fuel wood as major source of energy. The annual consumption of fuel-wood in India is estimated to be around 306.50 million m³. Growing trees on farmlands, which combines food production and wood production, could be the best option to meet the fuel wood requirement of farming communities. To promote agroforestry in the Mysore region of Karnataka, India, to meet the energy requirement of the farming community, ITC Limited, in collaboration with MYRADA, an NGO and the College of Forestry, Ponnampet (University of Agricultural Sciences, Bangalore), has initiated the process of developing suitable agroforestry models for different cropping situations through identification of best performing clones of fast growing fuel wood yielding tree species and development of appropriate agroforestry models with the selected species. Preliminary survey with some of the progressive farmers in the region was carried out and based on the discussion; eucalyptus was the preferred species from the point of growth and its ability to withstand drought and harsh conditions. To identify best performing clones of eucalypts for the region, clonal trial was established and growth performances of different clones are being monitored. To identify the suitable spacing for introduction of trees on farm land for different agricultural crops in the region, spacing trials of 8.5 m X 1.5 m, 8.5 m X 1 m, 6.5 m X 1.5 m, 6.5 m X 1 m & 3 m X 1 m spacing have been established at two locations. To understand tree-crop interaction, important soil parameters and agricultural crops are being assessed annually along with the growth performance of the tree species.

Keywords: *energy security, clonal trial, spacing, soil property and growth*

PP1.4.17. Performance of Certain Rainfed Fodder Crops under Custard Apple Based Horti-Pastoral System on Loamy Sand Soil

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Fruit growers do not commonly utilize the interspaces between the custard apple trees, though there is ample scope to utilize the interspaces. The present experiment has been designed to assess the growth performance of fruit tree species (Custard apple) and to study the performance of intercrops and the economics of return. A total of nine treatment combinations comprising custard apple as a horticultural crop and four fodder crops viz; pearl millet, cowpea, sorghum and clusterbean were tested. The experiment was laid out in randomized block design with three replications. At the time of experimentation, the custard apple plants were 4 years old. The *kharif* drought tolerant fodder crops were sown at the onset of monsoon in respective years. There was no adverse effect of fodder crops on the growth performance of custard apple, however increased the custard apple fruit yield over sole custard apple. The green fodder yield of pearl millet, cowpea, sorghum and clusterbean were 6.07, 8.69, 0.58 and 6.56 tones ha⁻¹ in comparison to sole green fodder yield of 9.88, 10.12, 4.81 and 2.72 tones ha⁻¹, respectively. Significantly higher gross income was recorded by the combination of custard apple with cowpea (10302 Rs ha⁻¹) which was at par with sole cowpea (10123 Rs ha⁻¹) and sole pearl millet (9876 Rs ha⁻¹). The interspaces of bearing custard apple orchard may be successfully utilized by growing

fodder crops mainly fodder cowpea and pearl millet which increased the yield of custard apple and income under rainfed condition.

Keywords: custard apple, pearl millet, sorghum, cowpea, clusterbean, intercropping

2.0 South Asia Day: Climate change, multifunctionality, livestock systems and fish systems

2.1 Agroforestry for climate change mitigation and adaptation

PP2.1.1. Carbon density of *Eucalyptus deglupta* Blume in smallholder tree –based agroforestry systems in Mindanao, Philippines

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Quantifying the impact of tree component of an agroforestry system for climate change adaptation is essential to be able to better design agroforestry systems prescriptions tailored to promote climate change adaptation. The study was undertaken to assess the carbon sequestration potential of selected agroforestry systems tree component. The aboveground carbon density of *Eucalyptus deglupta* Blume was determined non-destructively using Brown and Lugo formula, “AGB (ton per tree) = volume over bark (m^3 per tree) * wood density (kg m^{-3}) * biomass expansion factor (BEF). Biomass expansion factor for *Eucalyptus deglupta* Blume was developed. Results of the study showed that as tree age increases, the tree biomass and carbon stock also increases in decreasing rate. The average aboveground biomass density of bagras under woodlot at age 2, 10 and 20 yr were 0.02, 0.68 and 1.44 Mg per tree. For alley cropping, the aboveground biomass density at age 6, 12 and 18 yr were 0.2094, 0.2209 and 0.2330 Mg per tree. On the other hand, the aboveground biomass density of bagras on boundary planting at ages 1, 10 and 20 yr were 0.4700, 1.4052 and 1.5129 Mg per tree. Comparison of the aboveground biomass accumulated by bagras from alley, boundary and woodlot relative to the abovementioned equation was in order woodlot > boundary > alley. This study explicitly showed the great potential of agroforestry in channeling its impact to the people and environment.

Keywords: agroforestry systems, carbon density, bagras, adaptation

PP2.1.2. Carbon storage potential of tea agroforestry system in Barak Valley, Assam, North East India

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The study focuses on assessment of carbon stocks in the above-ground biomass (shade trees and tea bushes), litter and soils (up to 100 cm depth) in three tea plantations of different ages; viz. 5, 13 and 21 years. The study area (Rosekandy Tea Estate) lies between 24°39'27.7"N, 92°41'46.8"E and 24°40'49.3"N, 92°39'49.9"E in Barak Valley, Assam. Above-ground biomass in shade trees was estimated using species-specific volume equations. Carbon stock was calculated by multiplying biomass with a 0.5 conversion factor. Allometric equation was developed considering diameter as an independent variable for biomass estimation in tea bushes. Carbon content in biomass of different tea

compartments, litter and soil organic carbon stock was estimated using standard methods. The carbon storage in tea agroforestry system was estimated as 140.59, 123.12 and 125.04 Mg ha⁻¹ in 5-, 13- and 21-year-old plantations. An increasing trend was observed in above-ground carbon stocks for tea bushes, shade trees and litter compartments compared to soil compartment which expressed the reverse trend. Above-ground biomass was estimated to be 32.86 ± 2.43, 40.52 ± 4.80 and 43.73 ± 5.36 Mg ha⁻¹ for 5, 13 and 21 years old plantations respectively. Tea bushes and shade trees together contribute 23.4%, 32.9% and 35% having individual share of 31% and 69% towards carbon stock allocation in 5-, 13- and 21-year-old plantations. Litter components share 0.30%, 0.50% and 0.50% carbon whereas soil compartment hosts 76.3%, 66.6% and 64.5% of total carbon stocks in 5-, 13- and 21-year-old plantations. Tea agroforestry system could contribute as a significant carbon sink having considerable amounts of carbon stocks in different compartments as a beneficial attribute for climate change mitigation.

Keywords: Above-ground biomass, carbon stock, soil organic carbon, tea agroforestry

PP2.1.3. Carbon sequestration potential of agroforestry practices in the mid hills of central Himalaya

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Himalayan region has a long tradition of agroforestry, several indigenous agroforestry systems based on people's needs and site-specific characteristics have been developed over the years. Agroforestry practices have attractive, wide and promising potential to store carbon and remove atmospheric carbon dioxide through enhanced growth of trees. The study was conducted at experimental farm Hawalbagh (29° 36' N and 79° 40' E, 1250 m amsl) of Vivekananda Parvatiya Krishi Anusandhan Sansthan, Almora, India. In this study, to assess above-ground biomass, trees for height and diameter at breast height were measured and biomass×0.45 equation followed to assess the carbon stock in different agroforestry practices. Tree density of *Carya illinoensis* (Pecan nut) was 238 trees ha⁻¹ and the total of 21.90 Mg C ha⁻¹ was stored in the pecan nut stem biomass in pecan nut-based agrihorti system. The density of fruit trees viz., *Citrus lemon* (lemon), *Prunus domestica* (plum), *Pyrus ommunis* (pear) and *Prunus armeniaca* (apricot) was 277 trees ha⁻¹ and it was found that carbon stock in pear was highest (12.7 Mg ha⁻¹) followed by apricot (7.33 Mg ha⁻¹), plum (5.78 Mg ha⁻¹) and lemon (3.79 Mg ha⁻¹) in fruit based agrihorti system. The carbon stock of high density (1m x 1m) plantation of *Quercus leucotrichophora* (oak) was measured and found carbon stock of oak in energy plantation system could be 17.55 Mg carbon per hectare per year. Co₂ equivalent carbon was 80.03 Mg C ha⁻¹ for pecan nut, 46.61 Mg C ha⁻¹ for pear, 26.90 Mg C ha⁻¹ for apricot, 21.20 Mg C ha⁻¹ for plum and 13.91 Mg C ha⁻¹ for lemon in pecan nut and fruit-based agrihorti systems, respectively. Thus, agroforestry systems are not only remunerative to the farmers but also contribute towards tapping of atmospheric Co₂ vis-à-vis mitigation of green house gases.

Keywords: agroforetry, carbon sequestration, high density plantation, Himalaya

PP2.1.4. Carbon sequestration potential of teak plantations of different agroclimatic zones and age-gradations of Southern India

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Carbon sequestration potential of teak plantations in different agroclimatic zones of southern India, viz. Northern Dry Zone, Northern Transition Zone, and Hilly Zone were studied. Teak plantations belonging to three age gradations viz. 10, 15 and 20 years were considered for the study. Above-ground biomass was computed based on volume estimation and wood density after considering three 10 x 10 m plots. Carbon sequestration potential of teak plantations on farmlands differed significantly with respect to agroclimatic zones and age. Teak plantations raised on the farmlands of Northern Transition Zone had significantly higher above-ground biomass than that in Northern Dry Zone and Hilly Zone at all the three age-gradations. Consequently, total above-ground carbon sequestered was also significantly higher among the teak plantations of the Northern Transition Zone (247.47 t/ha) than that in Hilly Zone (157.60 t/ha) and NDZ (103.73 t/ha). For obvious reasons the total amount of carbon sequestered was significantly higher in 20-year plantations (330.00 t/ha) than in 15-year (108.53 t/ha) and 10-year plantations (70.27 t/ha). Perhaps the optimal average annual rainfall of 749 mm and the medium black soil in Northern Transition Zone have contributed to the higher biomass in teak. Poor rainfall in Northern Dry Zone (<585 mm) and poor soil conditions (lateritic formations) in Hilly Zone must have contributed to the poorer growth of teak in these zones.

Keywords: age-gradations, agro-climatic zones, carbon sequestration, teak

PP2.1.5. Atmospheric CO₂ capture and photochemical efficiency determined adaptive potential of *Pongamia pinnata* to climate change

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Progressively rising atmospheric CO₂ is one of the crucial factors of global climate change that moderates growth, development and productivity of plants including trees. The increase in atmospheric CO₂ is of more concern for C₃ plants especially the perennials of agroforestry importance in the context of the rise in temperature and situations like water deficit, drought and atmospheric dryness. To make agroforestry the most suitable alternate land-use system for climate resilient agriculture, it is becoming essential to evaluate and select important tree species with higher climate change resilient potentials. With this aim, we conducted field experiments to assess the CO₂ capture potential of *Pongamia pinnata* (L.) Pierre trees and to delineate the photochemical efficiency in the context of atmospheric dryness. For this we have used advanced simultaneous measurement of gas exchange and chlorophyll fluorescence techniques to estimate the CO₂ assimilation, transpiration, water use efficiency and photochemical efficiency through analysing photochemistry of Photosystem-II comprehensively in clonal plants (plants grown in fields raising from mass propagation i.e. stem cutting technique) and seedling of *Pongamia pinnata* trees. During the post-monsoon period, photosynthetic photon flux density (PPFD) saturated rate of CO₂ assimilation (A_{max}PPFD) was in the range of 20 to 25 μ mole m⁻²s⁻¹. During the very hot summer season (the daily maximum temperature hovers around 42°C), matured leaves of clonal plants of *Pongamia pinnata* maintained considerably higher rate of A_{max}PPFD than seedling plants. During prevailing hot atmospheric dry season, clonal plants of *Pongamia pinnata* exhibited higher climate resilience potential through sustained photochemical efficiency in terms of atmospheric CO₂ capture, diurnal leaf

water relation, thylakoid electron transport and better management of cellular level oxidative stress. Various comparative physiological and biochemical aspects have been discussed to conclude that higher atmospheric CO₂ capture and photochemical efficiency are major determinants for assessing climate change adaptive potential of *Pongamia pinnata*.

Keywords: *atmospheric CO₂, climate change, photosynthesis, trees*

PP2.1.6. Biomass and carbon stock in trees grown in agroforestry under semi-arid regions of Central India

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Removal of carbon (C) from the atmosphere and storing it in terrestrial vegetation is one of the climate change mitigation options and large quantities of C could be stored if trees are included with crops and judiciously managed together. Thus, agroforestry plays an important role in issues related to climate change. A field experiment was conducted during 2008-2011 to assess the biomass and carbon stock available in a well-established agroforestry experiment on Shisham (*Dalbergia sissoo* Roxb.) and Safed siris [*Albizia procera* (Roxb.) Benth.] under irrigated; and Aonla (*Emblica officinalis* Gaertn.) and Anjan (*Harwickia binata* Roxb.) under rainfed condition. Allometric equation [$Y=a*(DBH)^b$ / $Y=a*(CD)^b$] was used to estimate biomass in tree. Where Y= above-ground biomass, DBH=diameter at breast height, CD=Collar diameter, a and b = model parameter estimated from destructive samples (30 to 42 samples from each tree species) of trees using non-linear regression. The C content in all components was analyzed by CHNS-O analyzer (Euro EA 3000, Euro Vector SpA, Milan, Italy). Carbon content in main bole, branch, foliage and root in Safed siris, Shisham, Anjan and Aonla varied from 44.84 to 48.10%, respectively. Safed siris accumulated maximum biomass and C (69.87 and 33.32 Mg ha⁻¹ respectively) at 8-year age with 312 trees ha⁻¹ but Shisham could store 69.71 and 31.99 Mg ha⁻¹ biomass and C, respectively at age of 14 with similar tree density. Similarly, biomass and C in aonla was 12.39 and 7.12 Mg ha⁻¹, respectively at age of 12 with 100 trees ha⁻¹ and anjan accumulated 78.12 and 35.74 Mg ha⁻¹, respectively at age of 17 with 200 trees ha⁻¹.

Keywords: *biomass, carbon stock, allometric equation, irrigated, rainfed*

PP2.1.7. Agroforestry-based watershed approach for livelihood security and climate change resilience in degraded agroecosystems

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Now it is clear that climate change is real and its effects are already being experienced in several parts of the world. It put the livelihood of millions of already poor people from arid and semi-arid regions under serious threat. Agroforestry and watershed management have been prominent approaches for resource conservation, agricultural sustainability, livelihood security, ecosystem development and climate change resilience. Meta analysis of 627 watershed case studies from India by an ICRISAT-led consortium revealed that watershed programs benefit people with a B:C ratio of 2.01, IRR 27.43%, enhancing rural incomes by 58%, agricultural productivity by 35%, irrigated area by 51.5%, cropping intensity by 35.5% and ground water table by 3.2m besides protecting environment.

The watershed experience at Garhkundar-Dabar by NRCAF clearly illustrated its combined effects on crop tolerance to drought, natural resource productivity and reduced vulnerability to climate shocks. Irrigated areas increased to 93% in 2009-2010 from merely 18% in 2005-2006 due to water harvesting and conservation measures at this watershed. As a result, the area under cultivation during 'kharif', 'rabi' and 'zaid' seasons increased by 119, 116 and 350% respectively. This increased the cropping intensity to 153.4% in 2009-2010 from 69.9% in 2005-2006. Further, the productivity of wheat, gram, pea, mustard and groundnut in treated watershed increased by 1.46, 0.13, 0.54, 0.64 and 0.42 tonne/ha, respectively. The enhanced fodder availability by 208% made the watershed fodder surplus. Additional 29 664 man days/year employment opportunities were created in watershed in 2009-2010 which reduced migration to 9% from 29% in 2007-2008. The integrated watershed management interventions also enhanced surface and ground water availability (both in time and scale), reduced runoff by 46%, peak discharge rate by 36%, soil loss by 42% total N loss by 42% and total P loss by 42%.

Keywords: agroforestry, climate change resilience, livelihood security, watershed

PP2.1.8. C-sequestration and its predictive model for Poplar (*Populus deltoides*) based agrisilvicultural system in north India

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The atmospheric C-sequestration in the terrestrial biosphere is one of the options to compensate greenhouse gas emissions. Trees on agricultural lands are believed to be a potential C-sink if judiciously managed together with crops and/or animals. Thus, agroforestry is an emerging land-use system both in terms of agricultural sustainability and issues related to climate change. Poplar (*Populus deltoides*) has gained considerable importance in agroforestry plantations in north India. The objective of this study was to analyse C storage data in sequential one to eight-year poplar-based agroforestry system and in reducing the concentration of CO₂ in the atmosphere.

Total C sequestration in poplar plantation (1-8 years) varied from 0.88-74.5 t/ha with bole contributing maximum (54-60%), followed by branch, twigs, stump root, leafs, lateral roots and fine roots. Predictive model for total C sequestration (Tcs) estimate was developed based on diameter at breast height (dbh) as $Tcs = 0.5 + 0.1 \times dbh^{0.51}$. Net carbon storage (soil + tree/ crop) in eight year poplar-based system was 148.3 tonnes/ha, which was 143.4% higher compared to sole rice-wheat (60.9 tonnes/ha) (soil + crop). In eight years poplar plantation, soil carbon stock (73.8 tonnes/ha) increased in soil by 46.1% than pure rice-wheat system (50.5 tonnes/ha). Though, crop system yield declined significantly under poplar but it was compensated by the poplar trees in terms of biomass, economics and carbon mitigation. Further, comparison was made in different land-use systems viz. mixed forest, poplar based agrisilviculture and pure agriculture in terms of above-ground biomass and carbon, SOC per cent. At the age of eight years, carbon stock in forest (150.9 t C/ha) was highest, being comparable with poplar-based agroforestry (148.3 t C/ha) and lowest in pure agriculture (60.93 t C/ha). Therefore, agroforestry seems to be a complementary option to bring improvement in livelihood, food security besides maintaining ecological balance.

Keywords: agri-silvicultural system, carbon sequestration and allocation, poplar, predictive model and system productivity

PP2.1.9. Carbon sequestration, storage rate and biomass estimation of multipurpose agroforestry tree species

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Uptake of CO₂ from the atmosphere and its utilization for production of photosynthates mainly for production of biomass is the key principle in CO₂ sequestration by trees. The conversion of CO₂ to tree carbon differs in different tree species mainly due to genetic nature, photosynthetic rate, energy conversion efficiency, age, edaphic factors and meagerly on the environment. The CO₂ sequestration rate among the different tree parts viz; stem, bole, foliage differs based on their activity. Due to the dwindling area under forestry, alternate land use system, agroforestry compensates the forest losses by increasing tree population on cultivable land to maintain carbon dioxide balance at optimum levels in the atmosphere.

The study of six major multipurpose trees species existed within the university campus includes legume, non-legume and timber species. Among the tree species selected a comparison was done for estimation of total carbon biomass by destructive method. Studies revealed that *Dalbergia sissoo* recorded the highest total biomass carbon (254.72 kg tree⁻¹) and *Albizia lebbbeck* (219.84 kg tree⁻¹) has the lowest values. The CO₂ sequestration rate of above-ground parts maximum value recorded with *Dalbergia sissoo* (916.98 kg tree⁻¹) and minimum with *Albizia lebbbeck* (791.43 kg tree⁻¹). Further it was observed that the high rate of CO₂ sequestration 48% and lowest rate 43% were noticed with the *Dalbergia sissoo* and *Albizia lebbbeck* tree species respectively.

Keywords: carbon, multipurpose trees, sequestration

PP2.1.10. Carbon storage and carbon sequestration of tree species influenced by planting geometry under farm forestry

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Tectona grandise, *Gmelina arborea*, *Ailanthus excelsa*, *Dalbergia sissoo* and *Eucalyptus tereticorn* were planted under agrisilviculture and block plantation at different planting geometry (spacing) on the experimental farm of this centre. The highest tree density of 2500 trees/ha was retained at spacing 2 x 2 m under block plantation and lowest 313 tree /ha was retained at spacing 8 x 4 m under agrisilviculture. Maximum MAI of DBH cm/tree was attained by *Ailanthus excelsa* (2.42) under agrisilviculture followed by *Tectona grandise* (1.32) under block plantation. Maximum bole volume cum/tree was attained by *Tectona grandise* (0.172) under agrisilviculture followed by *Ailanthus excelsa* (0.141) under agrisilviculture. Maximum bole volume/ha was produced by *Dalbergia sissoo* (122.37) under block plantation followed by *Eucalyptus teriticornis* (110.58) under block plantation. Maximum bole biomass t/ha was produced by *Dalbergia sissoo* (75.80) under block plantation followed by *Tectona grandise* (46.80) under block plantation. Percent contribution of bole biomass in total biomass ranged from 63.00 to 75.00. Percent contribution of branch biomass in total biomass ranged from 11.00 to 23.00. Percent contribution of bole biomass in total biomass ranged from 7.00 to 11.00. Maximum total above-ground biomass t/ha was produced by *Dalbergia sissoo* (95.94) under block plantation followed by *Tectona grandise* (65.47) under block plantation. Maximum carbon storage in above-ground biomass t/ha was estimated in *Dalbergia sissoo* (76.94) under block

plantation followed by *Tectona grandise* (45.83) under block plantation. Maximum annual carbon sequestration t/ha was estimated in *Dalbergia sissoo* (6.568) under block plantation followed by *Tectona grandise* (3.830) under block plantation.

Keywords: agrisilviculture, agrisilviculture, carbon sequestration, farm forestry

PP2.1.11. Terrestrial carbon sequestration in Poplar based agroforestry systems in North-Western states of India

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Populus deltoides (Poplar) has emerged as one of the promising species with multipurpose importance in agroforestry systems in the North-Western states of India. This study investigated terrestrial (trees as well as soil) carbon sequestration up to four-year-old plantation of *Populus deltoides* at Hara Farm, Yamunanagar (30° 7' N and 77° 18' E). Carbon sequestered by four year old plantation of *Populus deltoides* in different tree components was 49.98 Mg C ha⁻¹ in timbers, 1.41 Mg C ha⁻¹ in fuel wood, 0.35 Mg C ha⁻¹ in twigs and leaves. Carbon accounted by root alone was 12.9% of the total sequestered carbon by the tree. At the age of four year, the actual and estimated C-sequestration rate was 14.85 and 17.4 Mg C ha⁻¹ year⁻¹, respectively. The soil samples were analysed up to 100 cm depth for different carbon forms *i.e.* total carbon (TC), total inorganic carbon (TIC), total organic carbon (TOC) and soil organic carbon (SOC), microbial biomass carbon (MB-C), Permanganate oxidizable carbon (POXC) and nutrient (N, P and K) dynamics. SOC increased with the age and decreased with soil depth. POXC was 662.6 mg kg⁻¹ in four year of plantation. Carbon stock in upper soil layer (0-15 cm) in a four-year-old plantation was 16.1 Mg C ha⁻¹, which was 17.3 % higher than the one-year-old plantation. The soil MB-C being an active pool of carbon was found highest (506.88 µg g⁻¹) in four year and lowest (152.1 µg g⁻¹) in a one-year-old plantation in 0-15 cm soil layer. Over the soil depths mean soil TC, TOC, SOC was 10.3, 9.66 and 4.44 g kg⁻¹, respectively in four year, which was higher by 23.7, 25.4 and 21.8 % than one-year-old poplar plantation. TIC reduced by 4.8 % in a four-year-old plantation compared to a one-year plantation, indicated their dissociation with the tree age. Available N, P, K in four year was 12.2, 57.7 and 41.6 % higher than a one-year-old plantation. Our results indicated that poplar based agroforestry practices positively affected soil MB-C, POXC, TC, TIC, TOC and SOC with the age of plantation. This study suggests that different carbon forms, POXC, MB-C are important C fraction that reflects key processes such as nutrient cycling and availability, soil aggregation, and soil health. Poplar-based agroforestry systems are not only remunerative to the farmers but also explore many veiled environmental benefits besides improving soil health to a great extent.

Keywords: Poplar, carbon sequestration, POXC, MB-C, organic carbon, inorganic carbon

PP2.1.12. Assessing the local preconditions for climate smart agricultural projects

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This paper presents findings on the local preconditions for agricultural carbon projects, drawing on evidence from the Kenya Agricultural Carbon Project (KACP). KACP is the first World Bank-supported project on climate smart agriculture in Africa and has worked with groups of smallholders in

western Kenya since 2008. We applied the Matched Control Intervention approach to test for any significant assets for the project's activities. One hundred households, equally sampled within (intervention) and outside (control) project sites, were interviewed. The household interviews were triangulated with focus group discussions, key informants and in-depth interviews with project staff to specifically rank the significance of selected livelihood assets to the project activities. Water access and land tenure had the most significant influence on the project activities and outputs at $p \leq 0.01$ and $p \leq 0.05$ respectively. Dependence on rainfed agriculture for livelihoods in the project area meant that periods of unreliable rains constrain growth of planted tree seedlings with associated crop failures that tend to increase charcoaling pressure on mature agroforestry trees. Farmers with land title deeds appear to be more committed to implementing sustainable land management activities (SALM). However, most of these farmers (64%) would sell or convert their land to non-agricultural uses to cope with shocks such as drought or death. While the project reasonably enhances farmers' capacity on SALM, it may find it necessary to fairly attend to these key preconditions. This will ensure farmers' long term commitments towards achieving triple win goals of emission reduction, climate resilience and increased yields. On a wider scale, both private and public policy support for climate smart agriculture must attend to wider development issues such as water management which bear heavily on such projects. This is vital if smallholder farmers are to become more empowered to expand their opportunities in the context of climate change.

Keywords: *climate smart agriculture, evidence, livelihood assets, preconditions*

PP2.1.13. Woody biomass and carbon sequestration potential in agri-horti-silvi systems in arid region of north-western Rajasthan

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The importance of agroforestry systems as carbon sinks has recently been receiving attention due to climate change mitigation as well as carbon sequestration potential. The study was made to compare the carbon accumulation both in tree biomass and in the soil in agri-silvi-horti systems growing in arid region of Rajasthan. The planted three horticultural and three silvicultural species were horti and silvi species combination in alternate plant in Randomized Block Design. The planted silvicultural species were *Prosopis cineraria* (PS), *Ailanthus excelsa* (AE), and *Colophospermum mopane* (CM) and horticultural species were *Zizyphus mauritiana* (ZM) *Cordia myxa* (COM) and *Embllica officinalis* (EO). It was intercropped with wheat (*Triticum aestivum*). Biomass production of horti and silvi species was higher in agroforestry plots as compared to respective control plots. Biomass production was highest (14.02 kg per tree) in *P. cineraria* tree and lowest biomass in *Z. mauritiana* tree (2.07 kg per tree) in agroforestry system, whereas biomass production decreased half in sole tree plots (control). The maximum reduction was observed in *A. excelsa* tree in control plot as compared to agroforestry tree plots. The carbon content (%) was the highest in leaf and it was the lowest in the root of the all horti and silvi tree species. Highest carbon content was 45.84% in *C. mopane* and lowest was 43.61% in *A. excelsa* trees.

Among the horti-silvi combination, highest carbon stock was recorded in *Cordia myxa* and *P. cineraria* combination (5.07 t C/ha), followed by *Cordia myxa* and *C. mopane* (4.58 t/ha) combination. The biomass carbon and soil carbon stock varies among the horti-silvi combination but was also similar to total carbon stock. Average of carbon stock was highest in *P. cineraria* combination than the other two silviculture species. All the combination of horti-silvi systems indicated more carbon than sole horti and silvi species as well as agriculture plots.

Keywords: arid and semi arid region, biomass, carbon sequestration, agri-horti-silvi system

PP2.1.14. Variability, heritability and association studies among different clones of *Eucalyptus tereticornis* planted at two sites

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Tree plantations under farm and agroforestry are an important source of timber, fuelwood and other raw material requirements for industries in developing countries due to non-availability of the same from natural forests and can play a vital role in mitigating the climate change effects. Eucalypts are widely planted in farm forestry systems throughout the world and in India, due to their high productivity and adaptability to wide geographical conditions. According to a report by Forest Survey of India, *Eucalyptus* is the most preferred tree species by farmers of Punjab in both rural and urban areas. Farmers in India have shown keen interest in planting eucalypts in the recent past on their farmlands due to the availability of genetically proven highly productive clonal planting stock of *Eucalyptus* with manifold increase in productivity as compared to seed raised plants. Productivity of each clone can be further increased with the careful matching of each clone most adaptable to each site. With this hypothesis in mind, a study was conducted to evaluate the performance of 20 clones at two sites. The estimates of phenotypic coefficients of variation and genotypic coefficients of variation clearly reflected the presence of large amount of genetic variability for clearbole height and unforked height at the age of six and a half years after planting. The estimates of heritability and genetic advance clearly suggested the potentiality of the clonal material for improvement of clearbole height and unforked height. Highly strong positive association was observed among clearbole height and unforked height in both the environments. Significant positive correlation was observed among total height and diameter at breast height (dbh) in better environment (Environment 1) whereas in Environment 2, non-significant negative correlation was observed between height and dbh.

Keywords: clones, correlation, *Eucalyptus tereticornis*, genetic parameters

PP2.1.15. Carbon storage and carbon sequestration of tree species influenced by planting geometry under farm forestry

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Tectona grandise, *Gmelina arborea*, *Ailanthus excels*, *Dalbergia sissoo* and *Eucalyptus tereticornis* tree species were planted under agrisilviculture and block plantation at different planting geometry (spacing) on experimental farm of this centre. Highest tree density 2500 trees/ha were retained at spacing 2x2m under block plantation and lowest 313 trees/ha were retained at spacing 8x4m under agrisilviculture. Maximum MAI of DBH cm/tree was attained by *Ailanthus excelsa* (2.42) under agrisilviculture followed by *Tectona grandise* (1.32) under block plantation. . Maximum bole volume cum/ tree was attained by *Tectona grandise* (0.172) under agrisilviculture followed by *Ailanthus excelsa* (0.141) under agrisilviculture. Maximum bole volume/ha was produced by *Dalbergia sissoo* (122.37) under block plantation followed by *Eucalyptus tereticornis* (110.58) under block plantation. Maximum bole biomass ton/ha was produced by *Dalbergia sissoo* (75.80) under block plantation followed by

Tectona grandise (46.80) under block plantation. Percentage contribution of bole biomass in total biomass ranged from 63.00 to 75.00. Percentage contribution of branch biomass in total biomass ranged from 11.00 to 23.00. Percentage contribution of bole biomass in total biomass ranged from 7.00 to 11.00. Maximum total above ground biomass ton/ha was produced by *Dalbergia sissoo* (95.94) under block plantation followed by *Tectona grandise* (65.47) under block plantation. Maximum carbon storage in above ground biomass ton/ha was estimated in *Dalbergia sissoo* (76.94) under block plantation followed by *Tectona grandise* (45.83) under block plantation. Maximum annual carbon sequestration ton/ha was estimated in *Dalbergia sissoo* (6.568) under block plantation followed by *Tectona grandise* (3.830) under block plantation

Keywords: *agrisilviculture, carbon sequestration, farm forestry*

PP2.1.16. Trends in soil carbon stock of three major forests of Indian Central Himalaya

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Current investigation reveals the stock of Soil Organic Carbon (SOC) along with altitudinal gradients in Oak (*Quercus leuchotrichophora*), Pine (*Pinus roxburghii*) and Sal (*Shorea robusta*) dominant forests in Shiwalik region of Kumaun Himalayas in India. The estimated soil organic carbon was found to be 16.0 ± 4.3 to 19.4 ± 6.4 g Kg⁻¹ for Oak, 17.8 ± 2.0 to 25.6 ± 1.6 g Kg⁻¹ for Pine and 15.8 ± 2.2 to 21.4 ± 1.9 g Kg⁻¹ for Sal forests, respectively in 0-10, 10-20 and 20-30 cm soil depths. SOC stock was found to be in decreasing pattern with increasing altitude from 193.6 to 166.4, 146.4 to 137.6 and 159.2 to 141.6 t C ha⁻¹ in Oak, Pine and Sal forests, respectively. It is an indicator of higher biological activity or anthropogenic disturbance associated with top layers of these forest areas. Higher SOC was recorded in Sal forest compared to Oak. In Sal forests, high tree density leads to higher accumulation of SOC compared to conifers while it was low in wide spread Pine forest, resulting in less storage of carbon stock in turn. As soil depth increases, steep fall in SOC was found as a characteristic decline in vegetation with increasing altitude, results in less accumulation of litter and low input of organic carbon in soils. In such circumstances at lower elevations, the management of vast areas of Himalayan forests may be regarded as major sinks of mitigating atmospheric carbon dioxide.

Keywords: *carbon stock, Shiwalik belt, soil organic carbon*

PP2.1.17. Vegetation composition and socio-economic significance of homegardens in Aizawl district of Mizoram, North-East India

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Tropical home gardens are identified as important production systems of food and other essential products and provide various socio-economic benefits to the households. However, very little information on these exists for Mizoram. This paper examines plant composition, species diversity, use and contribution to socio-economic domains of the households. Forty home gardens selected randomly from three size classes viz. large (0.75-1.5 ha), medium (0.05-0.75 ha) and small (0.025-0.05 ha) were

thoroughly studied for species diversity using various phyto-sociological tools, plant use through direct observation and questionnaire survey, process analysis on energy input and outputs using standard method. A total of 198 species (82 trees, 31 shrubs, 79 herbs, 6 palms) belonging to 69 families were recorded from the sampled homegardens. Papilionaceae had the highest species number (11) followed by Cucurbitaceae (9) Caesalpiniaceae, Euphorbiaceae and Rutaceae (8 each). The utility function of the plants comprises of vegetable (24%), fruit (18%), firewood (12%), medicine (11%), ornamental (9.8%), fodder (9.2%). Shannon Weiner index ($H' = 3.78$, $P < 0.005$) of medium gardens was higher for tree and shrub diversity than the large and small sized homegardens. Evenness index for trees, shrubs and herbs varied widely among the homegardens and it was maximum for trees (0.814) in large homegardens and minimum for shrubs in small homegardens (0.421). The energy output and input ratio was highest (61) in large home garden and lowest (34) in small garden. The contribution of the income was less for small homegardens as compared to medium and large gardens as the products are mainly used as supplemental food and not market oriented. However, many large home gardens are commercial-oriented to generating high income. This study suggests that home gardens are maintained deliberately for meeting diverse needs of the household and also for serving as a means for species conservation through utilisation.

Keywords: home garden, composition, plant diversity, Mizoram, conservation

2.2 Tropical homegardens: multi-functionality and benefits

PP2.2.1. Tropical home gardens for ecological balance in a changing climate scenario

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Home gardens are integrated tree-crop-animal production systems, often in small parcels of land surrounding homesteads and primarily found in tropical environments. They have potential to mitigate the loss of biodiversity and elevated CO₂. Home gardens help in adaptation to climatic variability with high resilience by ensuring food, nutritional and energy security through sustainable income. The present paper generate outputs that will add to integrated farming, transformative changes in landscapes, tree improvement, innovative tree-based value chains, sustainability, reforms of land and tree tenures with a holistic education to the rural masses and associated business prospects. The paper summarizes the multiple benefits with species composition, conservation of bio-cultural diversity, product diversification as well as intangible values of products and services, social and cultural values including the opportunity for gender equality. With increasing emphasis on industrial models of agricultural development, economic valuation with mechanisms of resource sharing in mixed plant communities and realistic valuation of benefits of carbon sequestration will provide a basis for formulation of sound policies. Harvesting tree products and (or) raising cattle or small ruminants were found to be local adaptation strategies against weather aberrations in most of the tropical home gardens. Global climate change threatens all ecosystems with altitude shifts.

Tropical home-gardens have potential for biological diversity in working landscapes by growing commercial crops in shaded-perennial systems, such as coffee (*Coffea sp.*) and cacao (*Theobroma cacao*) under the shade. About 90% of the biodiversity resources in the tropics are located in human-dominated or working landscapes and become the basis for the concept of *eco-agriculture*. They have the potential to sequester substantial quantities of carbon (C). Homesteads are estimated to help regain 35% of the original C stock of the cleared forest in the tropics. Global deforestation, estimated to occur

at the rate of 17 million ha yr⁻¹, is expected to cause the emission of 1.6 billion tons of C yr⁻¹. Models with home gardens are discussed in the present paper.

Keywords: *tropical home gardens, multifunctionality, carbon trading, resource conservation technologies*

2.3 Tree fodder and animal nutrition

PP2.3.1. Study on exploring tree fodder as livestock feed in silvipasture system

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The study was undertaken to explore the tree fodder as livestock feed in silvipasture system, containing *Leucaena leucocephala*, *Gliricidia sepium*, *Albizia lebbek*, *Erythrina indica* and *Inga dulci*. In the first experiment, a 60-day lactation trial was conducted to study the impact of subabul (*Leucaena leucocephala*) on milk yields and composition in crossbred (Jersey x Sindhi) dairy cows. Eighteen cross-bred dairy cows were grouped, namely Group I (control), II and III. Green fodder C03 was offered to all the three groups of animals, whereas in Group II animals were fed with 15% subabul in green fodder portion and Group III animals fed with 25% subabul in green fodder portion on dry matter basis. After 21 days of adaptation, milk samples were collected and analysed for composition. The average milk yield in Group I, II and III was 5.94, 5.86 and 5.91 kg, respectively and comparable among the groups. Fat percentage in Group I (4.85), Group II (4.90) and III (4.89) was comparable. Similarly, SNF percentage in Group I, II and III was 9.09%, 9.11% and 9.11%, respectively. Therefore, present study results showed that subabul can safely include up to 25% of green fodder portion on DMB without any change in milk yield and composition. In experiment II, 60 days growth trial was conducted in adult male New Zealand white rabbits to study the evaluation of nutritive value of *Erythrina indica* leaves. Twelve rabbits were divided into two groups of six animals each and maintained in the individual cages. Group I animals were fed on *Stylosanthes scabra* as control and Group II animals fed with *Erythrina indica*. The weight gain in Group I and II were 832 and 813gm respectively. Thus, tree fodder can be effectively used as feed resources to livestock without affecting the productivity.

Keywords: *livestock, milk yield, tree fodder, weight gain*

PP2.3.2. Selection and performance of Mulberry provenances (*Morus indica* L.) – A promising agroforestry tree species of, India

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The rooting behaviour of four provenances of *Morus indica* under the effect of growth regulator (IBA) was studied in a factorial RBD experiment at Nauni, Solan Himachal Pradesh. The collection was made from four provenances viz. Solan (Nauni), Hamirpur (Hamirpur), Sirmour (Dhaulta Kuan) and Kangra (Jachh) districts of the state. The growth parameters studied were: sprouting, rooting, survival and plant height etc. under nursery stage. Significant variations in most of parameters were recorded due to different IBA formulations, provenances and diameter classes. The treatment with 0.6% IBA performed

better for all the rooting behaviour parameters studied. The provenance Hamirpur (P₄) showed overall best rooting response with 80.91% sprouting and 70.18% survival per cent. However, provenance P₁ (Nauni) gave the maximum rooting 74.07% and maximum plant height (121.00 cm). Diameter class D₃ (Cuttings having diameter greater than 1.25 cm) exhibited significantly better performance in respect of rooting behaviour. Proximate principles estimation was also carried out in four provenances. Solan (Nauni) and Sirmour (Dhaulakuan) provenances exhibited better values for most of the proximate principles.

Keywords: IBA formulations, rooting behaviour, growth parameters, proximate principles

PP2.3.3. *Gliricidia*-Alley cropping system for sustainable Islands agriculture in India

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Alley-cropping is a promising agroforestry cropping system particularly for Island ecosystem in which crops are grown between the hedgerows. Plant to plant distance of *gliricidia* within a hedgerow is 50 cm but distance between the hedgerows varies according to terrain, slope, terrace size and purpose of the system. One year after planting, harvesting can be started by lopping the plants at 1m above the ground. Pruning should be done at least thrice during the year; *i.e.*, in June, November and March. After pruning, the loppings are made into smaller pieces and mixed into soil before crop sowing. The production of *Gliricidia* leaf dry matter value reported around 12.6 tonnes /ha/year. *Gliricidia* leaves were found most suitable for green manuring in Islands ecosystem because it contains 2.5-3.0 % nitrogen in its leaves and also fixes 80-100 kg N/ha. Black pepper cultivation is generally practiced on arecanut trees in the Islands. The pepper vine trails very high on the arecanut trees which makes the harvesting of both the crops difficult. This system is found suitable for pepper cultivation which would yield 2.5 kg of dry berries per plant. *Gliricidia* loppings can also be applied in the alleys as manure and bio-mulching of intercrops of vegetables as brinjal and okra for checking soil erosion and improving soil health status. Vegetable crops like brinjal and okra did not need any additional N, P, K and micronutrients application, if 5 tonnes *Gliricidia* lopping ha⁻¹ was applied properly for obtaining the significantly higher yield and net returns as compared to 8 and 3 tonnes of lopping treatments. Thus through indigenous application of *gliricidia*, adds sufficient nutrient to intercrops vegetables.

Keywords: green manure, hedgerow, vegetables, yield

PP2.3.4. *Heterosis in intra-specific hybrids of grewia optiva* genotypes using line x tester mating design

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Grewia optiva is an important agroforestry tree of north western Himalayas and widely used as green fodder in the hilly areas for feeding livestock. But till now there is no work reported regarding the improvement of the species for increasing the fodder production. There is collection of *G. optiva*

genotypes from different districts of Himachal Pradesh maintained in the seed orchard of Department of Tree Improvement and Genetic Resources, Dr Y. S. Parmar University of Horticulture and Forestry Nauni, Solan (H.P.) India. For carrying out present study ten superior genotypes were chosen from the orchard for estimation of heterosis. The plant material of 6 females (SO-1, SO-2, SO-4, SO-8, CH-2 and SI-15) and 4 male (SO-3, SI-6, BI-4 and HA-4) genotypes were control crossed using Line X Tester (6X4 factorial) mating design. All the twenty-four crosses produced viable seeds. The per cent successful crosses were highest in cross SO-2 X SO-3 (88.10 %) and minimum was for SO-8 X HA-4 (23.81 %). Outcome of the present investigations revealed that heterosis over mid parent value was prevalent for the entire nursery characters (plant height, collar diameter, number of leaves, internodal length and leaf area) studied. Maximum relative heterosis (28.75 and 49.06 %) for plant height was displayed by cross SI-15 X BI-4. With respect to collar diameter, SI-15 X BI-4 (57.30 % and 98.63) expressed maximum positive heterosis. F₁ SO-8 X SI-6 exhibited maximum positive significant mid parent heterosis (+37.10 and 23.16 %) for number of leaves. In case of internodal length, SO-8 X HA-4 and SO-8 X BI-4 (+ 45.76 and 46.63 %) exhibited maximum positive heterosis. Maximum positive mid parent value of 122.57 % was found in SO-8 X SI-6 for leaf area (cm²). Heterosis for leaf fresh and dry weight (g) F₁ hybrids displayed highly significant positive heterosis over their mid parents (%), which was revealed in F₁ SO-8 X SI-6 (169.29 and 171.56). In case of leaf dry matter production, maximum positive mid parent heterosis of 61.20 % was revealed in F₁ SO-1 X BI-4. On the basis their performance in nursery, hybrids SI-15 X BI-4, SO-8 X HA-4, SO-8 X BI-4 and SO-1 X BI-4 has been recommended for field level exploitation. Whereas, SI-15, SO-8 and SO-1 (female) and HA-4, BI-4 and SI- 6 (male) genotypes may be considered as stable parents in future breeding programmes.

Keywords: *heterosis, Grewia optiva, hybrids, nursery characters*

PP2.3.5. Variation in proximate and mineral content in fruit and leaf of 12 provenances of Gamari (Gmelina arborea Linn Roxb.)

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A study was carried out to observe the differences in the nutritive values in fruits and leaves of twelve provenances of *Gmelina arborea*. Crude protein content was low in fruits than leaves; soluble sugar was higher in fruits than leaves; phenol was low in fruits than leaves and crude fibre content was low in leaves than fruits. Phosphorus, calcium and magnesium content were less in fruits than leaves; potassium content was higher in fruits than leaves. The range among different provenances for crude protein was observed to be 2.47-11.23% in fruits whereas the value ranged from 11.53 to 24.37% and 8.95 to 23.92% in nursery leaves and mother leaves respectively. Soluble sugar, crude protein and phenol could be considered as meaningful parameters for provenance selection because of their high heritability with moderate genetic gain and moderate to low genotypic coefficient of variation. The differences between phenotypic and genotypic coefficient of variability indicated that these parameters are sensitive to environmental changes. It is concluded that fruits and leaves of *G. arborea* vary greatly for their nutritive values depending on the geographical regions and can be fed to the ruminants as an alternative feed resource without any supplement.

Keywords: *Crude protein, Gmelina arborea, Phosphorus, Provenances*

3.0 The business of agroforestry: applying science

3.1 The viability of trees as crops: agroforestry, pulp and wood-based enterprises, cocoa, coffee

PP3.1.1. Economic benefits of eucalyptus clonal plantations under agroforestry system in three different agro-climatic zones

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Agroforestry can play a vital role in rural livelihood sustainability in the face of increasing poverty and health epidemics in some parts of India. It can enhance food security, provide income-generating activities that are not labour-intensive, mark ownership of land, and offer a safety net of subsistence and income. Integrating an agroforestry tree planting model with approaches to improve soil fertility may address this problem since well-managed trees do not adversely affect crop growth. The general objective was to put together eucalyptus plantation into intensive pulses and oil seed crops in agroforestry systems with minimal negative interaction, therefore increasing wood and agricultural crop productivity, profitability, nutrient use efficiency, soil enrichment and environmental services. The evaluation in eucalyptus clonal plantation farmer's field with pulses and oil seeds crops in agroforestry systems was conducted in three different agro-climatic zones –Odisha, Maharashtra and Andhra Pradesh. Data collected were tree parameters, spatial performance of pulses, oil seeds crop and economics. The economical benefits to farmers in agroforestry models were more than 50% when compared to other plantation models.

Keywords: *agroclimatic zones, agroforestry system, economic importance, Eucalyptus*

PP3.1.2. Evaluating domestication potential of *Pentaclethra macrophylla* Benth in view of increasing its contribution to food production

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Pentaclethra macrophylla has emerged as a tree species with considerable economic and nutritional value for the Baka, a marginalized community in Cameroon. The survival of the species is threatened by habitat loss due to agricultural activities and bark harvesting for medicinal purposes. Propagation, ethno-botanical and socioeconomic studies were conducted to assess the domestication potential of this species. Results showed that seeds and bark are the major parts of *P. macrophylla* of interest to farmers. Inventories showed diameter class distribution in forest and fallows in the form of a bell curve, while in home gardens distribution tended to be erratic with some missing classes reflecting threats faced by this species. *P. macrophylla* was vulnerable based on seed use (Iv=2.38) and highly vulnerable based on bark use (Iv=3.81). 55.9% of Baka men and 44.1% of Baka women were involved in *P. macrophylla* seed collection. The wholesale price of 100 kg of seeds was evaluated at USD 350, contributing up to 60% of household revenue. In terms of DBH, height, crown diameter, number of seeds per pod and seed weight, 4 specific trees were identified as ideotypes to be targeted for cultivar development. *P. macrophylla* is amenable to rooting of leafy stem cuttings and seeds germination with the percentages of 60.26±6.22%, 100% respectively. Therefore, because of its economic value and current threat to survival in its natural habitat, wider on-farm cultivation of *P. macrophylla* will be promoted.

Keywords: *Baka, cuttings, ideotype, morphological variation*

PP3.1.3. Phenotypic variations in fruits and seed traits of *Chrysophyllum albidum* in three agroecological zones in Nigeria

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Chrysophyllum albidum is a priority indigenous fruit tree in Nigeria with a wide distribution across West Africa. This fruit tree has immense socioeconomic, nutritional and medicinal importance. However, it is under threat due to a high consumption of the fruits and seeds and this has led to serious genetic erosion. A study was designed to assess the extent of phenotypic variation in fruits (mass, length, width) and seed (weight and number) traits in 105 trees. This was further complemented by socioeconomic characterization in three agroecological zones (arid, humid and mangrove). The results from the study indicated that in all agroecological zones, 64.4% of the fruits were collected from naturally regenerated trees. Households own averagely 2 trees which yield an annual average of 3 to 9 baskets, (of about 42 kg per basket) with a market value ranging from USD 187 to USD 562. Phenotypic traits like fruits and seed mass varied continually and significantly ($p < 0.001$) between trees and agroecological zones. Mean fruit and seed mass recorded in the humid zone were $59.56 \pm 0.20\text{g}$ and $6.95 \pm 0.23\text{g}$ respectively, compared to $56.79 \pm 0.19\text{g}$ and $6.56 \pm 0.23\text{g}$ in the mangrove and $56.85 \pm 0.20\text{g}$ and $6.87 \pm 0.23\text{g}$ in the arid zones. Tree EW/IK/CA/018 had the heaviest fruit ($97 \pm 1.56\text{g}$; $P < 0.001$) while tree ET/IV/CA/004 had the lightest fruit ($36 \pm 1.71\text{g}$; $P < 0.001$). A significant and positive correlation between all fruit traits ($P < 0.001$) was observed with the strongest relationship between fruit mass and fruit width ($R^2 = 0.76$). These results represent the first quantitative assessment of tree-to-tree variation in fruit traits of *C. albidum* and will help in the development of cultivars through tree domestication techniques, and so promote poverty alleviation and sustainable agriculture in Nigeria and beyond.

Keywords: *characterization, domestication, poverty alleviation, regeneration*

PP3.1.4. Productivity assessment and economic analysis of teak plantations in different agroclimatic zones of southern India

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Productivity assessment and economic analysis of teak plantations of three age gradations (10, 15 and 20 years old) in different agroclimatic zones of Karnataka, viz. northern dry zone, northern transition zone, and hilly zone was carried out during the present investigation. Observations on growth parameters like total tree height, clear bole height, diameter at breast height, basal area, total volume and clear bole volume, etc. were recorded in $10\text{m} \times 10\text{m}$ sample plots and average data per hectare was calculated. Teak plantations raised on the farmlands of the northern transition zone had significantly higher productivity and greater economic returns. 20-year-old teak plantations of the northern transition zone of Karnataka had on average two times more clear bole volume ($738.98\text{m}^3/\text{ha}$) than those among the northern dry zone ($313.22\text{m}^3/\text{ha}$) and hilly zone ($322.86\text{m}^3/\text{ha}$). Net present value was highest in 20-

year-old plantations of the northern transition zone (11,96,567Rs./ha) than in the northern dry zone (4,69,514 Rs./ha) and hilly zone (4,91,805Rs./ha). Similarly, the highest benefit: cost ratio of 8.67 was obtained among the 20-year-old teak plantations of the northern transition zone when compared to other study areas. Optimal average annual rainfall of 749 mm and medium black soil in northern transition zone might have contributed to higher productivity thus higher economic returns. It was concluded that large-scale teak plantations can be raised on farmlands of the northern transition zone for greater economic returns.

Keywords: *agroclimatic zones, benefit: cost ratio, clear bole volume, teak*

PP3.1.5. The Wave Project – two years of a space and time experiment

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Available solar radiation is one of the most important vegetational production factors. Several studies have confirmed that crop biomass is effectively proportional to the amount of radiation intercepted by the canopy. Tree structures associated with farm management will determine the interaction intensity and performance of the combined crops. Thus, studies concerning trees and crop parameters and their relation to the radiant energy interception are essential. The majority of published studies on production systems report structures empirically established by farmers and their various relations of production, protection and profitability. There are few attempts in the literature to propose structural patterns of mixed plantings intended to increase solar radiation capture. How we should draw a productive system in view of maximizing solar radiation absorption and use is still an open question. In this first attempt I have tried to establish links between the vegetative structure of a forest with a productive system. In this sense I designed a tridimensional dossel structure with a wave-like appearance in a long-term experiment. Trees were planted in a temporal and spatial planting design in order to raise the dossel and form the proposed shape. Eucalyptus (COP1277) was planted in October 2011 by 3 x 2 m spacing – in: *i.* monocrop; *ii.* alley crop system with 24 m spacing – Short-Wave and, *iii.* 42 m spacing – Long Wave. In all these situations, cassava (IAC-90) were intercropped (1 x 1 m spacing) being planted some months earlier - June 2011 and harvested in July 2012. The second line of eucalyptus, closing the gap between edges, was planted in February 2013. This situation was replicated in four blocks.

Cassava commercial root production was 3.5 kg plant⁻¹ in average with no significant difference. Eucalyptus reacted to the environment by increasing canopy volume and trunk diameter with increasing spacing. The proposed design, in these early years, has allowed for increased and continued production.

Keywords: *dossel, Eucalipt, solar radiation, tridimensional*

PP3.1.6. Canopy modification of Eucalyptus camaldulensis sprouts due to shade

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Eucalyptus spp. is the main tree used in cellulose production cultivated all around the world essentially in extensive monocrop plantations. The extension of the area used, its location and land immobilization

for long periods, makes *Eucalypt* cultivation to be no longer encouraged in many places. At the same time, these huge plantations present many opportunities by integrating *Eucalypt* into Agroforestry Systems (AFS) in different production systems with many advantages –social, economical and environmental. In this research we attempt to perceive the canopy modifications *E. camaldulensis* sprouts present in a degree of shade. *E. camaldulensis* were under a regime of 51%; 58%; 63%; 67%; 71%; 75%; 77%; 81%; 86%; 90% and 94% of available solar irradiation. *E. camaldulensis* presented canopy plasticity modifying radiation interception patterns under diverse available irradiances. Most of these variations were of small amplitude with some important parameters remaining almost unchanged (leaf density, canopy percentage; tree, trunk and canopy height) or with a small increase (Leaf Area Index, canopy opening). The main changes presented by *camaldulensis*, with a steep increase towards full sun, were: foliage area; canopy surface; canopy volume; and area of canopy projection. It is necessary to determine at which point these variations can support reasonable production so we can design appropriate agroforestry systems with young Eucalypt being under the shade of outré crops.

Keywords: *adaptation, growth, shade, solar radiation*

PP3.1.7. Cassava production in an agroforestry system with eucalyptus

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The planting of trees in farms is taken with caution given the permanent occupation of the soil and the long-term return. The planting of eucalyptus in extensive plantations, as in Brazil (c. 5 million hectares of eucalyptus), has generated worldwide environmental and socioeconomic concerns due to the reduction of the area for production of food crops. The success of an Agroforestry System (AFS) is related to the combination of crops and its easy adoption by local farmers - either by tradition or by profitability, and the similar requirements of the physical environment and phytosanitary compatibility. The mutual shading, originally from intercropping on the seedling and then in reverse, is the main interaction in AFS. Given the fast growth of eucalyptus in the tropics, timing is essential in ordering the sequential fieldwork. In this study we attempt to investigate the possibility to generate production in areas usually cultivated with sole eucalyptus. Cassava (IAC-90) were planted in June 2011 by 1x1m spacing – in *i.* monocrop; *ii.* two alley crop system with eucalyptus (clone: COP1277) in double rows with 24 and; *iii.* 42 m spacing and; *iv.* intercropped with eucalyptus planted by 3x2m spacing. All eucalyptus was planted in October of the same year. This situation was replicated in four blocks. Cassava commercial root production was evaluated in each situation in July 2012 by pulling the plant and weighing the production at field with a precision spring balance (Pesola[®]). Cassava fresh productions in these situations were: 4.33; 3.52; 3.01 and; 3.2 kg.m⁻² respectively with no significant difference. Cassava nearer the eucalyptus at the alley crop system presented a small decrease in root production. Meanwhile, it was higher than the fraction of available radiation. It is possible to plant cassava with eucalyptus in the first stage of its development with satisfactory production.

Keywords: *adaptation, food crop, solar radiation*

PP3.1.8. Addressing constraints in propagation of *Allanblackia* spp. through seed sectioning and air layering

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Agriculture is the foundation of the economy of many African countries and is dominated by smallholder farmers. The agriculture sector therefore needs to be managed sustainably with special attention to indigenous tree species with high potential for improvement of rural livelihoods. *Allanblackia* species are indigenous to West, East and Central African regions with the potential to provide an alternative source of income for rural populations. Seed oil is the most important economic benefit from the species. Supply of seed oil (≈ 200 ton/yr) is far below annual demand of $>100\,000$ tonnes suggesting that wild harvesting is unsustainable, hence the need for domestication of the species. Propagation of *Allanblackia parviflora* through seed germination and air layering was undertaken. Whole seeds and seed sections (distal end, proximal end and longitudinal sections) of both stratified and non-stratified seeds were germinated in sand, plain and black polythene bags. Layering was undertaken on pollarded shoots growing on 1.5, 4 and 6 m stumps using coir dust as the medium. Germination of whole seeds ranged from 8 to 28% with stratified seeds in plain polythene bag being the highest and non-stratified seeds in sand being the lowest ($P < 0.05$). For proximal end sections, germination ranged from 0 to 66% ($P < 0.05$) with non-stratified seed sections in plain polythene bag being the highest and all seed sections in sand having zero germination. Longitudinal sections of non-stratified seeds had highest germination (48%) in plain polythene bag and zero germination in sand ($P < 0.05$). All distal seed sections did not germinate but only produced seed roots. For layering, rooting success was highest (70%) for shoots on 1.5 m stumps and this declined with increasing stump height to 21.4% for 6 m stumps ($P < 0.05$). The results are discussed in relation to mass propagation of *Allanblackia* spp. to support large-scale cultivation.

PP3.1.9. Correlation and path analysis studies in teak for stem volume production: a suitable tree species for agroforestry

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The investigation on "correlation and path analysis studies in teak (*Tectona grandis* L.) for stem volume production" was undertaken on thirty clones of teak from a teak seed orchard. The genotypic and phenotypic correlation coefficient studied between stem volume and its contributing character indicated that plant height, girth and number of branches exhibited positive and significant correlation. The girth exhibited positive and significant correlation with volume while it exhibited positive but non-significant correlation with the leaf area number of branches; and it exhibited negative but non-significant correlation with dry weight of leaf at genotypic level. The number of branches exhibited a positive and significant correlation on volume at genotypic and volume at phenotypic level. This correlation amongst the volume attributes indicates that plant height and number of branches are in positive direction and they are helpful and advantageous for improvement in volume. The height exhibited highest positive direct effect on stem volume followed by leaf area. Dry weight girth and negative direct effect was observed for a number of branches. The girth exhibited highest positive indirect effect on volume followed by plant height, leaf area and number of branches and negative indirect effect was observed for dry weight. Path analysis indicated the importance of

volume contributing characters like plant height followed by girth, leaf area, dry weight of leaf and number of branches, which have directly and indirectly influenced all the correlations of volume with its components. Thus, it is concluded that, selection pressure exercised on the genotypes possessing more plant height and more number of branches will be useful in identifying the genotypes as parents for further improvement in teak. Hence, these characters may be given consideration while making selections for the improvement of teak.

Keywords: *genotypic correlation coefficient, path analysis, phenotypic correlation coefficient*

PP3.1.10. Do propagation methods affect tree growth and fruiting in African plum (*Dacryodes edulis*)?

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One of the concerns raised by farmers cultivating indigenous fruit trees like *D. edulis* in West and Central Africa is the long juvenile stage to reaching stable fruiting and the production of fruits with desirable traits. Vegetative propagation methods (cuttings and marcotts) were developed as a feasible and reliable propagation option compared to seedlings for precocious and quality fruit production in *D. edulis*. However, the effects of these propagation methods on tree growth, phenology and fruit attributes have not been evaluated. A study was conducted on 12-year-old *D. edulis* trees of seed, cutting and marcott origins to evaluate the effect of propagation methods on tree growth parameters (height, crown diameter, collar diameter, diameter at breast height (dbh), phenology (flowering, fruit yield), and fruit traits (fruit length, fruit with pulp thickness and kernel weight). The results revealed that trees of cutting origin were tallest (10.92 ± 0.46 m), with the widest crown (9.84 ± 0.28 m), collar diameter (26.49 ± 0.89 cm) and dbh (21.06 ± 0.90 cm) compared to trees of marcott and seed origins 12 years after establishment. Flowering rate was highest in trees of marcott origin (70.6%) while the highest number of fruiting trees was recorded amongst trees of cutting origin (83.3%). Fruits from trees of marcott origin were generally superior in fruit traits (fruit length, fruit with pulp thickness) than trees from cutting and seed origins. The findings of this study suggest that *D. edulis* trees of vegetative origin are superior in growth attributes, fruit yield and fruit traits compared to trees of seed origin. Thus, it can be concluded that trees of vegetative origin will bring early returns in terms of fruit quality, yield and income which are incentives for investments in the large scale cultivation of *D. edulis*.

Keywords: *agroforestry, domestication, fruit traits, indigenous fruit trees, propagation methods*

PP3.1.11. Viability of veneer industry and its implication on poplar cultivation

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The state of Jammu and Kashmir, especially the valley of Kashmir, has rich diversity of agroforestry species which are in existence since time immemorial and are based primarily on the natural occurrence of trees out of which poplar has a great significance of commercial importance. Almost 36 species of poplar trees are grown throughout the state out of which farmers make a good source of income and

also sustain the thriving veneer and ply board industry of the state. The veneer and ply board industry in the state is new in origin and came into existence in the late eighties. Previously, the ply industry of the neighbouring states was thrived on the raw material (core veneer) base of the Kashmir valley and in turn the state had to import the finished ply and its products worth of INR 300 crores annually. A total of 27 units surveyed under UGC sponsored study showed the cost benefit ratio of 1:1.41 of the veneer industry. A strong backward linkage of veneer units with suppliers of raw material was observed. The suppliers of poplar logs are traders who buy from the farmers/growers of poplars throughout the valley and supply to these industrial units. On average, 42 people are employed in one veneer unit with six as permanent and the rest as casual staff. These units generally operate for a time period of eight to nine months in a year and remain closed during the winter season. The procurement of raw material is within the state. Most of the veneer core (about 73%) gets exported outside the state and only 27% is supplied to the ply board industry within the valley. The government had fixed a processing limit of 1.8 lakh CFT per unit per annum but they were found to operate beyond that to minimize their fixed investments per unit output. The entrepreneurs revealed that the capacity utilization of plants is basically influenced by the demand of veneer core from the ply board industry operating outside the state. Value addition to the tune of 66.85% was observed in the veneer industry. The study showed that the veneer industry is plays a great role in creating demand for poplar cultivation which benefit the farmer who generally implants on marginal and waste lands.

Keywords: *Kashmir valley, poplar cultivation, veneer industry, viability*

PP3.1.12. Agroforestry domestication potential of a native tree species in Vanuatu

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Traditional gardens in Vanuatu provide household food and some cash income from excess crops. The gardens are generally grown for several years and then left for fallow. The fallow has potential to support tree crops, and the combination of gardens to achieve weed control and tree crops to provide income from fallow has potential to greatly improve household incomes. The use of trees also has potential to clarify land tenure issues. The native tree whitewood (*Endospermum medullosum*) is an excellent timber species with potential in many growing situations. This paper presents results of work showing there is a large available high quality land base which is underutilised and weed infested. Growth rates of whitewood are high with potential for improvement and the wood properties are excellent including ease of processing and drying, stability and permeability to preservative. There are also existing domestic and high value export markets. Trials of whitewood have been established in a variety of situations including mixed agroforestry gardens, old coconut plantations and in single species plantations. Planned work on areas such as nutrient cycling during the fallow period and wood product development for value chain improvement will also be outlined.

Keywords: *Endospermum medullosum, Pacific, timber, whitewood*

PP3.1.13. Wheat performance and soil properties under high density plant geometry of fast-growing tree species in north Indian plains

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In India, wheat is increasingly being intercropped with poplar, *Eucalyptus* and other tree species. Poplar, *Eucalyptus*, bakain and *Luecaena* are the successful fast growing tree species in India with extremely high productivity up to 40-60 m³/ha/yr. In view of limited information, the present investigation was conducted to identify suitable tree species and its spacing combination for productivity of mixed agroforestry system in north India. Four tree species viz., *Eucalyptus camaldulensis* (Eucalyptus), *Populus deltoides* (Poplar), *Melia azedarach* (Bakain) and *Leucaena leucocephala* at varying spacing (3.0 m×1.0 m, 3.0 m×1.5 m, 3.0 m×2.0 m, 3.0 m×2.5 m) was laid out in split-plot design with 3 replications. Under different tree species, the grain yield reduced by 46-57.0% as compared to sole crop with minimum reduction under poplar and maximum under *Eucalyptus*. The highest wheat yield was recorded in 3.0 m×2.5 m spacing under all the tree species. The tree DBH and height varied among the tree species and were adversely affected by tree spacings with maximum (188.0 m³/ha) volume recorded for poplar having an annual increment of 17.44 m³/ha. Whereas, the minimum (32.69 m³/ha) volume was achieved in bakain with annual increment of 9.38 m³/ha. Organic carbon (O.C.) increased understorey trees as compared to open control which observed lowest O.C. (0.83 %) with highest increase (58%) in poplar and lowest in bakain (21.6%) over control. Highest available N, P and K content (180.5, 17.7 & 169.6 kg ha⁻¹, respectively) were observed under *Leucaena* (3.0 m×2.0 m). Bulk density (1.47 Mgm⁻³) was higher under poplar and bakain (3.0 m×2.5 m). Therefore, poplar followed by *Eucalyptus* with 3.0 m×2.5 m spacing has proved to be superior for wheat intercropping. However, spacing of 3.0 m×1.0 m was more remunerative than other species-spacing combinations as the loss of wheat yield was compensated well from the production of timber.

Keywords: high density, fast growing tree species, soil properties, wheat and yield

PP3.1.14. Effect of moisture conservation and nutrient management on growth of *Eucalyptus pellita* plantation

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On a global scale, soil moisture conservation methods have been recognised to play an important role in solving the problem of erosion, siltation of lowlands and retaining the productivity of lands. Soil moisture and nutrients are critical for better growth. There is need to diversify suitable techniques of soil moisture conservation and also nutrient management for better productivity of plantations. A field experiment was carried out at farmers field, Dasankoppa of Sirsi Taluk, Uttara Kannada District of Karnataka during 2010-2011 on “effect of moisture conservation measures and nutrient management on growth of *Eucalyptus pellita* plantation” with four main treatments viz., trapezoidal staggered trench, conservation pit, ring trench and control and four sub treatments viz., 200:100:200 N, P2O5, K2O (Kg/ha), 250:125:250 N, P2O5, K2O (Kg/ha), 125:75:75 N P2O5 K2O (kg/ha) + FYM (5t/ha) and control with all the combinations. Significantly, higher plant height increment was recorded in trapezoidal staggered trench with 200:100:200 N, P2O5, K2O (kg/ha)

from 3 to 12 months after treatment (MAT) *i.e.* 1.27 to 5.25 m. Plant diameter increment (4.48cm) and crown diameter increment (10.86cm) were significantly higher in trapezoidal staggered trench with 200:100:200 N, P₂O₅, K₂O (kg/ha) 12 MAT. The number of branches (25.33) and volume increment (10.02 m³/ha) recorded significantly higher in trapezoidal staggered trench with 200:100:200 N, P₂O₅, K₂O (kg/ha) 12 MAT. Soil moisture content at 0-30 cm depth in treatment receiving trapezoidal staggered trench with 200:100:200 N, P₂O₅, K₂O (kg/ha) was maximum 12.43 percent at 10 MAT and soil moisture content at 30-60 cm depth in trapezoidal staggered trench with 125:75:75 N, P₂O₅, K₂O (kg/ha) + FYM (5t/ha) was 13.16 percent.

Keywords: *staggered trench, conservation pit, ring trench, plantation*

PP3.1.15. Studies on seed germination and storability of Rohida (*Tecomella undulata*)

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Tecomella undulata (Sm.) Seem, a member of the family *Bignoniaceae*, is popularly known as ‘Rohida’ in the arid zone of India and is valued for its high quality timber and medicinal value. Due to the large-scale cutting of trees with slow growth and poor regeneration, it has become a threatened species. The present investigation was carried out on Rohida seeds. The seed material was collected from four different seed sources viz., Churu, Ding Mandi, Jhumpa and Rajgarh. The present study was conducted during 2005 to 2006 at the nursery area of the Department of Forestry and Laboratories, Department of Seed Science and Technology and Department of Forestry Chaudhary Charan Singh Haryana Agricultural University, Hisar. The objective of the investigation was to evaluate different seed sources for seed viability, germination and seedling growth behavior; and to determine the storability of rohida seed.

Various morphological characters of rohida trees from four different geographical locations were recorded and seeds were collected from the selected trees. Seed quality parameters such as seed size (length and breadth), colour, test weight, germination percent (74%), speed of germination (13.63%), radicle (6.30 cm) and plumule length (5.30 cm), seedling dry weight (415.60 mg), dehydrogenase activity (1.40), electrical conductivity, vigour index I and II, were studied of freshly harvested seeds and then stored in ambient storage conditions. The seeds of all the four different places were aged artificially at various times (24, 48 and 72 hours) and temperature (40±1⁰C) variables. Accelerated ageing of seeds for 24 hours at 40±1⁰C produced a clear separation and provided better results. Then seeds of all the four different places were tested to study physiological basis for loss in viability. It was observed that standard germination, seedling length, dry weight, vigour index I, vigour index II and viability percentage was found maximum in Rajgarh seed source.

Keywords: *germination, seed quality, rohida trees*

3.1.16. Vegetative propagation of *Corymbia* (*C. torelliana* X *C. citriodora*) hybrids rejuvenated through micropropagation

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Corymbia citriodora syn *Eucalyptus citriodora* is a tall tree of up to 51 m and *Corymbia torelliana* syn

Eucalyptus torelliana grow up to 30 m. Both are native to Australia and are used as timber. Natural hybrids between *Corymbia citriodora* and *C. torelliana* were reported for the first time in India by Kapoor and Sharma (1984). The hybrids produced a high degree of hybrid vigour and 3-5 times superiority in growth than their parent species in field. Besides, some of the recombinants possess better fibre characteristics than their parents and also showed resistance to insects. The farmers/planters will be interested in growing *Corymbia* hybrids for both wood chip (short rotations of 6-8 years) and for sawlogs (moderate length rotations of 15-18 years). But there was lack of availability of these hybrids to the farmer despite demand because *Corymbia* spp. shows low amenability to vegetative propagation (Lee 2007). In vitro propagation has been a powerful tool for the multiplication of such hybrids by maintaining their hybrid vigour. To multiply *Corymbia* hybrids in mass scale, a strategy was adopted; first the development of juvenile material through in vitro propagation followed by macro propagation. The former was achieved at the Forest Research Institute, Dehradun and plantlets were grown for 8 months in hardening chamber. A study was conducted for the rooting of micro-cuttings from micropropagated material under intermittent mist condition. Seasonal effects and auxin combinations were studied. Data revealed that up to 55% successful rooting was obtained in 5000 ppm Indole Butyric Acid (IBA) during June. These rooted plants attained a maximum height of 35 cm in three months and were ready to plant during post monsoon. IBA-induced rooted plants were healthier compared to those from IAA and NAA.

Keywords: *Eucalyptus*, recombinant, tissue culture

PP3.1.17. Assessment of growth characters of bamboo spc under rainfed conditions in humid tropics

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Bamboo occupies an important place in the sociocultural and religious life of Indian communities. Their multifarious use by rural and tribal production depends upon inherent variability. Being a fast-growing species available in the tropics, its importance increases day by day. Bamboo has also been called the poor man's timber as it is available at a much lower price compared to others woods. An attempt was made to compare the performance of ten species of bamboo viz., *Bambusa nutans*, *B. tulda*, *B. arundinacea*, *B. polymorpha*, *B. burmanica*, *B. vulgaris*, *Dendrocalamus strictus*, *D. longispathus*, *Pseudoxytenanthera stocksii* and *Yushania waghiana* in the humid lateritic condition of Konkan region of Maharashtra. The growth parameters viz., total number of culms per clump, new culms per clump, diameter of 5th internodes (cm), length of 5th internodes (cm) and height of bamboo (metre) were recorded annually after five years of plantation. These ten species of bamboo were planted in 2004 in randomized block design with three replications at spacing of 4 x 4 meter. These were grown naturally. It was noticed from annual and pooled data analysis of four years that there were statistically significant differences among the ten bamboo species in all the five parameters. The total number of culms per clump was recorded highest by *Pseudoxytenanthera stocksii* (12), followed by *Bambusa arundinacea* (11.78). The maximum diameter of 5th internodes and length of 5th internodes was significantly superior in *Bambusa nutans* than the other species, whereas the highest height was reported in *Bambusa arundinacea* (7.72m) followed by *Bambusa burmanica* (7.05 m). Overall *Bambusa nutans* was found to be the most superior bamboo species among ten species in most of the parameters in the Konkan region of Maharashtra.

Keywords: *bamboo species*, growth parameters

PP3.1.18. Agroforestry domestication potential of a native tree species in Vanuatu

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Traditional gardens in Vanuatu provide household food and some cash income from excess crops. The gardens are generally grown for several years and then left for a fallow. The fallow has potential to support tree crops and the combination of gardens to achieve weed control and tree crops to provide income from a fallow has potential to greatly improve household incomes. The use of trees also has potential to clarify land tenure issues. The native tree whitewood (*Endospermum medullosum*) is an excellent timber species with potential in many growing situations. This paper presents results of work showing there is a large available high quality land base, which is underutilized and weed infested. Growth rates of whitewood are high with potential for improvement, wood properties are excellent including ease of processing and drying, stability and permeability to preservative. There are also existing domestic and high value export markets. Trials of whitewood have been established in a variety of situations including mixed agroforestry gardens, old coconut plantations and in single species plantations. Planned work on areas such as nutrient cycling during the fallow and wood product development for value chain improvement will also be outlined.

Keywords: *Endospermum medullosum*, Pacific, timber, Whitewood

PP3.1.19. Impact of open and regulated market on the pricing and receptivity of trees culture in Haryana (India)

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The share of the agriculture sector in the total GDP has declined rapidly (24.2%) after 1980/81 (34.8%) and this trend will continue. Indian agriculture is characterized by small farm holdings. The average farm size is only 1.57 hectares. Crop diversification, as one of the strategies to deal such situations, is intended to give a wider choice in the production of a variety of crops in a given area so as to expand production related activities on various crops and also to lessen risk. The crop diversification has also roped in agroforestry to improve the land productivity per unit area and income. India has about 2.5% of the world's geographical and 1.8% of the forest area. Forest in India cannot meet the demand for timber, industrial and fuelwood on a sustainable basis because of poor growing stock, low growth rate, inadequate financial and technical inputs, and biotic pressure. Improving productivity of degraded forests and encouraging farm and agroforestry by using genetically superior material may provide relief. Apart from saving in foreign exchange, such plantations would help in greening India, conserving our natural forests, providing vast employment opportunities, and generate sustainable incomes for local communities. A survey was conducted on marketing and receptivity of farmers for adopting the tree planting. The data of open auction of standing tree was collected from the research farm of CCSHAU University, Krishi Vigyan Kendras at Kurukshetra, Yamuna Nagar and Kaithal, and College of Agriculture Farm, Kaul. Information regarding the adoption of plantations of different tree species and their marketing was collected from 100 farmers of each district of Panchkula, Yamuna Nagar, Kurukshetra and Kaithal (Haryana). It was observed, in an open auction of different tree species for the period 2005-2013, that standing trees were sold at higher prices as compared to those offered by the

Forest Corporation, Government of Haryana (India). During the survey, it was also observed that 86% farmers were interested in planting the genetically superior seedlings on their farms, but they faced a lot challenges in marketing. Thus, policy must be framed at national level, not only for marketing, but also for increasing the forest area.

Keywords: *agriculture, diversification, tree*

PP3.1.20. Genetic improvement strategies for promoting *Melia composita* Willd. under agroforestry systems

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Melia composita Willd. is an important deciduous member of family Meliaceae which has been gaining significance among the growers under various farm and agroforestry systems. Native to the Indian Sub-Continent, it is emerging as one of the most acceptable raw materials for ply and pulp wood industries. The species not only has greater adaptability to various geographical and climatic conditions across different states of India, but also has the potential to overcome well known limitation of *Populus deltoides* to grow only under limited geographical areas of North India and decomposition of leaves. Demand for industrial as well as other woods has been growing rapidly and has resulted in an ever-increasing gap between demand and supply. The demand could either be met by increasing total forest cover or by promoting production of genetically improved planting stock under various farm and agroforestry systems. The former seems to be an impossible task, and therefore the second option ought to be the only possible way for sustainable development. However, availability of genetically improved planting stock for the species is non-existent, and therefore selection plus trees was carried out using index method based on height, diameter at breast height, straightness, clear bole height, crown diameter and knots, and genetically divergent genotypes were characterized to suite to agroforestry systems. Genetic evaluation of different progenies is being carried out in different geographical conditions to analyse stability and adaptability for screening suitable genotypes. The genotypes which survive and sustain in the toughest as well as rainfed conditions are expected to play a crucial role. The programme would essentially ensure development of appropriate ideotypes for various agroforestry systems with sustainable water to grow even under degraded regions, and contribute substantially in carbon sequestration when deployed commercially.

Keywords: *Melia composita, genetic improvement, agroforestry, adaptability, geographical regions*

PP3.1.21. Short rotation trees in agroforestry: A tool for enhancing income through industry linkage

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Forest-based industry has traditionally been developed with the subsidized and committed supplies of wood from government forests. Timber harvest and its supply to the industry were almost truncated during the last two decades when many states stopped green felling from government forests. Ever-increasing demand for wood as raw material for various forest-based industries and shortage of supply of raw material supply from state owned forests compelled the industry to depend on the trees outside the forests such as trees from the farmland and other non-traditional forest areas. In the recent years,

agroforestry play a crucial role in supplying wood for various wood based industries such as pulp and paper industries, wood panel and plywood industries etc. Realizing the importance of agroforestry as a source of meeting their raw material, many forest-based industries in the country approached the farmers to grow trees and which has been found successful especially in drier parts of the country. In this, context it is prudent to present the success story of a farmer and industry linkage on farm grown wood. In the area the farmer has been cultivating Eucalyptus since 1984 with an objective of supplying fuelwood to tobacco curing units around Hunsur and Periyapattana taluks of Mysore district in Karnataka. He could not harvest and sold the produce till 1996 and realized that fuel wood would not fetch attractive returns. However, the liberalization of tree felling and transportation rules on farm grown eucalyptus in Karnataka made the farmer to establish linkage with the Western India Plywood Industry, Kannur, Kerala for supply of raw material. Since then, the company is buying the wood and other leftover materials from the farmer. The wood with bark on wet weight basis is being purchased at farm gate and the price is negotiated on an annual basis. As of now, the farmer has taken 5 rotation of eucalyptus with rotation age of 3-4 years. Wood yield realized was 75 tonnes ha⁻¹ during first harvest, 112 tonnes ha⁻¹ during the second harvest 87 tonnes ha⁻¹ during the third harvest. Later the yield started gradually declining and it was less 20 tonnes ha⁻¹ in the last rotation. The farmer could negotiate the price of Rs. 900 per tonne in 1996 to Rs. 2500 per tonne during 2012. Based on his experience the farmer concluded that on average, he is realizing an average return of around Rs. 35000 ha⁻¹ per annum with eucalyptus-based agroforestry with industry linkage.

Keywords: *Industry, short rotation, linkage*

PP3.1.22. Trademarks, geographical indications and eco-labels to promote biodiversity: the case of agroforestry coffee in India

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The district of Kodagu also called Coorg in the Western Ghats of India produces two percent of the world's coffee in complex and biodiversity-rich agroforestry systems. The expansion and intensification of coffee production has reduced the forest cover by more than 30% in 20 years. New techniques (especially irrigation) and access to agrochemical inputs have reduced farmers' dependence on environmental services provided by shade trees such as preservation of soil fertility, control pests and diseases, and maintenance of a microclimate suitable for coffee. Under these conditions, reconciling rural development and conservation of natural resources requires proactive schemes, connecting sustainable agricultural practices to payment of environmental services, coffee value addition and farm profitability. PES can take the form of a value addition scheme for goods originating from the target ecosystem. These products may derive a quality or reputation from the ecosystem and be identified by their geographical origin, whose name is registered as complex trademarks or as geographical indications. Alternatively, the products can be produced according to practices guaranteeing the continuous delivery of ecosystem services, certified via eco-labels. The study shows that none of the eco-labels are adapted to preserve the rich tree diversity of the coffee agroforestry systems of Coorg as this would require specifying a threshold of 30% of *Grevillea Robusta*, a condition far beyond the standard of Utz or Rainforest Alliance. On the other hand, a GI specifically tailored for Coorg could also include biodiversity-friendly practices adapted to local context, especially to deter the increasing trend of managing mono-specific exotic canopy cover. Yet, GIs are mainly seen as relevant for specialty coffee with high organoleptic qualities, which is not the case of Coorg Coffee, and explains the choice for trademarks registration, with no specification regarding cultivation of coffee.

Keywords: biodiversity, PES, eco-labels

PP3.1.23. Hybrids of *Eucalyptus torelliana* Hook. and *Eucalyptus citriodora* F.V. Muell.: suitable species to increase productivity

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Eucalypts are widely planted in many countries due to wide adaptability, fast growing and short rotation. It supports industries for pulp, paper, furniture, cellulose, poles, etc. It is intensively used to produce energy from charcoal that reduces the net production of greenhouse gases. Spontaneous interspecific hybrids of *E. torelliana* x *E. citriodora* (Syn. *Corymbia torelliana* x *C. citriodora*) were planted in the year 1987 and characterized for morphological traits and heterosis. Some of the hybrids have shown good performance in terms of volume and straight bole. Recently a gall wasp has been noticed in many clones of eucalyptus. So far, the gall insect problem has been reported in 26-year-old parents and hybrids of *E. citriodora* and *E. torelliana* as well as in young seedlings of these species. There is urgent need to produce eucalyptus clones which are free from pest and disease and having high productivity. Attempts have been made to propagate the hybrids of *E. torelliana* x *E. citriodora* which are not available in the market. Success has been achieved in propagating these hybrids through vegetative means via conventional method.

Keywords: spontaneous, interspecific hybrids, *E. citriodora* and *E. torelliana*

PP3.1.24. Socioeconomic and household's contribution of African conophor nut, a neglected livelihoods product full of promise

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Conophor nut is a strong rambling vine which originates in the humid tropical forests of West and Central Africa. This liana is cultivated for its multipurpose needs. Seeds are used to provide cholesterol-lowering properties oil. They are also used in medicine as well as leaves, bark and roots to cure several diseases. New surveys in six villages of Cameroon, involving 35 smallholder farmers reveal its huge potential to bring socioeconomic and environmental gains. It also reveals areas needing research and intervention, such as seedling production, storage, processing and marketing for smallholders. Besides its nutritious seeds which can be eaten raw or cooked, or sold for cash, cocoa farmers grow the vine for the partial shade its high canopy provides to their cocoa orchards. Inventories in agroforests reveals that mature vines are heavy, fully grown plants can attain a diameter of up to 17cm with a density of about 14 plants/ha. Another survey with 93 retailers and wholesalers interviewed in Yaounde city and its surroundings indicated that they wished the supply of the vine would more steady, as there was a strong and ready market in the entire sub-region. A 15-kg bucket of raw, unshelled nuts costs from 7,000 to 12,000 FCFA (US\$10-18); depending on the season and where it is bought. A major hindrance to improved production of the vine is the unavailability of planting material; not a single nursery in the

survey area sold its seedlings, and the only way farmers could obtain them was from neighbours who had germinated them from seeds. Then there are many improved techniques developed by ICRAF that farmers and nursery owners can learn and apply to the vine. Also value chain development work is needed that will allow farmers to reap livelihood benefits from cultivating the vine, as well as research into better processing and storage methods.

Keywords: *cocoa agroforests, conophor nut value chain, multipurpose seeds, planting materials*

PP3.1.25. Major achievements of WCPM-SARA to promote agroforestry and clonal plantations for better gains

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The West Coast Paper Mills Limited, Dandeli is a leading paper manufacturing industry actively engaged in plantation activities under its CP Project through CFF under the aegis of SARA and has covered more than 45000 acres of planting area. WCPM-SARA is duly certified with FSC-FM certificate for Well Managed Group Plantation since 2011. All the plantation activities are running under the aegis of SARA, which is a non-governmental, non-profit organization registered under Karnataka Societies Registration Act 1960, in 2001. To date SARA has covered around 8000 member farmers. The plantation activities are done on farmer's wasteland, barren, fallow land to promote plantation amongst farmer communities to raise their living standards and employment generation from plantations. These activities are done through a simple agreement i.e. Contract for Farming for five years. Farmers are getting good income from their plantation. Under plantation, superior planting material of various pulpwood species suited to particular conditions i.e. Eucalyptus, Subabul, Casuarina & Acacia were planted. SARA is also promoting agroforestry along with plantation programme. SARA is also providing free fodder to the livestock of farmers and free fuel wood to the rural community. Various types of fodder grass such as *Stylosanthes scabra*, *S. hamata* are grown with plantation. Farmers are also adopting Intercropping with various crops like Cashew, Peanut and Ginger. WCPM-SARA has set up a hi-tech clonal nursery in its campus and producing 50-60 lacs/year of clonal saplings. We have harvested our first rotation crop in some area and till date we have received 1 lac MT of pulpwood from the plantation. The yield from the plantation is coming around 35-40 MT/acre after five years. This type of activities will prove a boon for farmers as well as for industry, which are in great crisis of wood. It will conserve our Natural resources, HCVF and will reduce the pressure on Forest for wood.

Keywords: *captive plantation, contract for farming, Eucalyptus*

PP3.1.26. Economic efficiency of pulpwood based agroforestry models in Tamil Nadu

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Global demand for paper and paperboard was 402 million tonnes in 2011. In India, 759 paper industries with the growth of 10 per cent demanded 21.92 million m³ of pulpwood during 2011-12. In Tamil Nadu, Tamil Nadu Newsprint and Papers Ltd, and Seshasayee Paper Board demanded 8-9 lakh tonnes of pulpwood from casuarina and eucalyptus plantations of Tamil Nadu Forest Plantation Corporation, partly from farmlands and the rest from Bagasse and other agricultural residues. The gap of nearly 1.5 -

2.0 lakh tonnes per year could be from the Tree outside Forest area (farm lands). The quantum of supply from farms is chiefly decided by farmers' resource use efficiency and their economic efficiency. This paper examined the resource use efficiency and economic efficiency of pulpwood based agroforestry with Cobb Douglass production function and Data Envelop Analysis (DEA) in Erode, Karur and Namakkal districts. One taluk per district, two blocks per taluk and five villages per block and five farmers per village were selected to the total sample size of 150. In both eucalyptus and casuarina based agroforestry models; the seedlings and inorganic fertilizer and machine hours were significant. The mean technical efficiency of eucalyptus and casuarina sample farms was 0.79 and 0.92. The mean scale efficiency of eucalyptus and casuarina farmers was 0.86 and 0.95. The technical efficiency among the eucalyptus and casuarina sample farms could be increased by 21 per cent and 4 per cent respectively through the best use of available production resources. The mean allocative efficiency of both eucalyptus and casuarina farms was 0.82. Allocative efficiency implies that both yields of eucalyptus and casuarina farms could be increased by 18 per cent in the study area through the optimum use of resources in given their respective prices. The economic efficiency of eucalyptus and casuarina indicated that 35 per cent and 25 per cent of production costs could be saved as per the best practiced farms producing the same output. The non-availability of adequate hired human labour (57.82) was the most important constraint in both eucalyptus and casuarina production and followed by water scarcity, monsoon failures and natural calamities, long duration of tree crops and lack of timely credit facility.

Keywords: *technical efficiency, agroforestry, paper industries, DEA*

PP3.1.27. Complementarities of intercropping in Casuarina junghuhniana pulp wood production system in Tamil Nadu, India

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A field experiment was conducted at T. Goundampalayam, Tamil Nadu in 2008-2010 to screen suitable intercrops and tree spacing for intercropping in a plantation of *Casuarina junghuhniana* in a split plot design with four spacing as main plots viz., 2 x 1m, 2 x 1m paired row, 2x2 m and 1.5x1.5 m and seven intercrops viz., cowpea, black gram, groundnut, gingelly, tomato, bhendi and small onion as subplot treatments with three successive intercropping. *C. junghuhniana* with 2x1m paired row spacing (7500 trees ha⁻¹) accommodates more trees, highest volume production and highest net return. Cowpea, groundnut and black gram emerged as suitable intercrops and had beneficial effects on mean tree volume per hectare. The highest organic carbon, available N, P and K was recorded under the 2x1m paired row spacing. Cowpea and groundnut showed significantly highest nutrient status and the sole crop of trees had the lowest fertility status. Economic analysis also revealed that 2x1m paired row planting of trees with the intercrops viz., cowpea or groundnut had the highest benefit-cost ratio. Land equivalent ratio also exposed that tree + cowpea and tree + groundnut combinations gave the highest LER. All the tree + intercrop combinations showed LER>1 implying that intercropping is advantageous in *C. junghuhniana*. In a high input based agroforestry system with clonal plantation of *Casuarina junghuhniana*, it is recommended that 2x1m paired row planting of trees, with intercrops of cowpea, groundnut or black gram for one year, is ideal and mutually benefitting for economic and overall improvement of this *Casuarina junghuhniana*-based pulp wood production system of 36 months rotation.

Keywords: *agroforestry model, Casuarina junghuhniana, intercropping, pulp wood*

PP3.1.28. Genetic improvement strategies for promoting Melia composita Willd. under agroforestry systems

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Melia composita Willd. is an important deciduous member of family Meliaceae which has been gaining significance among the growers under various farm and agroforestry systems. Native to Indian Sub-Continent, it is emerging as one of the most acceptable raw materials for ply and pulp wood industries. The species not only has greater adaptability to various geographical and climatic conditions across different states of India but also has potential to overcome well known limitation of *Populus deltoides* to grow only under limited geographical areas of North India and decomposition of leaves. It is a known fact that demand for industrial as well as other woods has been growing rapidly that has been leading to ever increasing gap between demand and supply. The demand could either be catered by increasing total forest cover or by promoting production of genetically improved planting stock under various farm and agroforestry systems. The former seems to be an impossible task, and therefore the second option seems to be only possible way for sustainable development. However, availability of genetically improved planting stock for the species is non-existent. Selection of plus trees was carried out using index method based on height, diameter at breast height, straightness, clear bole height, crown diameter and knots, and genetically divergent genotypes were characterized to suite to agroforestry systems. Genetic evaluation of different progenies is being carried out in different geographical conditions to analyze stability and adaptability for screening suitable genotypes. The genotypes which survive and sustain in toughest as well as rainfed conditions are expected to play a crucial role. The programme would essentially ensure development of appropriate ideotypes for various agroforestry systems with sustainable water to grow even under degraded regions, and contribute substantially in carbon sequestration when deployed commercially.

Keywords: *Melia composita*, genetic improvement, agroforestry, adaptability, geographical regions

3.2 Biofuels: using trees as a sustainable energy resource

PP3.2.1. The role of short rotation coppice technology in fuelwood supply in Rungwe District, Tanzania

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Households in developing countries depend primarily on wood fuel as a source of energy. However, the role of Short Rotation Coppice (SRC) Technology in fuelwood supply and offsetting CO₂ emissions in the Tanzania and most African countries remains poorly understood. This study was carried in Rungwe district, Mbeya region in Tanzania to determine trends, extent and drivers of adoption of SRC; identify various sources of household energy; and assess the contribution of SRC to the total household fuelwood needs; and trees and shrub species used as sources of fuelwood. Data were collected using reconnaissance, field and social surveys and analyzed using the Statistical Package for Social Sciences (SPSS). Results revealed that 97.5% of the local community adopted the SRC technology since the 1960s. *Eucalyptus spp* are mostly planted in woodlots and field boundaries while *Persea americana* and *Leucaena leucocephala* are intercropped in farmlands. The survey indicated that out of 176 tonnes of

fuelwood used annually, 73% comes from SRC technology, 25% from non-SRC technology, and only 2% is purchased to supplement household fuelwood shortage. Thus local communities depend heavily on biomass energy from woodlots and farmlands where tree species like *P. americana*, and *Eucalyptus spp* play a key role in meeting the energy demand. This study demonstrates that SRC technologies like woodlots, boundary planting, and intercropping in farmland hold high promise to meet the household energy demand. If promoted and backed with strong policies and supportive land tenure, these technologies may reduce the harvesting pressure on native forests for energy demand and contribute to climate change mitigation and adaptation.

Keywords: *bioenergy, boundary planting, Tanzania, woodlots*

PP3.2.2. Developing Populus ilicifolia as a bioenergy agroforestry tree species and genomic research tool for adaptive evolution

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Many species in the genus *Populus* and their hybrids are economically valuable, fast growing, short rotation woody crops for producing wood, fibre, and biofuels, as well as sequestering atmospheric carbon in large plantations and agroforestry settings. Industrial facilities to produce liquid transportation fuels from *Populus* feedstock are currently being built in the USA. *Populus ilicifolia* is endemic to three river valleys in Kenya and is the only extant member of this genus in the tropics. *Populus ilicifolia* is listed as a vulnerable species in the IUCN red list. The major threats are habitat degradation by cultivation of river valleys while in the protected areas, heavy floods, and large herbivores uprooting mature and young trees along the river systems. Unlike its relatives in the Americas, Europe and Asia, *P. ilicifolia* has received very little attention for utilization and conservation. Incorporating this species into ongoing tree improvement and genomics research on temperate *Populus* species is expected to have tremendous economic and scientific benefits to Kenya. The genome of *P. trichocarpa*, a member of this genus, has already been fully sequenced. Use of marker-assisted breeding that reduces the tree improvement period by more than half would be the best approach. Preliminary analysis using amplified length polymorphism (AFLP) and flowering locus specific markers revealed significant genetic variation that can be exploited in the species improvement strategy. Further genomic research will not only enable *P. ilicifolia* improvement for biomass production, stress tolerance, and wood properties via breeding and biotechnology using advanced genetics and genomics tools, but also facilitate a research on adaptive evolution hence giving more insight to species response to climate change.

Keywords: *bioenergy, conservation, genomics, Populus ilicifolia*

PP3.2.3. Effects of arbuscular mycorrhizal inoculations and cotyledons removal on early seedling growth of Pongamia pinnata (L.)

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Pongamia pinnata, a fast-growing oil seed producing tree legume, has the ability to grow on wastelands. It can be utilized for biofuel plantation on such lands. The preconditioning of young

seedlings during the early stage of development with efficient arbuscular mycorrhizal (AM) fungi confer several benefits, which enhances the possibility of their establishment in fields after out-planting from nurseries. But before recommending these fungi for inoculation, the suitable AM species must be identified. Therefore, to find out the potential AM species, nine purified fungi (isolated from different sites) were tested for their growth promotion activity. The inoculated fungi were not able to increase the seedling growth. Some fungi reduced growth, which was attributed to more utilization of carbon by fungal symbiont. Development of fine roots was delayed up to 30 days after sowing, hence their colonization by AM inoculants. This could be due to the large amount of nutrients stored in cotyledons of big *Pongamia* seeds. Removal of cotyledons significantly reduced seedling growth. Plants showed some extent of dependency on AM inoculants. Thus, it was concluded that AM inoculations should enhance biomass of *P. pinnata* only after depletion of metabolic reserves in its cotyledons and such mycorrhizal seedlings can be utilized for biofuel plantation.

Keywords: *Arbuscular mycorrhizae, biofuel, cotyledon removal, Pongamia pinnata*

PP3.2.4. Provenance variation in growth and fruit production of *Jatropha curcas* Linn. in

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Jatropha curcas, a drought-resistant perennial, is grown in the tropics and used mainly for erosion control, life fencing, medicine, fodder and bioenergy. In Africa, its cultivation for bioenergy would have development potentials as reduction of the dependency on domestic energy. However, little work on its genetic improvement has been undertaken. In order to quantify the genetic variability as part of domestication and for the production of improved germplasm in Mali, a provenance trial was established in 2010. Seeds were collected from 147 accessions from 68 provenances and landraces in 10 countries (Burkina Faso, Guatemala, Guinea Bissau, India, Kenya, Malaysia, Mali, Mexico, Tanzania and Uganda). Results show significant differences between provenances for all growth and fruit production parameters both in 2011 and 2012. Stem collar diameter and shoot height were higher for all accessions collected from Africa and Asia than those collected from America. There was no significant difference between African and Asian accessions. Ndebougou N14 and Kita mixture from Mali and Guatemala provenances were the best for collar diameter; while Acateno Puebla, Pueblillio, Tlapajoyan Veracruz, Huitzilán Puebla, Coytla, Cuautla Morelos and Zozocolco from Mexico had the least diameter growth. For plant height, Mazatepec Toxic and Mazatepec accessions from Mexico displayed the highest values compared to Coytla, Cuautla Morelos, Huitzilán and Zozocolco accessions also from Mexico that showed the least height growth. In 2012, accession 174 (Tierouala-Mali) was the best regarding fruit production (180.5g plant⁻¹) in contrast to 65 (Acateno-Puebla) and 79 (Huitzilán-Puebla) producing less than 5g plant⁻¹. These different accessions of *J. curcas* exhibited considerable amount of variation in growth and yield traits suggesting genetic variability of the plant material that can be captured through selection. However, the present study needs more observations in order to determine the magnitude of such variability, and identify the best provenances for Mali.

Keywords: *Jatropha curcas, provenance selection, genetic variation, bioenergy*

PP3.2.5. Performance of *Ocimum* species under *Pongamia pinnata*-based silvi-medicinal agroforestry systems in South Gujarat

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The present investigation was carried out at the Experimental Farm, ASPEE College of Horticulture and Forestry, Navsari Agricultural University, Navsari in 2011. Four *Ocimum* species viz., *O. sanctum* (S1), *O. tenuiflorum* (S2), *O. basilicum* (S3) and *O. gratissimum* (S4), were cultivated under four-year-old karanja (*Pongamia pinnata*) based silvi-medicinal (M1) and sole cropping (M0) system. Factorial Randomized Block Design (2 x 4) with three replications was used to analyze the data generated. Significantly higher plant height, collar diameter, number of branches and leaves per plant, fresh as well as dry above and below ground and total herbage (panchang) yield, essential oil recovery and oil yield of *Ocimum* species were recorded under silvi-medicinal systems as compared to sole cropping. Out of four *Ocimum* species, maximum plant height, number of branches and leaves per plant, higher fresh and dry above ground and total herbage yield and oil yield were recorded for *O. tenuiflorum*. Whereas, maximum collar diameter, below ground fresh and dry herbage yield were recorded for *O. basilicum*. Maximum leaf area and higher essential oil recovery was recorded from *O. gratissimum*. Among intercrops, *O. tenuiflorum* accrued highest net returns and BCR from herbage (Panchang) and essential oil irrespective of land use systems. The higher value addition realized due to differences in net returns from essential oil and panchang per hectare was accrued from *O. sanctum* and *O. tenuiflorum*. The findings of the study substantiate that integration of *Ocimum* species under karanja based silvi-medicinal systems proved beneficial due to positive tree crop interface giving higher yield, net returns and value addition. Thus, these systems can ensure early returns which can make karanja-based tree borne oil seed (TBOs) plantations economically sustainable.

Keywords: *Pongamia pinnata*, *Karanja*, *Ocimum* spp., *agri-silviculture*, *yield*

PP3.2.6. Biofuel trees species in agroforestry system –a source for agribusiness

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Biofuel plant species viz. pongamia, neem, simarouba, amoora, calophyllum are favourable for agroforestry. These trees help in maintenance of soil health and also as an energy source. The economics of these species are interesting with sustained benefits that account for >10% of agriculture income with least investment. The business model for villages sustain on the technology available to the farmers in the villages. The multipurpose equipment developed for use in villages has impact on value chain activities and benefit ecologically, and economically also meets the basic needs of farmers. Fruits harvested, processed and crushed in the village with appropriate machines for fruit dehiscing, seed decorticating, and oil expelling encourage entrepreneurship in the village. A village with 100 households with small (< 2ha), medium (2-5 ha) and large (>5ha) farmers growing 10-15 trees and 50-100 shrubs per hectare will fetch 350-400 kgs of oil seed per annum. The 100 households account for about 35 tonnes seeds. The oil extracted (28%) from the seeds is sold at a rate of INR 40/- per litre fetching income of IN R 4.0 lakh, while remaining oil cake will provide an income of INR 3.6 lakhs. The farmers get an additional income of INR 2.35 lakhs by value addition instead of selling the seeds which would have provided an income of IN R 5.25 lakhs.

Additionally 20-50 kg biomass from each tree serves as a source of green manure. Thus, each farmer would get additional income of about INR 7600 per annum. The average annual agriculture income of farmers in Karnataka is INR 52 650, while biofuels account for additional 15%; besides the carbon sinks are permanent and income generation is regular. A comprehensive model developed by Biofuel Park is presented.

Keywords: *Biofuel, Income generation, Multispecies*

PP3.2.7. *Pongamia pinnata* value chain of biofuels as an economic venture in agroforestry system

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Pongamia (*Pongamia pinnata*) is a leguminous semi-evergreen tree well suited for agroforestry systems with multiple benefits. The tree grown on the bunds of the farmers land can benefit with seeds, oil and oil cake which are of economical importance. The tree has a yield range of 15-200 kgs with an average yield level of 30-50 kgs. The oil content in the seed varies at around 27-40% based on the climatic and genetic parameters.

The seeds processed in mechanical expellers yield oil (28%) and oil cake (70%). The oil can be used as an energy source directly blending with diesel, also upon conversion into biodiesel; while the oil cake can be utilized for production of biogas and later slurry as manure. The cake can be used directly as manure or upon composting with nitrogen content varying from 4-5.5%. The cake through processing can also serve as animal feed locally by adopting simple techniques. Karangin, a natural plant protection chemical, is also obtained during the process for use locally, and also for some medicinal uses. The fruit shells accounting for 45-50% of fruit yield are used for briquetting for gasifiers and also in composting.

The oil is used for production of biodiesel with a minimum yield of 90% and the byproduct glycerine (10%) is used in the pharmaceutical industry as medicine and also in cosmetics. The value chain economics is presented in the paper which provides sustainable income of 8-10% of agriculture income from the marginal activity with about 10-15 trees per hectare.

Keywords: *Pongamia pinnata, value chain*

PP3.2.8. *Bioprocessing of lignocellulosic poplar (Populus deltoides Bartr.) wood for biofuel production*

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The plant based lignocellulosic biomass appears to be one of the most sustainable energy resources that can be used efficiently for production of liquid transportation fuel (bioethanol). Poplar (*Populus deltoides* Bartr.) is rated among the most promising feedstock for energy generation because of its low fertilizer requirement and suitability for agroforestry systems with several food and fodder crops. Its high cellulose content (~50%), low ash content and moderate lignin and hemi-cellulose contents make it a desirable feedstock for bio-ethanol production. However, despite possessing several advantages,

cellulosic ethanol has not yet been taken to commercial levels due to high costs, lack of cost efficient technology and robust cellulase that can function efficiently at harsh conditions of lignocellulosic bioprocess. Lignin fraction makes the biomass more recalcitrant towards hydrolysis with poor sugar yield and hence needs proper treatment. Considering these facts, present investigation was conducted for delignification of wood biomass and characterization of broad pH tolerant thermo-stable cellulase enzyme which can remain stable for efficient hydrolysis of the processed biomass. The indigenous bacterial isolates were evaluated qualitatively and quantitatively for cellulase production and the bacterial isolate (ARC3) showing maximum extracellular FPase, CMCase and β -glucosidase activities was selected and its cellulase complex was characterized. The enzyme was highly stable over broad pH and temperature ranges, retaining >90% and >70% of its maximum activities at the pH range 5-9 and temperature between 70-90⁰ C. The enzyme from ARC3 isolate was purified and used for saccharification of alkali pre-treated wood powder. Higher saccharification rate of 57% was achieved under optimized conditions using enzyme concentration of 24.95 FPU/g substrate compared to only 13.5% saccharification with untreated samples. Scanning electron microscopy (SEM) revealed the structural changes and lignin removal in alkali-treated samples before and after enzymatic saccharification.

Keywords: *bioethanol, biofuel, poplars, saccharification*

PP3.2.9. Retrospective on the hype: bottlenecks for jatropha bioenergy value chain development in Africa

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In Africa, the jatropha hype around 2006-2008 left many affected smallholder farmers confused and disappointed. Yet, after the burst of the hype, there have been very few assessments that critically examined the rather disorganized promotion of the crop and analyzed what had gone wrong on the ground.

This paper tries to analyze the factors and conditions which affected the viability of the jatropha biofuel value chain in Africa, with the following hypothesis –the recent jatropha boom in Africa failed to develop the opportunity for claimed benefits for economic development, because (i) the biofuel value chain, inherently more complicated than the value chains of other agricultural commodities and agroforestry products, remained under-developed and rudimentary in Africa, and/or (ii) the jatropha value chain in Africa (specifically Kenya) did not have an enabling environment like the biofuel value chains in other regions such as India.

This paper firstly describes the drivers and consequences (yields achieved, livelihood impacts) of the recent jatropha hype in Africa, with a Kenyan case as an example. Then the jatropha biofuel value chain in Africa is characterized, including (a) actors and technologies involved across the various stages of the chain –input procurement, production, distribution/transport, processing, marketing and consumption, (b) R&D status and capacity, and (c) policy environment. The complexity and maturity of the jatropha value chain in Kenya are compared with (i) the value chains of agricultural commodities/agroforestry products on one hand, and is compared with (ii) the biofuel value chain in India on the other hand.

The post assessment of the hype is expected to give important lessons to the development and research communities of managing the risks of the premature introduction of undomesticated biofuel crops and insights into future biofuel development in Africa.

Keywords: bioenergy, value chain, jatropha

PP3.2.10. Karanja (*Pongamia pinnata* L.) based agri-silviculture system under rainfed conditions

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In general, farmers are not interested to grow karanja in the agricultural fields because of small land holdings and no income during the initial years of establishment. But agrisilviculture can accommodate both the trees and arable crops. Intercropping, especially during the tree gestation period, could be economically profitable and is environmentally sound indeed, given the prevalent hostile environmental conditions in arid and semi-arid regions. After one year of karanja (*Pongamia pinnata*) plantation, four crops viz., cowpea (*Vigna unguiculata*), clusterbean (*Cyamopsis tetragonoloba*), dhaincha (*Sesbania aculeata*) and moongbean (*Vigna radiata*) were grown in the interspaces of trees separately for grain as well as fodder whereas was raised only for grain yield. The crops were raised as per recommended cultural practices of the region. During the period of experimentation, the crops were raised under rainfed conditions. The yield (grain and fodder) of different crops was not affected by the karanja trees during the initial four years. Karanja growth (height and diameter) was more in agrisilviculture as compared to sole plantation. Maximum height (300.00 cm) and diameter (89.2 mm) was recorded when karanja was intercropped with cowpea. Agrisilviculture system also improved the organic carbon and available N, P, K as compared to the area without trees. The lower net returns from agrisilviculture system were mainly due to the fact that during the initial years karanja plantation required some costs without any economic return. It is evident from the results that the cost of establishment of plantation can be met through intercropping during the gestation period of plantation and after that karanja will start producing seeds for biodiesel production.

Keywords: *Pongamia pinnata*, karanja, agrisilviculture, yield

PP3.2.11. Fuelling the future: poplar and willow as renewable bioenergy crops in Canada

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Globally, there is growing interest to utilize biomass from agricultural systems for the production of renewable energy. Canada has vast areas of agricultural land that can be utilized for biomass and bioenergy production without reducing the nation's capacity for food production. At Agriculture and Agri-Food Canada's Agroforestry Development Centre, we use fast growing native poplar and willow (*Salicaceae spp.*) to provide a sustainable and renewable clean energy resource. By incorporating biomass harvest in agroforestry systems we can provide cost effective utilization of agricultural land without land use change requirements. In addition, purpose-grown woody biomass on marginal agricultural land can reduce the environmental footprint (air, water, land) of Canada's current energy systems, while achieving long-term economic and social sustainability. Through advancements in agroforestry practices across Canada (i.e. riparian buffer planting in eastern Canada or smallscale agroforestry willow systems in the western Prairie Provinces), the woody biomass generated is used for carbon sequestration and low-cost heating purposes. Selection and breeding of superior feedstock for present and future climates occurs simultaneously, while gaining knowledge on fuel characteristics and

opportunities associated with it. The speaker will highlight some of these advances of renewable bioenergy crops managed through three-to-five harvesting cycles, particularly: (i) riparian buffers producing annual biomass of 25tDM ha⁻¹yr⁻¹ through nutrient interception and uptake; (ii) natural willow ring harvest surrounding wetlands with an annual re-growth of 4 tonnes ha⁻¹ of biomass, and (iii) a farm scale bio-burner producing 19GJ of heat per dry ton replacing 400 liters of heating fuel. The management of energy crops in agroforestry systems has the potential to provide energy-economic-environmental linkages for agricultural land-owners.

Keywords: *bioenergy crops, sustainability, woody biomass, renewable energy*

PP3.2.12. Genetic improvement of *Jatropha curcas* suiting to agroforestry module –biofuels for the rural poor

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The genetic improvements of feedstock for second generation biofuels have begun recently, but none of the feedstock has so far emerged with promising strain or variety combining desirable traits with proven outcome and scalable demonstration. *Jatropha curcas* gained recognition, hype and ultimately suffered neglect due to unwarranted extension around the world. The screening and evaluation of large indigenous collection of *J. curcas* from eleven states of India and from NOVOD sponsored trials were short listed for quality (oil content and non-toxic plants) and morphological traits. The CPT's identified along with few elite types were involved in intra and interspecific crosses and backcrosses and developed double and triple cross combining desirable traits and plants have been identified with high oil and seed yield in toxic and non-toxic background. The evolved genotypes with early flowering and fruiting, dwarf with optimum branch length and foliage different to the traditional architecture of *jatropha* will be planted in suitable densities to develop clonal orchards for development in agroforestry model/modules accommodating two to three species viz. *Pongamia*, *Moringa*, *Calophyllum* and *Azadirachta* with intercrops to initially support the stakeholders.

The systematic R&D efforts in *jatropha* summarized and performed elsewhere, indicate its comeback and we expect more efforts for improvement to harness full potential and plantation in agroforestry model to revive *jatropha* with stability and uniformity of genotypes, innovative cropping systems from monoculture to mixed cropping and to spread it to adjoining uncultivable land with models and modules, followed by plantation in degraded land.

The energy plantation programme with proven technology and case studies will highlight the synergies in research translating the dream of IFAD-ICRAF initiatives and address MNRE's and MDG's goal.

Keywords: *agroforestry, biofuel, dwarfing, *Jatropha curcas* breeding*

PP3.2.13. Biofuels: Energy transition and strategic necessity for developing countries

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The dangers of excessive dependence on oil require us to look at alternative ways to augment the supply of transportation fuel. There is a need to examine options that not only help reduce burgeoning imports, but also reduce harmful emissions. Biofuels offer promising prospects in this context. Biofuel crops are usually grown either to make Bio-diesel crops that are the quiet revolution, having the potential to be economically viable, less maintenance without huge capital investments or perfectly suited land. Bio-diesel in form of jatropha plantations enable communities in rural India to develop alternative energy options that will be good for the environment and help promotes suitable live hoods in the region, hopefully without exposing them to adverse effects of modernization, and allowing them to retain independence in the face of globalization.

Economic development in India has led to huge increases in energy demand, which in turn has encouraged development of the jatropha cultivation and Bio-diesel production systems. The establishment of the jatropha cultivation and local community based production of environmentally friendly bio-diesel fuel will benefit four main aspects of development and secure a sustainable way of life for village farmers and the land that supports them:

1. Renewable Energy
2. Erosion Control and Soil Improvement
3. Promotion of Women Employment
4. Poverty Reduction

Thus, jatropha cultivation and bio-diesel production should be a low risk venture with attractive returns but Jatropha refining is a challenge that will build the technical capacities of rural entrepreneurs. There are new works opportunities in jatropha cultivation and bio-diesel production related sectors, and the industry can be grown in a manner that favours many prosperous independent farmers and farming communities in future.

Keywords: *renewable energy, erosion, biofuels*

PP3.2.14. Biofuel trees species in agroforestry system – a source for agribusiness

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Biofuel plant species viz. Pongamia, Neem, Simarouba, Amoora, Calophyllum are favourable for agroforestry. These trees help in maintenance of soil health and also an energy source. The economics of these species are interesting with sustained benefits that account for >10% of agriculture income with least investment. The business model for villages sustain on the technology available to the farmers in the villages. The multipurpose equipment developed for use in villages has impact on value chain activities and benefit ecologically, economically also meeting the basic needs of farmers. Fruits harvested, processed and crushed in the village with appropriate machines for fruit deshushing, seed decorticating, and oil expelling encourage entrepreneurship in the village. A village with 100 house hold with small (< 2ha), medium (2-5 ha) and large (>5ha) farmers growing 10-15 trees and 50-100 shrubs per hectare will fetch 350-400 kg of oil seed per annum. The 100 households account for about 35 tons seeds. The oil extracted (28%) from the seeds are sold at a rate of Rs. 40/- per litre fetching income of Rs. 4.0 lakh, while remaining oil cake will provide an income of Rs. 3.6 lakhs. The farmers get an additional income of Rs. 2.35 lakhs by value addition instead of selling the seeds which would have

provided an income of Rs.5.25 lakhs. Additionally 20-50 kg biomass of from each tree serves as a source of green manure. Thus, each farmer would get additional income of about Rs. 7600 per annum. The average annual agriculture income of farmers in Karnataka is Rs. 52,650, while biofuels account for additional 15% of it, besides the carbon sinks are permanent and income generation is regular. A comprehensive model developed by Biofuel Park is presented.

Keywords: *biofuel, income generation, multispecies*

3.3 Improving nutrition through agroforestry: the business case

PP3.3.1. Vegetative propagation by stem cuttings of 12 fodder woody species indigenous to West African Sahel

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In the West African Sahel region, many woody species are used as fodder as they bear leaves with high nitrogen content during the dry season, contrary to grasses and crop residues. However, due to high pressure threatening these tree species, there is a need to find appropriate regeneration options to sustain availability of their fodder. Thus, a series of stem-cutting experiments were carried out with 12 fodder tree species (*Azelia africana*, *Balanites aegyptiaca*, *Bauhinia rufescens*, *Commiphora africana*, *Faidherbia albida*, *Ficus gnaphalocarpa*, *Guiera senegalensis*, *Kigelia africana*, *Pterocarpus erinaceus*, *Pterocarpus lucens*, *Pterocarpus santalinoides*, and *Terminalia avicinioides*) in non-mist propagators in Mali. Preliminary experiments did not show any difference between four rooting substrates for the rooting ability of *P. santalinoides*. Further experiments revealed two easy-to-root species, *P. santalinoides* and *C. africana*, showing high rooting ability (up to 95%), followed by *B. aegyptiaca* (up to 55%), in contrast to *A. africana* and *T. avicenioides* which did not root at all. Tree pruning and indole butyric acid improved the rooting capacity of cuttings collected from one month resprouts of *P. erinaceus*. Big diameter (15-20 mm) cuttings of *C. africana*, deeply planted, gave the best rooting success (up to 95%) in contrast to a smaller diameter. No difference was found between meristem and inter-nodal cuttings whereas lignified cuttings of *P. santalinoides* performed better than the non-lignified ones. Percentage of rooted cuttings varied from 10±2% to 75±9% for 12 genotypes of *P. santalinoides*. Finally 4000 ppm naphthalene acetic acid increased the mean number of roots (8.1±0.7 vs 2.7±0.2), while decreasing the number of secondary roots (6.2±0.6 vs 9.0±1.0) compared to the control. Results clearly indicate that *P. santalinoides*, *C. africana* and *B. aegyptiaca* are easily amenable to clonal propagation using low-cost non-mist propagators, but further work is required to improve the rooting ability of other species.

Keywords: *clonal propagation, rooting ability, tree fodder, non-mist propagator*

PP3.3.2. Physico-chemical characteristics and fatty acid profile of Balanites aegyptiaca kernel oil in Uganda

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The desert date, *Balanites aegyptiaca* (L.) Del., is an indigenous fruit tree common in the arid and semi-arid lands of Africa. Its fruits, available in the height of the dry season, contain edible pulp which is an important food for both humans and livestock. Balanites seed kernel is a source of highly regarded edible and medicinal oil. Both the fruits and oil are trade items in many African countries including Uganda. Because of its growing importance as a source of food and income for dryland communities, an assessment of the physico-chemical characteristics and fatty acid profile of Balanites kernel oil from three tree populations in Uganda was carried out. Balanites fruit samples were collected from Teso, West Nile and Karamoja sub-regions representing three tree populations. Laboratory analysis using standard procedures revealed that Balanites kernels constituted 19.5% of the nuts and the kernel oil yield was 44.5% (w/w). The colour of oil was light yellow with a refractive index of 1.46 at 20°C and viscosity of 15.75-22.60 cSt at 40°C. Saponification value of the oil was 186.28 mg KOH g⁻¹ while the acid value was generally low (1.33 – 1.95 mg KOH g⁻¹). Iodine value ranged from 98.20 to 103.32 I₂ g/100g. Balanites oil contained four major fatty acids; linoleic (39.85%), oleic (25.74%), stearic (19.01%) and palmitic (15.40%). It is concluded that Balanites kernel oil is potentially a good source of essential unsaturated fatty acids. Attempts should be made to increase its utilisation through improved processing and packaging techniques for the benefit of rural communities.

Keywords: desert date, fruits, kernels, nutrition

PP3.3.3. Potential of fruit trees in the drylands of sub-Saharan Africa for food and nutrition security and income generation

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Many fruit tree species in the drylands of sub-Saharan Africa (SSA) provide edible fruits which are locally of great importance for food security, nutrition and income generation particularly during droughts and the ‘hunger gap’ periods occurring at the beginning of the cropping season. Women and children are often strongly involved in and benefit from wild fruit collection, processing and trade. Cultivation of exotic and indigenous fruit tree (IFT) species in agroforestry systems diversifies production options for small-scale farmers and can bring significant health, environmental and economic benefits, particularly in the face of climate change. In this study we present case studies from different dryland regions in SSA to showcase the importance of tree fruits for nutrition and food security and for local livelihoods.

In Adjumani district, Uganda, 44% of 68 respondents reported to use the fruit pulp of *Balanites aegyptiaca*. 84% of the fruits were harvested from the wild mainly by children and women. In Mwingi district, eastern Kenya, the 104 respondents consumed fruits of 57 IFT species; 36 species were found on-farm and 21 in the woodlands. During the ‘hunger gap’ periods, at least 12 IFT species have mature fruits. In semi-arid eastern Kenya, mango farming generated mean annual incomes of USD 320 per household (n=87) from 77 mango trees on average. In the miombo region of southern Africa, on-going participatory domestication of *Uapaca kirkiana*, *Strychnos*

cocculoides and *Sclerocarya birrea* has developed new tree crops to capture economic opportunities while at the same time reducing the dependence and exploitation of wild tree populations. Similar efforts are under way in the West African Sahel, where *Adansonia digitata*, *Tamarindus indica* and *Ziziphus mauritiana* are currently being domesticated.

More efforts are needed in research and development to fully utilize the potential of fruit trees for improving livelihoods in the drylands of SSA.

Keywords: *agroforestry, exotic fruit trees, indigenous fruit trees, participatory tree domestication*

PP3.3.4. Agroforestry and the role of tree fruits for diversifying diets and improving nutrition

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Low fruit and vegetable intake is a contributor to micronutrient deficiencies in the developing world. The highest incidence of people that are chronically malnourished, especially vulnerable groups, such as women and children, is found in sub Saharan Africa (SSA), not to mention that East Africa has the least fruit consumption per person and day anywhere in the world. The triple burden of malnutrition – the coexistence of hunger, malnutrition and micronutrient deficiencies existing in many developing countries – can be approached through a diet diversification focusing on highly nutritious foods such as fruits that can be available throughout the year particularly during gaps of nutrient availability and hunger periods. To address nutritional gaps which usually occur due to seasonality of fruit production, we need to identify what fruits are available, accessible and utilized throughout the year, particularly for the most nutritionally vulnerable households. From a production perspective, seasonality and availability of certain fruits is important not only for consumption but also for value chain development and income generation.

In Kenya, knowledge gaps exist on the relationship between on-farm fruit production, availability of fruits for household consumption and for the development of fruit value chains to improve nutritional outcomes. This study is being undertaken in western Kenya and aims to identify key trends in gender-disaggregated preferences, attitudes and decision-making processes of rural households for fruit consumption, fruit production and the income generated from this activity. Document diversity and seasonal availability of fruit trees on farms, assess how this contributes to household fruit consumption and income generation and undertake food consumption surveys to identify nutritional gaps and the contribution of fruits to the overall diet.

Keywords: *fruits, sub Saharan Africa, nutrition*

PP3.3.5. Farmers tree preferences: opportunities and challenges for agroforestry product value chain development in Ethiopia

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Key challenges facing many developing countries like Ethiopia are food insecurity, unsustainable natural resource management and vulnerability to climate change. Agroforestry has been proposed as

having the potential to produce food in a more sustainable manner. This study aims to identify key tree products that can be used in an agroforestry system in the East and the West Shewa zones of Ethiopia based on their market potential, and to understand the opportunities and constraints in their value chains. Key informant interviews and Focus Group Discussions (FGDs) with key actors along the tree products value chains were used to collect data. Findings reveal that in general tree products are less of priority to farmers who tend to be more interested in food crops mainly cereals. The most important tree products as ranked by farmers in the East Shewa included Eucalyptus, Papaya, Coffee, Mango and Gesho. In the West Shewa zone the key include Coffee, Eucalyptus, Khat and Mango. Major constraints in the value chains of the prioritized species are drought especially in the East Shewa, inadequate supply of germplasm and lack of extension information for highly ranked species. Analysis of the competitiveness of the prioritized species indicates that for most of the tree species there is high level of demand which exceeds its current supply meaning there is no threat of competition among traders and producers. Furthermore, there are diverse sources of germplasm supply and hence no threat of substitutes which can erode profitability. It is recommended that for further promotion of the prioritized species there is the need to deal with water supply problems, provide extension services to the seemingly neglected species like Khat and Eucalyptus, supply planting materials and enhance better regulations for tree planting.

Keywords: *Porter's five forces, priority setting, tree planting*

PP3.3.6. Characterization of livestock grazing management systems in semi-arid areas of central Tanzania

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A study was carried out in agro-silvopastoral systems of semi-arid areas of Kiteto and Kongwa districts in central Tanzania to: (1) characterize livestock grazing management, and (2) identify institutions and institutional arrangements responsible on enhanced rangeland resource management. Data were collected using rapid appraisal, key informant interviews and rangeland assessment. Results revealed variability in grazing management systems in the two districts, mainly due to variability in the land use system. In the two districts on the onset of dry season, livestock are at first grazed on crop residues such as maize, sorghum and sunflower stovers, and groundnut straws. Agropastoralists in Kongwa district would continue grazing crop residues up to when rains resumes. In Kiteto district, after the crop residues are exhausted, the livestock are normally grazed on preserved pastures. In Kiteto district, livestock keepers set aside portions of pastures as deferred feed during rainy season for livestock grazing during dry season. The latter Maasai agro-silvopastoral system is locally known as '*Alalili*'. *Alalili* is an indigenous natural resource management system whereby Maasai agro-pastoral communities set aside portions/ enclosures of vegetation as deferred feed during wet seasons for livestock grazing during feed scarcity in the dry season. Two types of *Alalili* are recognized; *Alalili* and '*Alalili roho*'. *Alalili* refers to *in situ* forages set aside for older cattle. '*Alalili roho*' refers to portions of pasture set aside for calves normally near homesteads. Utilisation of deferred feed in *Alalili* is regulated by traditional institutions such as elders' council, which is known as '*Laiguanani*' in Maasai. The elders' council enacts by-laws governing utilization of the fodder resource. The by-laws stipulate when to engage into grazing of the deferred feed resources. The youth reinforce the enacted by-laws. The *Alalili* agro-silvo-pastoral technology and the associated crop residue-rangeland livestock grazing management represents one of the strong intensification and raised and feed resources in these semi-arid areas of Tanzania.

Keywords: *deferred feeds, fodder banks, indigenous knowledge, ruminants*

PP3.3.7. The role of trees, agroforests, and forests in nutrition-sensitive food and agriculture systems

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Experts note that improving global nutrition will require conscious and sustained efforts in health, education, economics and agriculture (Pinstrup-Andersen 2009; Swaminathan 2012). Forests and conservation have often been overlooked in these calls for cross-cutting attention to nutrition, despite their significant influence over land use planning and policy. Recently, researchers have investigated ways that forests enhance nutrient-density of local diets and nutrition-sensitivity of agricultural systems (in addition to contributions to income, safety-nets and ecosystem services). In many rural communities wild foods make important contributions to dietary diversity, often increase nutrient-density of local diets, and are culturally important in many traditional food systems. Although less important for staple crop production, forests and tree-based agricultural systems provide many under-consumed and nutritionally-important foods (fruits, vegetables and meat). An emerging body of research shows links between tree cover and fruit and vegetable consumption (Ickowitz et al. in review; Powell 2012), adding to previous research asserting their importance for fruit production (Jamnadass et al. 2011) and improved micronutrient intake (home gardens) (Jones et al. 2005). Agricultural landscapes that include significant forest or fallow frequently provide bush-meat. Forests also provide fuelwood, an essential component of many food systems. Some ecosystem services that forests supply are particularly important to nutrition: loss of genetic resources found in crop varieties and crop wild-relatives could have repercussions on the success of bio-fortification. Fruit and vegetable crops (among the most nutritionally important foods) are more sensitive to loss of pollination services (Eilers et al. 2011; Gallai et al. 2009). Overcoming global malnutrition will require food systems that are simultaneously productive, sustainable and nutrition-sensitive, through management of complex landscapes for optimized nutrition, not just agricultural production and biodiversity conservation. Trees and forests not only contribute to biodiversity conservation and sustainability of agricultural systems, but also to enhanced nutrition-sensitivity of food systems.

Keywords: *nutrition, trees, fruits, vegetables*

PP3.3.8. Food system pathway modeling and homegarden agroforestry for combating urban food deserts

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Rapid urbanization has greatly impacted food distribution in developing regions, creating so-called “food deserts”: areas where poor, newly urbanized populations lack reliable access to healthy, safe, and culturally acceptable sources of nutrition. Constraints in the route food takes from crop production to end consumer (Food System Pathways; FSP) create food deserts that exacerbate food insecurity at household-, community-, and national levels. This paper explores the potential use of GIS (Geographic Information System) mapping to identify FSP weaknesses that result in urban food deserts, and the

utilization of this information to predict future food desert formation. The paper describes how to alleviate or prevent the problem through the adoption of agroforestry technology at both the origin of the food system path and at its end, which is the food-deficient access point. The appropriate agroforestry technology for the point of origin will be circumstance specific; however, food deficits in the food deserts surrounding constrained urban food access points could be alleviated through the adoption of home garden agroforestry. Home gardens have been used to alleviate demand on overburdened rural producers, increase nutrient variety and availability for urban residents, and provide supplemental income for practitioners. In addition, the well-known environmental services provided through agroforestry use, including water and air purification, microclimate amelioration, and biodiversity promotion, will have additional benefits for urban populations. Ultimately, the combination of these technologies will be presented in a framework utilizable by governance administrators for decisions regarding policies that affect FSP.

Keywords: *agroforestry-policy, food-insecurity, GIS, urbanization*

PP3.3.9. Technique for improved crop of Tamarind (*Tamarind indica* L., *Fabaceae*) in the parklands of Mali

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The traditional agroforestry parkland is the most common agroforestry system in arid and semi-arid areas of West Africa. It provides an essential part of timber and non-timber products, and other environmental goods and services that are useful for the local population. However, aging of parkland trees and irregular fruiting make the agroforestry parkland very vulnerable. Moreover, its regeneration capacity is negatively influenced due to the displacement of isohyets and consequent droughts.

Tamarindus indica L. (tamarind) is one of the characteristic species of parklands in Mali. In the latter country, the population of *Tamarindus indica* is estimated at 6.5 million trees that cover an area of 23,672,603 hectares. Our study proposes a technique for improving tamarind cultivation aiming at increasing parkland biodiversity. Results show that the type of soil used as a culture medium has little effect on seed germination. Scarification using a knife has improved seed germination. In tamarind plantations of 31 months old, irrigation with 10 litres of water per week during two dry seasons had a positive impact on the height and root collar diameter growth, and on fresh leaves production and branching. The same plantations responded positively to a dose of 100 g of traditional manure 31 months after planting, by a significant increase in height and collar diameter. As a result of irrigation and fertilization, fruits could already be collected 38 months after planting, as opposed to just after 20 years in natural conditions. This means tamarind parkland enrichment is possible in the short term.

Keywords: *agroforestry, baobab, domestication, parkland*

PP3.3.10. Provenance variation for pod and seed germination parameters of *Cassia fistula* L. in agro-climatic zones of N. Karnataka

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Increase in forestry planting activities is often restricted by adequate supply of quality seeds. *Cassia fistula* L. is an important medicinal valued ornamental tree species and having the potentiality to be used in large scale afforestation programme. Studies were conducted on the physical attributes of pods and seeds *Cassia fistula* L. and germination parameters from five different agro-climatic zones of northern Karnataka. The seed size, weight and germination are the important traits considered for early selection of provenances and improving seed production. Seed weight can be used as one of the useful criteria for early selection of superior provenances. Results revealed that pods and seeds collected from hilly zone showed better pod and seed characteristics and germination parameters such as germination percentage (64.81%), mean daily germination (3.36), peak value of germination (1.91) and germination value (6.85). Hence this seed source can be used for mass multiplication of the species for large scale wasteland afforestation programme.

Keywords: afforestation, *Cassia fistula* L, seed

PP3.3.11. Phenotypic variation in fruits of wild mango (*Mangifera sylvatica*): Implications for domestication

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Many wild species produce edible fruits having prospective to be a potential source of food and medicine. Wild mango (*Mangifera sylvatica*) is a multipurpose threatened indigenous species of Bangladesh which has not been utilized and domesticated yet. The domestication of such indigenous fruits could be introduced in farming system in Bangladesh to support the nutritional needs and income security of local people. Information regarding tree-to-tree variation about fruit traits is pre-requisite for cultivar development indicating the potential for selecting superior planting material for good quality products. Phenotypic variation was assessed in fruits of wild mango from Bangladesh. Fruits were collected from 15 trees from three local provenances (Sylhet, Chittagong and Cox's bazar). They were segmented into peel, flesh and kernel. Each fruit was labelled and its portions were analysed. The overall mean fruit mass was 27.22 ± 0.91 g (mean \pm SE) but fruits from Cox's Bazar provenance were significantly larger (35.96 ± 1.17 g) than two other local provenances (Chittagong 17.85 ± 0.94 g and Sylhet 27.84 ± 1.37 g). The results showed a strong correlation between fruits and their components ($P < 0.05$) though tree diameter was very weakly correlated with fruit traits. Trees, mainly from the Cox's Bazar provenance, showed superior phenotypic traits (in terms of fruit weight, pulp weight, peel weight and kernel weight). This evaluation of fruit trait variability can assist conservationist to identify populations with desirable characteristics for domestication which ultimately promote food production at farm level.

Keywords: agroforestry, domestication, phenotypic variation, wild fruit, food production

PP3.3.12. Quest for an appropriate bamboo species in tropical home gardens - can *Dendrocalamus stocksii* (Munro) fit the bill?

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India has a rich diversity in bamboo with 23 genera and 130 species. In recent times there has been an emphasis on bamboo cultivation in private lands by National Bamboo Mission, Govt. of India. Farmers in peninsular India are generally reluctant to adopt bamboo in agroforestry practices unlike in North-East India. Though several bamboo species are found in Peninsular India, these are mostly difficult to manage due to excessive branching pattern, distorted shape or thorny habit. Therefore, we initiated a quest for an appropriate species and narrowed down to *Dendrocalamus stocksii* (Munro). The reasons behind the choice of the species and the likelihood of its acceptance in tropical home gardens in peninsular India is discussed.

D. stocksii is naturally distributed in Central Western Ghats, in Karnataka, Goa, Kerala and Maharashtra. It is a strong, solid and thornless bamboo that can attain a height of 10 m, diameter of 2.5 - 6.0 cm and internodal length of 15-29 cm. Presently, it remains confined to the coastal tracts where it is cultivated in homesteads, and in farm and community lands as live fences and/or block plantations. Multi-location trials have shown that this species performs well in humid, sub-humid and semi-arid zones, which expands the scope for its cultivation across peninsular India. On-farm trials have shown success in intercropping with *Ipomea batatas*, *Eleusine coracana* and *Curcuma longa*. Larger culms (>4 cm diameter) has demand in furniture and construction sectors while smaller culms (<4 cm diameter) find use in agricultural implements, handicrafts, fencing material, etc. In a few villages in Maharashtra, cultivation of this species is a major source of income and livelihood. The species also has an ideal ideotype for agroforestry. However, large-scale adoption is hampered by non-availability of planting stock. Lack of viable seeds and scalability issues in macropropagation techniques have led to the nascent steps in micropropagation protocol development. There is also an immense potential for improving species through selection and breeding programs.

Keywords: Central Western Ghats, *Dendrocalamus stocksii*, multifunctionality, tropical ecosystem

PP3.3.13. Morphological and biochemical characterization in the germplasms of *Terminalia chebula* Retz.: an important tree species

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The study was conducted at RHRS, Jachh, Kangra and College of Forestry, Nauni, in January-2011 to June-2013, to characterize on the basis of morphological and biochemical levels among *T. chebula* germplasms viz., Kothi (G₁), Paragpur-1 (G₂), Paragpur-2 (G₃), Kallar (G₄), Bhella (G₅) and Tamber (G₆). Morphological features for six germplasms of *T. chebula* investigated based upon qualitative as well as quantitative traits. The tree crown of all the six genotypes was observed to be round and the branching was spreading type. The bark colour of all genotypes was dark brown. Leaf colour of all the genotypes were observed to be dark green and in sub-opposite type of arrangement. The shape of the leaf was found to be elliptic in majority of all genotypes. Leaves of all genotypes were found to bear

entire margin. Thus, there was no useful variation observed except leaf base which was rounded in Kallar (G_4) and leaf tip that was acuminate in Paragpur 1 (G_2) which helped in distinguishing the two genotypes among the six studied in *T. chebula*. Among the six different germplasms, the higher fresh fruit weight (44.41) along with maximum values of fresh pulp/kernel ratio (18.06) and dry pulp/ kernel ratio (5.39) was in the fruits from Paragpur 1 (G_2) shows this plant source as a better genetic material for raising plantations on large scale. The present study confirms the need for domestication of *T. chebula* to be based on two ideotypes, one for fruit flesh [Paragpur 1 (G_2)] and the other for seed trait [Paragpur 2 (G_3)]. This study makes an attempt to provide comprehensive descriptive accounts of variation in fruit and seed traits, which provides an idea about the traits of interest for *T. chebula* domestication. It was also revealed from the study that there was considerable phenotypic variation in almost every qualitative fruit parameters measured including closely related traits. Also, there is an opportunity to identify a small number of key traits (of both fruit traits and seed traits) that together would form an 'ideotype' that combines highly desirable characteristics of potential value. The overall profile of various macro and micro minerals as well as other chemical constituents shows *T. chebula* fruits as highly nutritious. Fresh fruits of *T. chebula* can be used as a source of vitamin C in human diet either raw or in the form of 'Jams' and 'Murabba' so that these fruits become an important part of our diet to supplement human dietary requirements.

Keywords: domestication, descriptors, human dietary requirements, *Terminalia chebula*.

3.4 Building livelihoods on tree products

PP3.4.1. Cork oak woodlands: a case of sustainable cork (bark) harvesting in southern Europe

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Mediterranean cork oak (*Quercus suber* L.) woodlands ecosystems in traditional human-shaped landscapes of south-western Iberia, broadly referred to as cultural landscapes, are complex agrosilvopastoral systems. The key defining features of these woodland ecosystems are the dispersed patterns of the trees mimicking the savannas natural ecosystems; the multifunctional land uses; and the cork oak, the only non-timber forest product species in Europe, which is periodically harvested in the stem and branches for the bark (cork) throughout the tree's life.

Concomitantly, with an increasing economical value of cork, there is an increasing concern on the sustainability of the cork oak woodlands' ecological value as these ecosystems seems to be in a declining pathway. In fact, cork oak woodlands, similarly to other cultural landscapes, face problematic threats that directly affect the ongoing existence of trees, the keystones structures of these ecosystems. Particularly, cork oak woodlands are threatened by poor tree health, which may be the result of cork harvesting pressure. It is common knowledge that cork harvest constitutes a stress to the trees and severely depletes their vigor but, so far, there is no information on the impact of (recurrent) cork harvests on tree growth at the long term. In this study, we assessed the cork oak responsiveness and ecological resilience to cork harvesting stress, at the long term. The results obtained suggested that cork oak do not respond in a smooth way to human-induced loss of resilience, likely through recurrent cork harvestings. Instead, the tree vigour suddenly collapses under a stochastic event such as one determined cork harvesting occurring over a tree's life. These results may directly impact the traditional cork oak rotation period assumed in most management plans and the overall way that we so far manage our cork oak woodlands. These results are critically needed to support a sustainable management of cork oak

woodlands, the only way to preserve the ecosystem's ecological and economical values in resilient cultural landscapes in Mediterranean-climate regions and livelihood non-timber forest product systems.

Keywords: *Mediterranean, Quercus suber L., Cork harvesting, non-timber forest products, cultural landscapes*

PP3.4.2. Establishment of silvopastoral systems for growing poultry in rural communities of Sergipe, Brazil

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Silvopastoral systems have been shown to provide better environment for animal growth and function compared to open pastures. Chicken farming in silvopastoral systems is common in eastern Brazil. The objective of this study is to evaluate the poultry rednecks maintained under silvopastoral system in small rural communities. The agroforestry plots include fruit plants such as banana (*Musa spp*), mango (*Mangifera indica*) and jackfruit (*Artocarpus heterophyllus*); and forage legumes such as Gliricidia (*Gliricidia sepium*), Leucena (*Leucaena leucocephala*) and Mesquite (*Prosopis juliflora*). Day-old chicks were housed in a confined poultry shed for the first 28th days. From the 29th day the birds had free access to paddocks with availability of alternative foods such as cassava leaves attractive for adaptation to the pickets. The treatment adopted was the creation of semi-confined areas where birds were allowed to graze in the morning and confined in the late afternoon. Diets were provided and prepared daily according to the requirement of each stage of growth, along with availability of alternative foods (grasses, fruits, insects, worms, etc.) in the native pasture. The implementation of silvopastoral poultry production in rural small farms helps in improving animal health, nutrition and well-being. Poultry silvopastoral systems could be an important rural livelihood-generating practice in Brazil. Apart from that chicken has excellent nutritional value both for the consumption of meat and eggs, resulting in better nutrition for the population, generating rural livelihood, and avoiding rural exodus. Thus poultry silvopastoral systems can be recommended as a sustainable farming practice.

Keywords: *agroecology, chicken, pasture, sustainability*

PP3.4.3. Improvement of the local communities' livelihoods on the Kilenzi hills and the surrounding areas by planting fruit trees

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The hilly Kilenzi which has 12 villages has long suffered the problems of poor methods of farming that have resulted in heavy soil erosion. In addition, floods in the low lands have lead to increases in waterborne diseases with the people suffering from food insecurity and the low incomes from agricultural products and consequently, malnutrition and low levels of education have been prevalent.

Planting of trees especially fruit trees such as mangoes, jackfruits, avocados and oranges into the existing coffee and pineapple plantations has created opportunities for different stakeholders, from the fruit grafters to the growers, fruit traders and the fruit juice makers. This has resulted in increased

income and therefore education for the children. In addition, the elderly and the HIV patients can now afford medical care leading to a healthy village. Moreover, the peelings from fruits are used as fodder for pigs. The tea plantations on the hill were also planted with grivillea trees and the branches of these trees together with those pruned from the fruit trees are a source of fuel to the local communities and tea factories hence solving the problems associated with encroaching on forests. There is also increased income from both tea and coffee due to the shade given by trees. In addition to bringing about adaptability to climate change, the trees are a source of medicine such as the mango bark and the avocado seed. This high ecological diversity has also resulted in the production of quality honey.

Keywords: *food security, climate change adaptabilty, economic independence, livelihood improvement.*

PP3.4.4. Priority indigenous fruit trees in the drylands of East Africa: examples from Kenya, Tanzania and Uganda

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A study aimed at improving incomes and livelihoods of rural people from three East African countries through management, processing and marketing of indigenous fruit trees (IFTs) was undertaken by three public forestry research institutions in the region with technical backstopping from Bioversity International. Its objectives were to identify priority IFTs, understand communities' familiarity with IFTs and their usage in periods of food shortage, and identify constraints and opportunities for management and utilisation. 35 villages were sampled across the three countries where focus group discussions were conducted and a semi-structured questionnaire administered to 282 randomly selected respondents. Priority IFTs were found to vary between countries and also between sub-regions in the respective countries. Through a participatory process, four IFTs (*Tamarindus indica*, *Vitex doniana*, *Vitex mombassae* and *Sclerocarya birrea*) were selected as of priority for the region. IFTs were found to play a vital role in times of both food shortage and plentiful harvest. Despite several constraints identified, communities highlighted great opportunities for IFTs. Investments in terms of research for development are needed in this region to overcome the identified constraints so as to unlock the potential of IFTs for improving incomes and livelihoods of resource-constrained communities.

Keywords: *Sclerocarya birrea, Tamarindus indica, Utilisation, Vitex mombassae*

PP3.4.5. Standardization of agrotechniques for cultivation of Sarpagandha (Rauvolfia serpentina) under Poplar (Populus deltoides)

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Sarpagandha (*Rauvolfia serpentina*) belongs to the Apocyanaceae family, and is a medicinal crop. The part containing more than 30 alkaloides mainly serpentine & rescinnamine are age-old practices for the remedies of high blood pressure, fever, dysentery and insomnia. During recent years farmers of eastern

& western Uttar Pradesh have started the cultivation of Sarpagandha under agroforestry system using suitable management practices. A study was conducted at the research plot of the School of Forestry & Environment SHIAT, Allahabad on a project entitled “Standardization of techniques for cultivation of Sarpagandha (*Rauvolfia serpentina*) under Poplar (*Populus deltoides*) based agroforestry system” during the year 2009-2011, sponsored by CST, Lucknow. In the first trial there were three spacings (45 cm x 30 cm, 45 cm x 45 cm, 45 cm x 60 cm) and four levels of inorganic fertilizers (N15 P20 K15 Kg/ha, N30 P40 K30 Kg/ha, N45 P60 K45 Kg/ha, N0 P0 K0 Kg/ha) were taken under poplar based agroforestry system. In the second trial four levels of organic manures and three levels of irrigation schedule were applied. From the first trial it was observed that treatment **S2F3** [Spacing **S2** (45cm X 45cm) with inorganic fertilizer dose **F3** (N45 P60 K45)] was found to be superior under poplar based agroforestry system. Maximum economic returns were obtained in treatment **S2F3**. From the second trial it was observed that treatment **I2F3** [Irrigation schedule **I2** - once in 15 days during the hot dry season and once in 30 days during winter and organic manure dose **F3** (20 t/ha)] was found to be superior under poplar based agroforestry system. Highest economic return was observed in treatment **I2F3**.

Keywords: *alkaloides, agroforestry, standardization of techniques, organic manures, irrigation*

PP3.4.6. Hunger and undernourishment in forest areas: positioning wild edible plants into food security and nutrition debates

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To date, research and food security activities have not paid sufficient attention to the ‘household food consumption value’ of forest and agroforestry systems. This can be justified by the fact that although Wild Edible Plants (WEPs) are highly cited in scientific literature to contribute to the diets of forest dependent poor, little efforts have been made in creating food group categories that can ease their valuation in food intake and nutrition studies. As such, the nutrition status of forest people is not well understood and documented. Nutritional studies classify food staples, supplements and additives into specific food groups which give a first indication of the dietary content of food items. However, up until now, most literature considers WEPs as edible Non Timber Forest Products (NTFPs). These are often classified into groups as bush meat, honey, edible fruits, nuts, leaves, shoots, tubers, whole plants and fungi. From these categorisations, it is difficult to perceive the nutritional value of these products and to capitalise them in any food security effort. Thus, using existing NTFPs categorisations or food groups’ categories, mainstreaming WEPs into food security is still too basic to raise reasonable cognizance on WEPs food value and significance to promote their domestication.

Through desk review on food groups and by restructuring/regrouping isolated categories of NTFPs in literature, this paper presents the importance of WEPs in food security and nutrition and develops a categorisation of WEPs that captures their peculiarity, numerous nature and styles of utilisation as food to ease their valuation in nutrition analysis. By creating and describing 11 food group categories for WEPs, the paper develops an understanding on how WEPs could be mainstreamed into food security and nutritional activities and encourages the domestication of these species.

Keywords: *food security, forest area, nutrition, wild edible plants categorisation and domestication*

PP3.4.7. Determinants of farmers' participation in agroforestry products' markets in the Sahelian and Sudanian ecozones countries

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Market participation by rural farmers is considered as one way of reducing poverty, since it opens avenues for increasing net returns to agricultural production. Yet many farmers in sub-Saharan Africa continue to practice subsistence farming. In the Sahelian countries, gathering of AFTPs is one of the few livelihood activities that hold great potential for income generation and poverty reduction especially among communities or households living near agroforestry parklands and resources. This study examines factors that determine participation and the intensity of market participation by using cross-sectional data collected from 1080 smallholder agroforestry farmers in West Africa Sahel. The study identified three categories of factors, namely predisposing, facilitating and re-enforcing, which determine the probability of participation in marketing of agroforestry tree products by smallholders' farmers. Predisposing factors are those related to the structure of the household such as the proportion of family members less than 15 years old generally involved in the collection and harvesting of tree products for consumption and sale, the size of arable land as well as the number of mature trees located on the household's farmland. Facilitating factors are those related to transportation and communication assets. Ownership of a charette, a motorbicycle or a bicycle increases the probability of participation in the marketing of agroforestry tree products. Likewise, farmers who own communication assets such as a TV or a radio are more likely to participate as well as those with at least high primary or high secondary levels of education. Re-enforcing factors are related to institutions and infrastructure. The results indicate that in places where markets for tree products are not well organized, farmers located in areas with poor roads are less likely to participate in the marketing of tree products. Similarly, farmers practicing natural regeneration to some extent and those involved in other agricultural projects are more likely to participate in market activities. Ownership of customary rights such as those of investment and exploitation of three in the parkland tend to affect the intensity of market participation. Wealthier farmers are less likely to be involved in the selling of agroforestry products, indicating that marketing of AFTPs could be a preserve of poor households.

Keywords: *agroforestry farmers, intensity, market participation, West Africa Sahel*

PP3.4.8. Multiple benefits of charcoal briquettes as an option for building tree-based livelihoods in Kenya

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Charcoal briquettes provide an opportunity to supply cooking fuel to help meet the increasing demand for cooking energy while saving trees. To address poverty, unemployment and meet their cooking energy needs, poor urban communities, mainly women and youth, are turning to charcoal briquettes made by compressing charcoal dust into a solid unit and used like charcoal or firewood. Community groups in Nairobi manually produce charcoal briquettes from charcoal dust which they bind with soil or paper. Charcoal dust is preferred as it is already carbonized and readily available from charcoal stalls within the low income residential areas. Around 2.5 million tonnes of charcoal is traded annually in Kenya, providing energy to 82% of urban and 34% of rural households; and 15% ends up as charcoal dust.

Sustainable production of charcoal by increasing planting of trees on-farm, and enhanced efficiency of its use, will be key elements of Kenya's climate change adaptation strategy. Improved livelihoods are also critical. Charcoal briquette producers generate income and save money that otherwise would have been spent purchasing other types of fuel. Households that purchase briquettes also save money, as they are cheap, burn for many hours with low emissions, and are used on common cookstoves. They are a relatively clean energy source as well causing no soot on cooking pots; a desirable characteristic in low income areas where access to clean water is a challenge. It costs a household of five people, cooking a traditional meal of green maize and dry beans, USD 4 cents using charcoal briquettes compared to USD 35 cents using pure charcoal and USD 60 cents using kerosene. Despite the multiple benefits of briquettes, there remain numerous technological, financial, communication and policy-related research needs in scaling out this opportunity more widely as part of broader climate change adaptation and agroforestry-related mitigation strategies.

Keywords: *Tree-based livelihoods, Kenya, charcoal*

PP3.4.9. Conservation and socioeconomic importance of some agroforestry fruit tree species: farmers' participation, tree growth

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Deforestation and demographic pressures have greatly depleted the population of indigenous forest fruit trees that produce socioeconomically important Non-Timber Forest Products. With increasing deforestation and forest degradation, the conservation of these species may be farmer-driven. This study assessed farm-level growth characteristics of *Chrysophyllum albidum*, *Irvingia gabonensis* and *Garcinia kola* trees in rainforest and derived savanna ecosystems of Ondo State, Nigeria; farmer's participation in conservation of the species; and the market potentials of the products. Growth measurements were made on 50 trees of each species from five villages in each ecosystem. Two sets of questionnaires were used to obtain information from 30 farmers and 60 marketers of the fruits/seeds in six urban and rural markets from each ecosystem. The trees were old (mean age: 32.3–43.5 and 19.5–35.2 years for *C. albidum* and *I. gabonensis*) and large (mean dbh: 36.0–64.3cm; 19.5–61.3cm and 46.3cm for *C. albidum*, *I. gabonensis* and *G. kola*, respectively). Between 92.3 and 100% of the trees occurred within farmlands, depending on species and ecosystem. Farmers' participation in tree planting (conservation) was higher in derived savanna (40–80%) than rainforest (2–6%). Tree planting is male dominated (76.2–92.3%) while marketing of their products is female dominated (60–100%). Annual fruit production ranged from 500 to 1000, depending on species. Most farmers practice whole-tree fruit sale: marketers buy fruits while on tree and harvest at their convenience. Most farmers consumed about 40% of their fruits, and sold 60%. 100% and 7.1% of *G. kola* and *I. gabonensis* fruits, respectively, were processed before sale. Farmers earned USD 300 to USD1300 annually, with income highest and lowest at farm-gate and urban markets, respectively. Income from fruit sale contributed 21–52% to total household annual income, which is important at times of economic difficulties. Thus, planting more trees of the species could improve farmers' livelihoods and economic sustainability.

Keywords: *conservation, farmer participation, income, livelihood sustainability, forest fruit species*

PP3.4.10. Lac cultivation: Livelihood security for Bundelkhand farmers of Central India

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Lac is a natural resinous substance. It is obtained from a minute insect called *Lacifera lacca*. It sucks the sap of shoots and releases resin encrustations to form lac. National Research Center for Agroforestry, Jhansi is carrying out establishment, evaluation and promotion of Rangeeni lac in agroforestry system with the collaboration of Indian Institute of Natural Resins and Gums (IINR&G), Ranchi in Bundelkhand region of central India. The region is a natural habitat of *Butea monosperma*. It is found commonly in wasteland and cultivated land. Farmers also grow it for fuel, gum, donas, pattal, etc. On trial basis the brood lac was inoculated in trees available at the farm during 2008-2009. After successful evaluation of the crop, the cultivation was extended outside viz., Garhkundar watershed site (Tikamgarh, Madhya Pradesh), Joint Forest Management (JFM) site, Talbehat and on farmers' fields. The programme is running successfully and producing encouraging results. Two crops (*Baisakhi* or summer season crop: Oct-Nov to July and *Katki* or rainy season crop: July to Oct-Nov) can be harvested in this region. In 2010-2011, for the first crop the brood lac was inoculated during October 2010 and was inoculated in July 2011 at the site for the second crop. In *Baisakhi* crop the settlement of lac insect ranged from 35.2 (GKD WS) to 57.6 no./ cm² (JFM site) and lac input: output ratio was recorded as 1:3.8 at NRCAF, 1:3.4 at GKD WS and 1:3.2 at JFM site whereas for *Katki* crop it ranged from 17.1 (NRCAF) to 18.9 no./ cm² (JFM site) and lac input:output ratio was recorded as 1:4.2 at NRCAF, 1:3.2 at GKD WS and 1:2.8 at JFM site. The farmers can adopt lac cultivation as it fetches enough income without much expenditure, care and time and could be a good source of their livelihood.

Keywords: agroforestry, income, Lac, livelihood security

PP3.4.11. Role of private sector in promotion and sustenance of commercial agroforestry

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Private sector is one of the key stakeholders in the promotion and sustenance of agroforestry in India. It has developed symbiotic partnerships with farmers to grow trees in association with agriculture crops on their fields. This practice of growing trees and/or intercrops together on farm fields for their sale is often referred as commercial agroforestry which is now happening in many parts of the country. Acute shortage of wood raw material with its rising demand, declining availability from government forests, and inability of private sector to hold agriculture land for captive plantations forced many of them to promote tree culture to ensure adequate wood availability. It is also promoted under corporate social responsibility (CSR) by some and many others developed it as an independent business line. Paper & pulp and safety matches industries have been promoting tree culture belonging to a few fast growing tree genera like *Eucalyptus*, *Populus*, *Casuarina*, *Leucaena*, *Ailanthus*, *Acacia* etc. Short rotation cycles and high biomass production potential of these trees with assured buy back arrangements for wood led to the large scale adoption and sustenance of commercial agroforestry. The sector is actively engaged in sustaining the activity through production and supply of planting stock of genetically superior cultivars; developing new productive cultivars; providing extension, credit and R&D support; ensuring wood

procurement at market competitive prices; and acting as a single window for agroforestry solutions on selecting site specific tree species and cultivars, technical inputs on tending operations for quality wood production and integrated crops. Country faces chronic shortage of wood raw material for industrial and domestic needs and this land-use for its production is likely to continue, and even strengthen over the years. Policy and institutional reforms are urgently needed to strengthen back-end and front-end linkages for long term sustenance of this land-use system.

Keywords: *private sector, promotion, sustenance, commercial agroforestry*

PP3.4.12. On-farm tree planting in Ghana's high forest zone: promoting sustainable livelihoods for smallholders

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Managing forests and trees are major avenues for creating wealth and improving local peoples' wellbeing. Hence, Ghana has since year 2001 introduced a number of reforestation schemes meant to directly affect the livelihoods of forest communities, as well as restoring forest cover and addressing timber deficits. The Timber Resource Management (Amendment) Act 2002 (Act 617), which recognizes ownership rights of individuals who plant economic trees on farmlands encourages smallholder farmers to invest in tree planting ventures. Based on focus group discussions, interviews with key respondents and a household survey among 106 small-scale on-farm tree planting farmers from six villages in the Sefwi Wiawso, Asankrangwa and Offinso Forest Districts in Ghana's High Forest Zone, this paper analyses how local communities' involvement in reforestation initiatives can be promoted to serve as sources of livelihoods for smallholder tree planters. The findings indicate that land and tree tenure arrangements are major issues in the promotion of on-farm tree planting, hence, where supporting institutions facilitate the process, more positive livelihood outcomes are achieved. Moreover, the nature and level of institutional support and collaboration play key role in the overall success of on-farm tree planting by smallholders. Lessons can be drawn from the on-farm tree planting efforts in Ghana's high forest zone to improve climate change mitigation programmes based on reforestation initiatives in other tropical countries.

Keywords: *institutional support, livelihoods, local communities, on-farm tree planting*

PP3.4.13. State initiated forest and tree-based livelihoods: The case of government plantation development programme in Ghana

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As means to address deforestation and timber deficit, and to contribute to rural livelihoods in Ghana, a number of reforestation schemes were since 2001 introduced by the government of Ghana through the Forestry Commission (FC) under the National Forest Plantation Development Programme. Among these was the state-initiated scheme called the Government Plantation Development Programme (GPDP), implemented with funds from the Highly Indebted Poor Countries (HIPC) Initiative. Based on focus group discussions, interviews with key informants and a household survey in the Nkawie, Sunyani

and Offinso Forest Districts in Ghana's High Forest Zone, this paper analyses the effects of the GPDP on rural livelihoods and the governance conditions that contribute to the success of the programme. The results indicate that the scheme adopted a multi-stakeholder coordination and implementation processes which ensured a more decentralized approach to co-management, as plantation contract supervisors could relate to the Forest Service Division (FSD) office in terms of seeking technical advice and reporting. Allocation of degraded forest reserve land for plantation development was strategically done, ensuring well maintained tree farms. Plantation workers were motivated through strong social capital formation and additional cash and non-cash incomes from the integration of food crops. The plantation workers perceived the GPDP as a way out of poverty, mainly because: it increased their access to land for farming; it improved their income levels; they experienced positive changes in their household food security; their basic needs were met; it helped them to diversify their sources of income; and they experienced improved quality of life. However, the workers reported a number of challenges that limited the poverty reduction potential of the programme. These include unfavourable conditions of service, particularly delays in payment of wages and the lack of social security benefits, making workers feel job insecure. The study contends that state-initiated forest plantation development can be a good strategy for creating high value forest estates and enhancing the livelihoods of local people when effective management and monitoring mechanisms are put in place.

Keywords: *forest governance, forest-based livelihoods, Government Plantation Development Programme, poverty reduction*

PP3.4.14. Exploring the production and marketing of non-timber forest products as a driver of agroforestry practices in Nigeria

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Agroforestry is a multiple land use system with combination of agronomic and forestry crops. However, it has been discovered that farmers in most cases allow trees on their lands when such trees could provide products with socio-economic benefits. Non-Timber Forest Products (NTFPs) contribute to income generation and sustenance of rural economy. The products have been one of the major drivers of agroforestry due to safety net they provide to farmers in term of low yield or crop failure. This study therefore explored the NTFPs produced on farmlands and the socio-economic benefits accrued to the rural economy through marketing of the products in Southwest States of Nigeria. Multi-stage random sampling technique was used for the study. Field survey was used to identify the NTFPs produced on farmland while marketing chain analysis was used to identify and determine the actors and their roles. The top ranked NTFPs selected for in-depth study include *Tetracarpidium conophorum* (95.0%), *Irvingia* spp (95.0%), *Garcinia kola* (90.0%) and *Parkia biglobosa* (90.0%). Marketing of NTFPs is a source of income and employment to the stakeholders along the marketing chain. The marketing chain started from the producer (local farmers) to the village merchant, wholesaler, retailer and finally to the consumer. Majority of the farmers were into production of NTFPs and processing of the products is done at the household level. However, participation in the production and marketing of the NTFPs by the farmers significantly depended on the rate at which returns obtained from sales of the products meet their financial needs. In order to improve adoption and sustainability of NTFPs producing trees on farmland contribution to sustenance of rural livelihoods, there is need for value addition through provision of adequate processing technology and appropriate storage facilities at the rural level.

Keywords: *income generation, marketing chain, non-timber forest products, rural livelihoods*

PP3.4.15. Incentives and constraints of clove based agroforestry in the uplands of Java, Indonesia

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Inappropriate land use in upland agriculture generates a large external cost in the form of soil erosion, landslides, and sedimentation. The Upper Solo River watershed in Java, Indonesia, is our study area where rain-fed paddy and maize-cassava farming system are commonly practiced. High population density and constant demand for food crops put pressure on deforestation and mountainous cultivation, resulting in high soil erosion. Thus, appropriate agricultural practices are needed to mitigate soil erosion while increasing farmers' income.

To explore the reasons of soil erosive agriculture in uplands, household survey was conducted. The results of household survey indicate that most farmers allocate their farmland largely to food crops even though the clove production is much more profitable than food crops. In addition, clove trees have deep and extensive root system that can hold soil and prevent erosion, possibly allowing for sustainable agriculture in uplands. Questions arise why clove trees are still underdeveloped, in spite of the promise of significant of-site and off-site economic benefits.

This paper identifies incentives and/or constraints of agroforestry development in uplands where the access to market, food, and credit are in part restricted. Number of clove trees each household holds is an integer number, so we employ a count data model to investigate farmers' investment decision into clove trees. Incentive for clove trees turns out to be its high profitability. Clove production and their leaves bring about cash incomes throughout a year. Count data regression indicates that the number of clove trees are related positively to land area, land tenancy, education level, food availability, and number of cattle. One of the drawbacks of clove is the considerable time lag between the planting and time of commercial harvesting. Therefore, small land size, food insecurity, lack of education and financial assets are key constraints of clove based agroforestry.

Keywords: *agroforestry, Central Java, Indonesia, household survey*

PP3.4.16. Potential of bamboo in agroforestry systems for economic development of tribals

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India is one of the world's richest source of bamboo, have approximately 130 species and covering 9.57 million ha. It plays an important role in rural economy. In Madhya Pradesh, *Dendrocalamus strictus* and *Bambusa arundinaceae* occurs profusely. Farmers in many districts grow bamboo for its multipurpose use on farm bunds, homesteads and some earn substantial income. It is grown under agri-silviculture, agri-horticulture and silvipasture systems. Some agroforestry models with bamboo have been evaluated by Ahlawat *et al*, 2008.

Almost 85 percent of bamboo of the state is produced in Balaghat district. Bamboo clumps are also found in interior parts of farmer's field. Earlier middlemen purchased bamboo at Rs. 2/- each whereas prevailing market price was Rs. 20/-. Market interventions with good price have made many poor farmers rich and some have earned almost Rs. one lakh from bamboo harvest (Soni, 2010). However, farmers continue to sell middlemen on lumpsum basis which cuts their profits. Since, many districts of the state are deficient in bamboos and if planted on field bunds, farmers can make considerable income

with market inventions. Bamboo being a fast growing species attains maturity in four years and planting on farm bunds, wastelands, etc will help tribals in meeting their requirements and also earn income.

Keywords: *agroforestry systems, Bamboo, economic development, tribal*

PP3.4.17. Development and evaluation of indigenous fruit products in South Africa

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Indigenous fruit trees are ideally suited to semi-arid climatic zones, which make up a large part of South Africa. These crops can enhance food security, increase global competitiveness and increase diversification of the agricultural sector. Indigenous fruits have been neglected in the past and yet offer potential to rural communities that have for centuries been utilizing these fruits. The potential lies in the development of indigenous products or products containing indigenous fruits that could potentially attain niche status in different ways. A number of products utilizing indigenous fruits have been developed and evaluated. Fruit nectars, jams, dried fruit rolls and liqueurs were made using pulp from various indigenous fruits including *Dovyalis caffra* (various selections), *Engelerophytum magalismontanum*, *Parinari curatellifolia*, *Grewia livingstonei* and *Syzygium guineense*. Various blends were also made utilizing conventional fruits such as mango, guava, litchi and banana. The best products were refined and evaluated by sensory panels as it is essential to have detailed insights about the sensory characterization of these products, as this information is indicative of their acceptability and potential. The products all have a unique taste and have the potential to be developed into a niche market. These fruits can now also be processed and stored by rural communities for times when fresh fruit is not available. The potential also exists to utilize the indigenous fruit pulps in combination with conventional fruits to improve flavour, colour or texture resulting in unique products. This study has demonstrated commercialization potential of indigenous fruit products and more species will be investigated and processing techniques refined.

Keywords: *indigenous fruits, product development, juice, jam, sensory evaluation*

PP3.4.18. Development of *Dovyalis caffra* as a multi-purpose crop for rural areas of South Africa

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The kei apple (*Dovyalis caffra*) is indigenous to Africa's southern region, including occurring naturally in South Africa, Mozambique and Zimbabwe. In South Africa the kei apple is indigenous to the Kei river area and is abundant in the wild around the Eastern Cape, Kwazulu-Natal, Mpumalanga and Limpopo Provinces. It has been planted in gardens throughout South Africa and has become naturalized in areas where they would not normally occur. *D. caffra* is subtropical and can survive brief drops of temperatures to as low as -6°C. It does well in almost any type of soil that does not have a high water table. It is drought resistant and tolerates saline soil. Male and female flowers are borne on separate trees. Most people consider the fruit too acidic for eating out of hand even when fully ripe. The fruits are pleasantly flavoured and make excellent jelly and jam when ripe, and as pickles when under-ripe.

They are widely cultivated both for their fruits and as a hedge. Fresh ripe fruit contains on average 83 mg ascorbic acid (Vitamin C) per 100g fruit. Initial selection has been undertaken in the Nelspruit region of Mpumalanga and approximately 500 trees have been evaluated. Fruit yield was the initial criteria utilized for female trees and only trees producing good yields were further evaluated. Fruit size, total soluble solids and yield have been used as further selection criteria. Male trees producing large quantities of flowers were identified. Available fruit from the highest ranked selections were collected and fruit analyses carried out. The parameters studied were fruit mass, total soluble solids (TSS) and total titratable acids (TTA). Kei apples are easy to propagate and seed, cuttings, air layering, grafting and budding can all be successfully utilized. The kei apple has been planted throughout South Africa as a living hedge. Its thorniness, and since it is evergreen, it makes an impenetrable barrier keeping animals and trespassers out. Initial product development has been undertaken and various products including jams & jellies, nectars including blends with other indigenous and commercial fruits, dried fruit rolls mixed with other fruits e.g. banana and litchi and liqueurs, have been produced. The kei apple has been shown to be a multi-purpose tree with the fruit playing an important part of rural people's diets. Product development offers many opportunities for commercial production.

Keywords: *Dovyalis caffra*, selection, propagation, product development, rural development

PP3.4.19. Ethephon-Induced Gummosis in Kardhai (Anogeissus pendula E.) in semi arid region of Bundelkhand, Central India

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Anogeissus pendula E., locally known as Kardhai, is one of the major gum producing trees occurring naturally in arid and semi-arid areas, particularly in Bundelkhand region. It has acquired greater significance due to the expanding industrial application of gum and resins. For enhancing gummosis, ethephon (2-chloroethylphosphonic acid) has been used in several plants. However, its unscientific application for tapping gum leads to the death of plants. Therefore, standardization of proper dose and season of application of ethephon are pre-requisite for optimizing gum yield without deteriorating tree health. We standardized dose of ethephon and season of gum tapping by conducting a field trial on 15 years old plantation of *A. pendula* at Research Farm of National Research Centre for Agroforestry, Jhansi. Three doses of ethephon viz., 390 mg, 780 mg and 1170 mg of active substance were injected at base of tree-trunk in a hole made by tree borer. Each dose was applied on four trees and trial was repeated every month throughout the year in 2010-2011. The results revealed that maximum gum yield was obtained in the month of October followed by March. During rainy season and summer months, exudation in *A. pendula* was not observed. Dose of 1170 mg ethephon yielded highest gum (65.3g/tree) while 390 mg ethephon the least (37.5g/tree). The exuded gum was of a variety of forms viz. globular, tear shaped or irregular masses and good in quality. Use of ethephon did not show any negative effect on tree health. The study concluded that in view of negligible gum oozing from *A. pendula* in nature, application of ethephon @ 1170mg/tree in the month of October will enhance gummosis and gum, and provide livelihood options for tribal of poverty stricken Bundelkhand region in Central India.

Keywords: *Anogeissus pendula*, Ethephon, gum inducer, tapping technique

PP3.4.20. Structure and Performance of Important Timber Markets of Northern India

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In this study we analyzed the structure and performance of important timber markets of northern India by taking a representative sample of tree growers, pre-harvest contractors, commission agents and wholesalers/sawmillers from the Saharanpur, Yamuna Nagar, Amritsar and Hoshiarpur markets. It was found that Eucalyptus and poplar were the most prominent tree species as far as relative allocation of land to growing of different tree species is concerned. Only Saharanpur market is regulated market. The functioning of other markets was regulated by local marketing organizations like Poplar Safeda Arhatiya Sangathan in Yamuna Nagar and Lakkar Mandi Samities in Amritsar and Hoshiarpur. The timber markets are working under imperfectly competitive market situations tilted more towards oligopolistic nature of the market. Contractors and commission agents are the marketing intermediaries with whom producers deal directly. The channel involving producer - contractor - wholesaler/sawmiller - consumer is the most important channel through which bulk of the timber is transacted. However, in case of poplar and eucalyptus the channel: producer – contractor - commission agent - consumer was found to be more prominent. Producer's share for poplar ranged from 73.20 per cent in Hoshiarpur market to 77.50 per cent of consumers' price in Amritsar market. Similarly, in case of eucalyptus the producer's share ranged between 66 per cent in Yamuna Nagar market to about 80 per cent of the consumer's price in Amritsar market. Contractor's margins in Yamuna Nagar were estimated to be about 13 per cent of consumer's price for poplar and 20 per cent of consumer's price for eucalyptus. In other markets these were in the range of 4 to 8 per cent in the case of poplar and 3 to 5.9 per cent of consumer's price in the case of eucalyptus. A high degree of market integration was there in the selected markets for different timber species.

Keywords: *timber, markets, structure, performance*

PP3.4.21. Domestication of Selected Non Timber Forest Products species Under Agroforestry System

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The study attempts to understand the domestication potential of six commercially important wild plant species: *Annona squamosa* (Sitafal), *Buchanania lanzan* (Achar), *Chlorophytum borivilianum* (Safed Musli), *Commiphora wightii* (Guggal), *Embllica officinalis* (Aonla) and *Litsea glutinosa* (Maida). The study was carried out in two Forest Divisions (Hoshangabad and Sehore) of MP and three Forest Divisions (Baripada, Koraput and Rairangpur) of Odisha which are known for NTFP collection and trading. Domestication of these plant species was categorised in 4 stages viz., Stage 0: Uncontrolled harvesting; Stage 1: Regulated and controlled harvesting; Stage 2: Cultivation of wild species outside forest and Stage 3: Germplasm improvement for desired qualities in the cultivars. Five parameters viz. (i) Ecological status of plant species in natural forest; (ii) Social acceptability of species; (iii) Technical knowledge of domestication; (iv) Economic returns and (v) Policy and legal framework to promote the

domestication process, were used to determine the domestication potential of the selected species. A detailed set of criteria and indicators was also developed for assessing the feasibility of agroforestry in the study sites. The values obtained in each parameter were then used to rank the species potential for domestication. It was found that *E. officinalis* with a domestication potential score of 27 and *A. squamosa* (26) have high potential for domestication. These species are widely accepted amongst the farmers as compared to the rest. *B. lanzan* (25) and *C. borivilianum* (17) have moderate potential for domestication whereas, *C. wightii* (11) and *L. glutinosa* (11) have the lowest potential for domestication. These species were also found to be vulnerable to extinction from wild due to their unsustainable harvesting. It was found that agroforestry is feasible in both the states, MP (65%) and Odisha (58%). However, the policy environment and focus of the government to promote domestication of tree species is more favourable in MP with a policy score of 75% as compared to Odisha (50%), while social acceptability score was higher in Odisha (76%) as compared to MP (71%).

Keywords: domestication, NTFP, agroforestry system, feasibility study, criteria indicator

PP3.4.22. Potential of integrating gum yielding species under agroforestry system for livelihood enhancement

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About two-thirds of India's forests are classified as dry forests. Gum yielding species are commonly distributed in dry regions, yielding a significant quantity of gums. They are an important source of seasonal income as well as multipurpose species providing fruits, fodder, fuel, medicines, etc. Due to an open access system in forests and unsustainable harvesting practices gum yielding species have declined in dry forests of Central India. Therefore, there is an urgent need to plant and propagate such species *in situ* and under agroforestry systems. They can be an additional source of income to farmers, who plant these species on their farm bunds along with crops. This paper evaluates the potential of four gum yielding species viz. *Butea monosperma*, *Buchanania lanzan*, *Sterculia urens* and *Boswellia serrata*, integrated under agroforestry system for enhancing the income of small farmers. When planted on farm bunds can generate income ranging between Rs. 300 to 1600 per tree annually.

Butea monosperma, a multipurpose tree has been integrated traditionally in various parts of Central India under paddy crops and for lac cultivation on farm bunds, earning about Rs. 800 per tree annually by lac culture and Rs. 300 by gum besides providing fuel, fodder and leaves whereas, *Buchanania lanzan* planted on farms for its fruits (*Chironji*) and gum provide a farmer cash income of ranging between Rs 1600 to 3200 and additional income from gum. *Sterculia urens* tree yields an average income of Rs. 500 per tree in 90-120 cm girth class and can also be cultivated as mixed crop. *Boswellia serrata* also has potential for raised on farm bunds. These gum yielding species need to be integrated with farming in dry lands.

Keywords: Agroforestry models, Non Wood Forest Products, Habitations, Gum yielding tree species,, Livelihood

3.5 Public-private partnerships: adding value to develop markets for producers

PP3.5.1. Enabling higher productivity in smallholder agroforestry - not by magic, but by sub-sector assessments

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The inclusion of trees in farming systems through integration of trees on farms is central to the definition of agroforestry. The quality of trees included can be defined by the time it takes for tree products to reach maturity as well as the quality of the products. A major constraint facing productive smallholder agroforestry is the lack of investments in sourcing quality reproductive material and the lack of input supply networks that can be sustainable without massive project support. The diversity of species and agroforestry products may seem to make planning of seed input supply a daunting problem; and innovation in the agroforestry sector has been slow compared to the smallholder crop sector, where experimentation has been lively and where smallholders are now reaping the benefits of access to crops that are adapted to their circumstances and which can provide more profitable crops.

In this paper we describe how sub-sector assessment can provide a flexible tool that takes into account the variability in agroforestry situations and can identify leverage points for improving smallholder access to improved reproductive material. We demonstrate that for most species, planning of production and distribution must be done at a landscape level (invalidating the popular notion of community seed sources) and that support to networks is at the core of sustainable solutions.

We will provide examples from Asia and Africa to demonstrate our approach from several types of smallholder commodity production and how the characteristics of the species, sources, and value chains will determine what types of networks may be most likely to be successful. Our main message is that "one size does not fit all" and that perhaps the largest challenge for improving smallholder productivity is to realise the diverse opportunities and identify the most appropriate in a given situation.

Keywords: *networks and sources, productivity and quality, public-private partnerships, sub-sector assessments*

PP3.5.2. Potential of medicinal species under agroforestry system: a case study from Madhya Pradesh

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Traditional medicine is one of the important health care systems practised widely in India. A wide variety of medicinal plant species occur in Madhya Pradesh which is the second largest state in the country. But overexploitation has led to depletion of this natural resource. A demand-supply study was undertaken in Madhya Pradesh (Bhatnagar, 2010) to find medicinal species in great demand by Indian System of medicine (ISM) and the need for their domestication. Most of the ISM industries surveyed (n=371) revealed that out of 92 indigenous medicinal species utilised by Ayurvedic industries, 23 species were cultivated in farms. Thus one fourth of medicinal plants are sourced from farms. Some medicinal species have been in cultivated sector in western Madhya

Pradesh since decades like *Withania somnifera*, *lepidium sativum*, *Plantago ovata*, *Mentha* and *Cassia angustifolia* and trade well established. The last decade saw extensive farming by small farmers with support from National Medicinal Plants Board (NMPB). A number of medicinal species were tried with mixed results, *aloe* sp. *Acorus calamus*, *Asparagus racemosus*, *Ocimum sanctum*, etc. were successful. Farmers reported lack of markets in Central and Eastern MP for cultivated species. Since 80 percent of ISM industries are skewed to the western part of the state, cultivation is more viable there due to locational and market factors. However, it is encouraging to note that traders who earlier preferred to purchase medicinal plants from wild sources are now demanding cultivated species. If markets are linked properly the farmers, traders, herbal industries, processings units and exporters will benefit; and agroforestry system will ensure regular supply of raw drugs. The paper highlights some interesting findings for the development of the sector.

Keywords: *agroforestry systems, markets, medicinal species*

PP3.5.3. Agroforestry-based enterprises: a framework for evaluating the enabling factors for enterprise development.

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Development of agroforestry-based rural enterprises is a key strategy to ensuring sustainable livelihood improvement and income diversification for rural farmers. No matter the degree of complexity of these enterprises, be they single-owned businesses or large group-based ones, they depend on a host of enabling factors that are required for their development, functioning and success. The increase in on-farm productivity due to agroforestry interventions will necessitate a more extensive linkage between the farm and these enabling factors, to support the smallholder farmer to gain the maximum economic value for his/her production. This paper takes an in-depth look at what these enabling factors for agroforestry-based rural enterprises are, and will present a theoretical framework to analyse their level of influence on specific agroforestry products or product lines. In addition, the intensity of resources required to advance farmer engagement in agroforestry-based enterprises will be addressed. Based on enabling factors cited in literature, these can be broadly classified into three groups; increasing capacity at the grassroots level for households and groups, improving the linkage to markets and services, and creating a favourable environment for enterprises to flourish. The theoretical framework will support the development of a decision support tool for researchers and development practitioners to better evaluate and support agroforestry-based enterprises for sustainable livelihood outcomes.

Keywords: *AFTPs, enterprise development, income generation, value chains*

3.6 Valuing the environmental services of trees in the landscape

PP3.6.1. Productivity and carbon sequestration under prevalent agroforestry systems in the Navsari district of Gujarat

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An investigation was carried out in the year 2011-2012, in Navsari district of Gujarat. The agroforestry

systems were identified through field survey following Stratified Random Sampling in five 'talukas' of Navsari district –four major agroforestry systems i.e. agri-silvi-horticulture (ASH), agrisilviculture (AS), agrihorticulture (AH), and hortipasture (HP). AH system had maximum (3) system types: mango + sapota + lemon + coriander, mango + cabbage, mango + rice; followed by AS system representing two system types i.e. teak + sugarcane and eucalyptus + spider lily. ASH and HP systems had only one system type i.e. mango + teak + brinjal and sapota + grass, respectively. Besides these AS system was represented by two more system types, teak + rice and arjun + nagali (*Eleusine coracana*). However these system types were found with only one farmer. The data of biological and economical yield, and carbon sequestration were collected in one cropping season and analysed to find out the economic viability. Among woody perennials, eucalyptus under Eucalyptus+spider lily (*Hymenocallis littoralis*) gave significantly higher woody biomass. Among intercrops under different agroforestry systems, sugarcane under AS (teak+sugarcane) system gave maximum biomass. Total biological yield (all components) was higher from AS (system type Eucalyptus+ *Hymenocallis littoralis*) and minimum was from AH (mango + sapota + lemon + coriander) system. Among seven agroforestry system types, the highest carbon tonnes per hectare (tree + intercrop) was sequestered by AS [eucalyptus+spider lily, (*Hymenocallis littoralis*)] system. The most viable agroforestry system on the basis of NPV (Net Present Value), Benefit Cost Ratio (BCR), Equivalent Annual Income (EAI) and compounded revenue was ASH (teak + mango + brinjal) system followed by AH (mango + rice) system.

Keywords: agroforestry, carbon sequestration, agrihorticulture, hortipasture

PP3.6.2. Soil Quality Index (SQI) for assessing the soil health of agroforestry systems: a vital sign for sustainability

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The basic objective of advocating agroforestry land use was its soil conservation value because agricultural sustainability has a strong link with soil health. Further, the goals of water and air quality and carbon sequestration also rely on improvement in soil quality. However, restoration and revitalization of soil resources by agroforestry land use is guided by the complex array of interactions and management strategies. In this background, a study was undertaken at National Research Centre for Agroforestry, Jhansi to develop a composite Soil Quality Index (SQI) based on functional scores of minimum data set (MDS) of indicators comprising soil physical, chemical and biological properties; and to determine how indicators respond to different management practices. The study was conducted in a well-established 10-year-old *Albizia procera* based agroforestry experiment consisting of five treatments viz. control (pure crop), pure tree (without inter cropping), zero pruning+ inter cropping, 50% pruning+ inter cropping and 70% pruning + inter cropping. The pruned biomass was added in soil. Representative soil samples were drawn from 0-30cm depths from all plots for assessing soil quality through a MDS. The minimum and maximum thresholds were established for soil quality indicators and linear scoring function (LSF) viz. 'more is better, less is better and optimum' were generated in 0 to 1 scale. From functional scores of each indicator, a composite value of SQI was calculated. Findings revealed that maximum value of SQI was observed for the practice of zero pruning (0.566) closely followed by 50% pruning (0.522) and 70% pruning (0.548). Pure crop had the minimum SQI (0.430). Agroforestry plots viz. pure tree, zero pruning, 50% pruning and 70% pruning had improved soil health to the tune of 16.05, 31.63, 28.37 and 27.44 percent respectively over pure crop. Biological activities and water holding capacity of soil were most limiting indicators.

Keywords: minimum data set, soil conservation value, soil function, soil health indicators

PP3.6.3. Agroforestry carbon project for climate change mitigation and poverty reduction: project demonstration from Senegal

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Tree cover in agricultural lands in west-central Senegal is now around 1% (Christensen, 2010 *in prep*). There is an urgent need to work with farmers to develop sustainable land management plans that integrate trees more into farming activities. An initiative of carbon agroforestry project is being implemented. The project entitled ARLOMOM (Local Trees for a Better World) aims to support and enable farmers to develop tree planting and sustainable land management plans. These plans will combine existing and improved agricultural land uses with the planting of mixed native tree species, agroforestry systems and assisted natural regeneration activities. Tree planting and management will reduce land degradation and improve agricultural productivity. Payments for Ecosystem Services (PES) will provide local farmers with additional revenue. At the first stage, 31 male farmers and nine women's group farmers of about 25 women each are involved; 40 hectares of agricultural land have been secured for agroforestry, a total of 5000 trees of 13 local species have been planted and a quantity of 5095 T CO₂ will be generated. The PIN and the PDD have already been accepted by the Plan Vivo foundation and participants have already received their first payment for ecosystem services from EU funding. The project is well appropriated by local communities and it helps them to restore degraded land, contribute to carbon sequestration and biodiversity conservation, and improve non-wood forest products availability and livelihoods through benefits from payment for ecosystem services that are used collectively for the community.

Keywords: *Agroforestry, carbon sequestration, payment for ecosystem services, restoration*

PP3.6.4. A new alternative of agribusiness through payment for environmental services in agroforests in southern Brazil

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The ecosystems of the Atlantic Rainforest in Brazil were highly devastated in the past. The worry is to reset the biome of the Atlantic Rainforest, the ecosystem of the Mixed Ombrophilous Forest or Araucaria Forest, and meanwhile, to promote economical profitability for the farmers through sustainable and ecological production. In this context, the payments for environmental services have stimulated the protection and sustainable use of natural resources and raised the profitability to farm families. Therewith, in 2011 the Social Network Carbon Project sponsored by Petrobras, through Petrobras Environmental Program, planted 500 000 native plants in areas of permanent preservation and legal reserve, promoting the payment for environmental services through carbon sequestration with the objective of seeking profitability with environmental sustainability. The objective of this study was to analyze the economical impact of payment for environmental services through carbon sequestration in agroforests in properties of family farmers in the mountain region of the state of Santa Catarina. 500 000 native trees were planted in areas of permanent preservation and legal reserve, forming agroforests in approximately 1000 family farms of 18 cities of the region mentioned above. The trees that were planted are native ones of the region (about 100 species) with economic potential for family income. These trees were offered for adoption by people and companies who also donated the profits to farmers.

The results/experiences of this study were that the farmers who joined the agroforestry program as a source of income added value to their production through the payments for environmental services. We concluded that the farmers easily accepted the use of agroforests in areas of preservation. Besides production profit, they had a highly profitable business with the payments for environmental services improving and encouraging the use of agroforests.

Keywords: *agribusiness, environmental services*

PP3.6.5. CO₂ sequestration potential of the West African tree species *Parkia biglobosa* – allometric model choice and economic pot

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Climate is going to induce a great impact on both society and the natural environment. Especially the people in developing countries are, and will be affected by climate changes. Two of the mechanisms coping with the combination of CO₂ mitigation and development in developing countries are: the voluntary carbon market and the mechanism of Reducing Emissions from Deforestation and forest Degradation (REDD+). Through the mechanisms, developed countries can buy CO₂ credits from CO₂ offset projects in developing countries, and thereby provide the latter with a monetary incentive to conserve these much needed CO₂ sinks. Estimation of a species' biomass is required to estimate its CO₂ sequestration potential. When data is collected non-destructively, an existing allometric model has to be used to estimate the aboveground tree biomass, and a species-specific allometric model does not exist for the species in question *Parkia biglobosa*. In this study the three most suitable models available, in context of environment and tree size, is used to estimate the biomass. The consequence of choosing a specific model in relation to a species' biomass, CO₂ sequestration potential and hence economic potential is discussed, and an answer to whether the models used in current CO₂ offset projects are robust or not is deduced. The data used in the allometric models was collected at three different sites in Burkina Faso. The three sites had dissimilar abiotic characteristics, which makes the basis for a discussion of abiotic factors' influence on biomass and growth rate. Finally, we are calculating the monetary value of the CO₂ storage potential in the species, thereby providing evidence of what can be gained for local people if engaging in *Parkia biglobosa* agroforestry systems.

Keywords: *allometric models, Burkina Faso, CO₂ mitigation, rural development*

PP3.6.6. Interactions between Site Factors, Shade Trees and Coffee Plant Characteristics: Coffee Agroforestry Systems in Costa Rica

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Llano Bonito (area: 1,800 ha, altitude: from 1,180 to 2,120 m. asl) is a productive coffee-growing watershed within Tarrazú region of Costa Rica - reputed for its favourable growing conditions and high quality coffee. The majority of small-holders in the watershed produce coffee intensively in various shade forms - under single or mixed shade tree species as well as un-shaded, full sun-grown mono-crop. The knowledge base about site conditions (altitude, aspect and slope), shade trees, coffee plants and their interactions is lacking in Llano Bonito.

To understand interactions between site conditions, shade trees and coffee plant characteristics, 95 sampling points were randomly selected in coffee fields of 37 representative farmers - spread all over the watershed, representing major variables of site conditions,. At each sampling point, site conditions were recorded, and shade tree and coffee plant characteristics were measured in nested square plots (100 m² for shade trees and 25 m² for coffee).

At each sampling point, site characteristics were recorded, shade tree species were identified and their diameter at breast height (DBH) was measured in all shade trees above 10 cm DBH within the plots. The distance between coffee plant and rows were also measured. Inspection of data indicates the sample sites represented local diversity of site factors - altitudes from 1,365 m. asl to 1,940 m. asl, slopes from 0% to 100% and aspects from 15° to 360°.

The total number of measured trees was 508, corresponding to a density of 535 ha⁻¹. The average basal area at DBH was about 8.13 m²ha⁻¹. The number of species recorded was 16, most of which were represented by only a few individuals. The most frequent species were *Erythrina* spp. (224 individuals), *Musa* spp. (207 individuals) and *Persea americana* (34 individuals). When plots were categorized into un-shaded and shaded, and different types of shades within shaded based on dominant shade tree species, four categories of plots were identified– erythrina (45), banana (26), mixed shade (12) and unshaded (12). The average density of coffee shoots was 6,530 ha⁻¹ (min 3080, max 11,150).

Results showing relationships between site factors, and characteristics of shade trees and coffee plants are presented as first step towards diagnosing coffee agroforestry systems of Llano Bonito watershed, Costa Rica.

Keywords: *Characterization, coffee agroforestry, landscape, shade trees*

PP3.6.7. Strategies for sustainable food and energy needs in a changing climate scenario

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Developing Countries like India are more vulnerable to the impact of climate change, in view of excessive pressure on natural resources and poor coping mechanisms. Models generally predict that rising temperatures, increased climate variability significantly impact food production and agricultural GDP. Several areas have been recognized predominantly as being risk prone to the impacts of climate change. Among these are the most productive coastal areas, Indo-Gangetic plains and the frequently drought and flood prone regions of the country. Recent climatic events like cold wave, heat wave, drought, and floods have demonstrated the significant potential of weather factors to influence the production of food crops like rice, wheat and pulses and horticulture crops like mango, onion, banana and several vegetables, eventually leading to shortages and increased prices. *Strategies to Greenhouse Gas Mitigation* include *Co-firing tree energy crop biomass at existing coal-fired power plants will achieve the greatest reduction of any renewable energy resource option, as:* 1. Electricity produced

from biomass fuel is carbon cycle neutral -- just like the most advanced wind or solar energy technologies. 2. Use of tree energy crop biomass also sequesters sizable amounts of carbon (e.g., a sustainable long-term storage through the trees' root system.). 3. Co-firing energy crop biomass fuel in base load power plants directly displaces / reduces coal use, which can achieve more than two times the Greenhouse gas reduction benefit of placing wind or solar power facilities on an integrated electricity power grid. Usage of Biochar is another option for potential benefits. Biochar is an organic material produced via the pyrolysis of C-based feedstocks (biomass) and is best described as a 'soil conditioner'. This has 10-1,000 times longer than residence times of most soil organic matter and becomes a potential sink for C. Home gardening, prevalent in the tropics in India, is a mitigation and an adaptation strategy to climate change. Carbon Sequestration potential of huge plantations in different agro-ecosystems offer immense scope for carbon trading, effective usage of human capital, corporate trading opportunities and sustainable healthy environments at the local and global level. The present paper deals with the opportunities for public-private partnerships in adding value by developing new vistas in carbon markets and involving producers for sustainable incomes.

Keywords: *carbon trading, energy saving, GHG mitigation, public private partnerships*

PP3.6.8. An innovative approach to commercialization of moringa production: experience from moringa value chain development in Ethiopia

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Moringa (*Moringa stenopetala*) possesses enormous potentials for food and nutrition security with a potential use as agroforestry tree in farming systems, but was a neglected and under-utilized tree species in Ethiopia. Moringa products were not supplied in any of Ethiopia's market, and awareness about the use and importance of moringa tree was absent. It was only a small tribe in South Ethiopia that consumed leaves of moringa tree. Intervention that aimed at commercialization of moringa through application of value chain approach was designed and implemented in Adama and Yabelo (Oromia) Shoaarobit (Amhara) and Alamata (Tigray) woredas. The intervention followed an innovative approach by primarily focusing on creating awareness and market in urban areas through organizing two women youth group in each woreda, each consisting of 25-30 individuals. Then, 1-2 million seedlings were distributed to farmers in each woreda. Because of the intervention, Moringa has now become high income (USD 8-10/kg) generating commodity. Our survey showed that those who started consuming moringa have got incredibly substantial relieve from several diseases, including blood cancer paralysis, diabetic etc and many have witnessed these benefits. Federal and regional governments, farmers, projects and private investors have started to plant the tree as agroforestry tree among smallholder farmers and as a commodity for large scale production for local and export market. To date over 55 investors have started planting moringa on 15-55 hectares of land in different parts of the country. Moringa is one of the species provided in participatory agroforestry trials by a recently launched "trees for food security project", which is being implemented in semi-arid area and sub-humid agroecologies of Ethiopia. Therefore, the innovative approach in the commercialization model of Moringa will be useful in marketing of agroforestry products and development of their value chains in the trees for food security project sites.

Keywords: *commercialization model, income, moringa, value chain*

PP3.6.9. Implementation challenges of conservation tenders in developing countries

The opportunities of conservation tenders can be of particular interest in developing countries where payments for forestry and agroforestry based ecosystem services schemes (PES) grow at a disproportionate rate, information gaps are large and public budgets small. However, developing country characteristics (e.g. poor infrastructure, institutional capacity) may affect auction implementation and success. This contribution's objective is to identify some of these challenges and discuss ways of dealing with them. I take a very practical approach to address the issue by outlining the implementation steps of a conservation tender and by discussing how each of the typical characteristics of a developing country could potentially affect the implementation process in its individual steps. In addition, I also briefly discuss poverty alleviation and equity effects of conservation tenders which are particularly relevant for their implementation in developing countries with high poverty rates. The results show that tenders are not the tool of choice for poverty alleviation but they can contribute to increase the equity of PES programs. Each of the implementation steps is potentially influenced by developing country characteristics. Influences are both positive and negative. Imperfect markets, higher subsistence levels and variability in prices and yields, less availability of structural information on the agricultural sector as well as higher risk-aversity among poor landholders all constitute potential chances for conservation tenders to provide benefits in the form of an improved service to cost ratio. On the other hand, differences in human capital and infrastructure (especially communication infrastructure) negatively affect the design of tenders and the dissemination of relevant information to potential participants. Also, highly integrated communities increase the risk of collusion especially in small scale programs. Some of these constraints can be dealt with but solutions unavoidably increase transaction costs which, in turn, may affect the scalability of conservation tenders in developing countries.

Keywords: *auction, environmental services, PES, tender*

PP3.6.10. Structure and composition of three major forest types in moist temperate climate of Shiwaliks in Indian Central Himalaya

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Forests are the most extensive, complex and biologically productive entities amongst all the terrestrial ecosystems. Understanding forest structures is a prerequisite to describe various ecological processes and also to model the functioning and dynamics of forests. A great variety of forest types inhabit the Himalaya, ranging from dry deciduous forests in the subtropical foothills to evergreen coniferous forests in the sub alpine zone. The forests play an important role in tempering the inclemencies of the climate, cooling and purifying the atmosphere, protecting the soil, holding the hill-slopes in position, sequestering carbon, building up huge reservoirs of soil nutrients and providing numerous ecosystem services to mankind.

Quantitative studies of forest communities lead to a deeper insight into the form and structure of their vegetation. It has been realized that for a sound management of the Himalayan ecosystem, knowledge of plant communities, diversity, population and distribution is essential to the conservation and restoration of the environment. Knowledge of distribution and dynamics of biological resources can provide a rational basis for planning and management decisions; otherwise, the conservation of these resources in

their natural habitat would be very difficult. The present study was undertaken in three major forest types (dominated by *Quercus leuchotrichophora*, *Pinus roxburghii* and *Shorea robusta*, respectively) between 500 and 2000 m a.s.l. in a moist temperate forest of Nainital district in Kumaun region of Uttarakhand, India. The aim was to assess the variation in composition and diversity in different vegetation layers, i.e., herb, shrub and tree, among these three forest types. Diversity indices, such as the Shannon-Wiener diversity index, density, total basal area, Simpson's concentration of dominance index and species richness were calculated to understand community structures. Dominance-diversity curves were drawn to ascertain resource apportionment among various species in different forest types.

Keywords: *diversity, dominance, Shiwalik, vegetation*

4.0 Sustaining development through agroforestry

4.1 Meeting development challenges with integrated approaches

PP4.1.1. Institutional and organizational innovation for better agroforestry: Moroccan experience to promote Argane forest

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Argania spinosa is an endemic tree to Morocco and the pillar of an agroforestry ecosystem. It is a barrier against desertification with a rich biodiversity and plays an economic role. During the last century around 200 000 hectares were lost. On the remaining 800 000 hectares a suitable farming system continues to be practiced on mountain terraces. However, since the 70s intensive agriculture is practiced in the plains. This exacerbated drought impact due to groundwater overuse. Argane oil international market increase led to less smallscale agriculture and over-collection of argane fruit. This induced terraces' degradation causing soil erosion and decreased natural forest regeneration. In recent years, oil has become a key economic component as it is intended to play a lever role for the development of marginal areas. However, several technical, organizational and political challenges have arisen to ensure a balanced development. The new strategy "Morocco Green Plan" supports this commodity; first through a value chain approach coupled with "Distinctive Signs of Origin and Quality" new Law. On the other hand, new farmer organizations provided a framework to implement technical and economic interventions, capacity building and knowledge-sharing. The regulatory and institutional mechanisms strengthened governance and improved market access. Since the launch of this strategy significant impacts were identified. A certification, "Indication géographique protégée" "Argane oil" has been obtained and 20 000 ha per year of the forest will be rehabilitated. Balance between protecting and use of forest products can only be achieved through innovative agroforestry practices meeting stakeholders' needs. Marketing and capitalization and knowledge sharing are two major issues to be addressed. This paper that shares the Moroccan experience on how to promote argane forest and its oil value chain through institutional and organizational innovation aims also to reflect on knowledge capitalization and sharing challenges.

Keywords: *agroforestry, Argania spinosa, institutional, Morocco*

PP4.1.2. Positive effects of backyard agroforestry in rapid post disaster recovery and disaster risk reduction

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Disasters, natural and man-made, are increasing steadily in recent decades causing heavy losses of human life, property and livelihood as well as destroying landscapes. As governments, NGOs and civic bodies become better in disaster emergency response, there is a substantial decrease in disaster-related death; hence more survivors (generally injured, displaced and homeless) to take care of for a longer period during the Post Disaster Recovery (PDR) and Disaster Risk Reduction (DRR) phases. NGOs and civic bodies assist the survivors through humanitarian intervention with only one goal—‘survivors must stand on their feet and become independent in the shortest possible time’. To achieve this goal in a rural setting, disaster-ravaged environment and minimal funding is challenging. The fact that every survivor needs food/nutrition, livelihood and environment security to stand on their feet, ADRA India (an International NGO) designed a project based on agroforestry.

The principle was the production of food/nutrition plants and caring for the environment (growing of trees/fodder to sustain livelihood) in a given area. BAP is multi-functional and flexible in livelihood options (dairy-based, aqua-based, livestock-based, and agriculture/horticulture-based). It is simple and low-cost to implement. Most importantly, BAP is a women-centered activity – an important feature because 95% of male disaster survivors leave their wives and children in search of jobs in towns. BAP has been implemented in 5 disasters in India: tsunami in Andaman and Nicobar, Kosi Flood in Bihar, cyclone in West Bengal, famine due to rat infestation in Mizoram, and Sri Lankan refugees in Tamil Nadu. Although the positive effects of BAP are clearly visible by looking at the improved living conditions and better surroundings of the survivors, no study has been conducted to measure the effects of BAP.

Keywords: *disasters, food security, BAP*

PP4.1.3. Silvopastoral agro-forestry system: A sustainable model for shifting cultivation management and livelihood improvement

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Silvopastoral agroforestry system has been piloted on shifting cultivation areas of two sites (Jhirubas and Hupsekot) in western Nepal. The government has leased a total of 408 hectares of shifting cultivation areas to small groups of poor households for a period of forty years with the goal of poverty reduction through sustainable use of natural resources. A total of 35 user groups were formed involving 408 poor households of ethnic *Magar* community. Silvopastoral agroforestry (cut n carry) model is practiced in the leased lands. As it is native to the area and generates multiple benefits in a short period, broom grass was chosen for the first year intervention. Multiple use tree species such as *Cinnamomum tamala*, *Zanthoxylum armatum*, and *Fraxinus floribunda* were planted as intercrops from the second year onwards. It has been able to bring back the greenery in the landscape which until recently was devastated and degraded and was of little use to the local people. Moreover, it has succeeded in improving the livelihoods of the local communities. The leasehold group members have benefited right from the second year of intervention from the sale of the inflorescence of broom grass. In addition, the group members benefited from the forage produced in the lease land. Improve in the livestock feed has also increased the production of milk and meat providing additional income. Being very good raw material for paper pulp, a huge quantity of the broom stalk produced (8 tonne per ha) in this model fetches good price. These two sites have proved to be a show case example in leasehold forestry in less

than three years of project intervention. All this is happening largely from the villagers' own efforts, of course with technical back up and a minimum amount of financial support on the part of FAO. There are enough reasons to believe that the whole endeavour is owned by local communities and the chances of the sustainability are fairly high. These sites have already been a centre of attraction to many visitors and received a series of support from development partners ranging from infrastructure development to health and sanitation.

Keywords: *silvopastoral agroforestry system, shifting cultivation, leasehold forestry, livelihoods, broom grass*

PP4.1.4. Conservation agriculture with trees for integrated sloping land management in the Philippines

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Degraded sloping landscapes are expanding rapidly in the Philippines due to severe soil erosion attributed to monocropping of maize and intense rainfall associated with frequent typhoons from changing climate. Agricultural productivity has decreased which in turn heightens food insecurity and exacerbates poverty particularly on the sloping acid uplands where soils are inherently poor and farmers are resource poor. Through conservation agriculture with trees (CAT) which principles revolved around minimal soil disturbance, continuous ground cover by mulch, diverse crop species, and deliberate integration of trees constitutes the best 'tool box' to create sustainable permanent cropping systems under wet tropical conditions. These practices reverse soil degradation, improve soil health, increase crop yield and profits, and reduce the labour burden on farmers.

The first CAT Center in the Philippines located in Claveria, Misamis Oriental of northern Mindanao, began in 2010 and was completed in 2013. In the CAT Center, conservation agriculture production systems (CAPS) have been evaluated in long-term experiments and compared with farmers' practices. Promising CAPS were cassava + *Stylosanthes guianensis*, maize + cowpea/upland rice, maize + *Arachis pinto*i and maize + rice beans. Various component researches in support of CAT also identified suitable trees, crops species and varieties with better economic and biomass yields than locally grown crops. Promising varieties of maize, upland rice, cowpea, forage grasses and legumes, sweet potato, "adlai" (perennial grass) and sorghum were identified. Promising rubber latex timber clones, indigenous and exotic timber trees were also identified. CAT good practices can be enhanced by natural vegetative filter strips establishment, cash perennials establishment and improved cropping patterns, timber and fruit tree-based agroforestry, vegetable agroforestry, livestock integration, rainwater harvesting, and integrated organic and inorganic fertilizer and pesticide management production. CAT on slopes provides better erosion control, slope stabilization, economic, social and environmental benefits. Our research results and experiences can be extrapolated to other upland areas in the Philippines as well as other areas in Southeast Asia through integrated sustainable land management approach espousing strong technical, institutional and partnerships building among various stakeholders.

Keywords: *agroforestry, conservation agriculture with trees, integrated sustainable land management*

PP4.1.5. Response of farmers for diversification of their agricultural land use to agroforestry in North India

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This study is based on a field survey involving 100 farmers regarding diversification of their agriculturally productive land use in Pilibhit district, Uttar Pradesh, North India which is known to grow paddy wheat and/or sugarcane. There is a gradual acceptance of the trees on farmland with agricultural crop production. As a result tree-based agroforestry is now expanding. Of the 100 respondents, 35% held <5 acres land, 35% 6 to 10 acres, 20% 21 to 40 acres and the remaining 10% >50 acres land. The findings revealed that poplar has emerged as the main choice among the planted trees as it is harvested at a short rotation of 5 to 7 years, gives higher consolidated net returns, has a wide marketing network and industrial use in the nearby wood-based industrial units and can be grown in integration with a variety of crops and vegetables during the greater period of their retention on the farmland. Other accepted trees for agroforestry are clonal and seedling eucalypts, kadam, teak and a few others, while some like jatropa were grown for some time have been rejected. The factors that affect the adoption level of tree species in agroforestry have been identified as size of landholding, soil type, net returns from crops and trees, alternate source of income and occupation of landowners, labour availability, water drainage, and awareness and experience in agroforestry. Agroforestry provided tremendous economic strength and financial security to farmers and has undoubtedly improved the lives of farmers. Net returns from poplar-based agroforestry for 6 year periods vary from INR 60 000 to INR 100 000 per acre per annum, and were the maximum among all other tree-crop combinations.

Keywords: *diversification, agroforestry, farmers' response, agriculture*

PP4.1.6. Seed treatment for raising quality seedlings of pomegranate (*Punica granatum* L.): an important fruit component of silvi-horti models

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Pomegranate (*Punica granatum* L.) is an important fruit component of agroforestry systems practiced in tropics and subtropics, and also grown successfully in arid and semi-arid regions of India. However, due to poor and prolonged germination, uniform size quality seedlings remain a bottleneck in the success of the silvi-horti models on farmers' fields. Hence, a study was conducted in the nursery of the National Research Centre for Agroforestry, Jhansi in 2012 to assess the effects of pre-sowing treatments on the germination behaviour of pomegranate seeds. Experiments conducted on pomegranate cv. Bhagwa in 60% shade net house consisted of three pre-sowing treatments viz. water, 0.5% KNO₃ and 1.0% KNO₃; four levels of soaking periods viz. 6, 12, 18 and 24 hours, and a control thus making a total 13 treatment combinations. Each treatment was replicated four times with 25 seeds in a complete randomized block design. After soaking, seeds were sown in raised beds having a mixture of soil and FYM in 2:1 ratio to observe germination. After one month of sowing, the seedlings were transferred in polythene bags filled with the mixture of soil and FYM in 2:1 ratio. Fifty seedlings were maintained for each treatment to collect the data on growth and other parameters. The findings revealed that germination started on the 9th day after sowing and lasted for 30 days. Maximum germination (86%), fastest germination rate (13.45 days), mean daily germination (3.58), peak value (4.65), germination value (16.83) and shoot vigour index (3012.38 at 90 days) were recorded in treatment T₂ (soaking with water for 6 hours) with ranking first in respect to most parameters or *at par* with the treatment ranked

first, while control gave the least values. The study concluded that for uniform and quality planting stock, seeds of pomegranate cv. bhagwa should be soaked in water for six hours before sowing in nursery.

Keywords: *agroforestry, seed germination, seed treatment, shoot vigour index, nursery*

PP4.1.7. South-South knowledge sharing for sustainable land management in agricultural landscapes

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Agriculture, the greatest form of human-environment interaction, can greatly benefit from integrative approaches that combine formal and informal knowledge to address current sustainability problems associated with global change. The increasing attention paid to local knowledge in recent years results from the recognition that the knowledge of people who have been closely interacting with their environment for a long time can offer many insights about the sustainable management of natural resources. It is argued that research efforts should further explore a balance between scientific precision and local relevance resulting in a 'hybrid' knowledge base. The generation of hybrid knowledge reflects an effort to understand land management in the context of many forces interacting within a dynamic rural livelihood context as well as in the promotion and protection of multifunctional land use. Increased concern about soil management as a key determinant of sustainability in agricultural landscapes has promoted the need to identify indicators to monitor changes in soil quality, and their impact in the provision of ecosystem goods and services, as affected by land use change and agricultural intensification. The InPaC-S methodological guide, developed through South-South collaboration between Latin America and Africa, provides participatory tools to systematically blend local and technical knowledge on indicators of soil quality. This is part of a continuing effort in the participatory development of land quality monitoring systems that strengthen local environmental/agricultural institutions and communities with tools that support decision-making in natural resource management and promote sustainable land use and resilience in agricultural landscapes.

Keywords: *knowledge integration, participatory approaches, land management, sustainability*

PP4.1.8. Merging gaps between forest conservation and agricultural production in protected areas: a case study of southern Bakundu

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The Southern Bakundu Forest Reserve (SBFR) was constituted in 1940. Recently, forest margin communities have invaded, deforested and degraded many protected areas in south west Cameroon including SBFR for search of arable farmland. About 7000 hectares out of the original 19 425 hectares of the (SBFR) have been converted to cropland through slash and burn. Illegal chainsaw milling of timber and non-timber forest products harvesting for commercial and local use has increased pressure on forest and carbon emissions. The problem is made worse by land tenure conflicts among stakeholders. Surrounding villages claim ownership of the land whereas the forest reserves are the exclusive property of the state. The government's forceful attempt to evict farmers out of the reserves met with outright

resistance as most of the established farms had both cash and subsistence crops. Despite rising food demands, the government rejected requests to declassify the reserves and hand over the already occupied portions for agricultural production. To ensure that forest reserves continue to provide much needed environmental goods and services, deforested areas were rehabilitated and standing forest sustainably managed to enhance carbon storage. Agricultural productivity increased tremendously because cropland was improved and managed through agroforestry systems. A consensus was attained through Participatory Natural Resource Governance approach. Stakeholders jointly drafted and implemented management plans for forest and agricultural resources. Research scientists, technicians from concerned sectors, traditional cultural groups and communities together collected and analyzed data. Results were used to develop and implement REDD+ projects. Further harm to forests was halted thus stabilizing local climate with food security and development goals sustained.

Keywords: *agricultural production, agroforestry, forest conservation, participatory governance*

PP4.1.9. The potential of backcasting for enhancing success of agroforestry projects: a case study from Nepal

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The economic and ecologic advantages of agroforestry only become apparent in the long run. Thus, long-term thinking and consideration of persistent and sustainable measures are of utmost importance for farmers to start an integrated farming system like agroforestry. However, most small-scale farmers focus mainly on short-term developments due to economic constraints. Hence for the transition towards an innovative system like agroforestry, it is necessary to develop new methodologies to enable farmers to think in the long term and overcome daily problems. This case study examines to what extent the methods of 'Transition Management' and 'Backcasting' are applicable in the context of development cooperation, in particular in promoting agroforestry. Backcasting is an action research method. In workshops with all involved stakeholders, future visions and a transition agenda are worked out to enable the participants do long term thinking and thus move to a more sustainable way of acting. These methods have been developed and tested only in Europe until now. Here, they are applied in a village in the mid-hills of Nepal in an agroforestry project that has been running since 2009. Furthermore it will be analysed to what extent it is necessary to adjust to the conditions in a developing country like Nepal to achieve a satisfactory process and outcome quality. Regarding first results from Nepal we conclude that the methodology needs several adjustments concerning the time frame and the preparation of the process to ensure success. Furthermore, instead of holding one workshop, it will be necessary to form focus groups to ensure active participation of all stakeholders. Prior to the seminars, an accurate system and actor analysis has to be conducted. The workshops' results and possible modifications are presented in detail; and topics for further research to support agroforestry-based development by means of backcasting are named.

Keywords: *agroforestry, backcasting, Nepal, transition management*

PP4.1.10. Traditional shea tree conservation practices in Uganda: Lessons for conservation science

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Shea trees (*Vitellaria paradoxa*) are a major source of livelihood for the people of northern and north-eastern Uganda. The nuts from these trees contain abundant oil which is extracted and used in cooking, in cosmetic formulations and medicinal ointments. These trees are therefore greatly cherished by the local people. Community conservation of the shea tree is governed by a complex mix of traditions, customs, taboos, rituals and legends handed down from generation to generation and are neither found in written form, nor organized and structured in ways accessible to science. This study was conducted to document major traditional practices in Uganda. Fifteen focus discussion groups as well as 41 key informants and 300 respondents from 9 districts (3 farming systems) within the shea belt of Uganda were interviewed. The traditional conservation practices documented range from shea tree and fruit ownership to traditional punishments for errant community members who disregard the local norms. The erosion of these traditional conservation practices have been attributed to wars, poverty, western education and other external influences. Promoting the use of mass media, action plays/drama and public education are suggested as some of the ways to reduce the erosion of these traditional conservation practices.

Keywords: *conservation, public education, traditional practices, Vitellaria paradoxa*

PP4.1.11. Enhancing livelihoods and food security from agroforestry and community forestry through action research in Nepal

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The Middle Hills of Nepal are home to 44% of the population, 66% of whom derive their livelihood largely from a combination of agriculture and forest products. The forests and agricultural lands are closely linked systems providing food, fodder, fuelwood, grazing, timber and non-timber forest products. Over the last 30 years, under the purview of a national community forestry program, 23% of the forest lands have been handed over to local communities by way of more than 17 600 Community Forest User Groups (CFUGs). However, the management of community forests and subsistence agricultural systems in the Middle Hills is sub-optimal and livelihood outcomes remain limited and inequitable with the result that food insecurity is widespread.

The improvement of agroforestry on private land and community forestry on public land is a priority for research and development.

Factors that impede the ability of agroforestry systems and community forestry to provide adequate livelihoods are complex and manifold, and are situated in social, cultural, political, economic and ecological domains. Some of the critical factors include: low productivity of agricultural lands; sub-optimum management of community forests; persistent inequity and marginalisation of some community members; limited marketing opportunities for community forestry and agroforestry products; and centralised planning and service delivery.

Keywords: *ACIAR, food security, interdisciplinary research, Nepal*

PP4.1.12. Exploring agroforestry interventions for alleviating the HIV/AIDS burden in developing countries: examples from Malawi

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In many developing countries, HIV/AIDS is not only a health issue but also a development problem with complex links to rural livelihoods, human capacity, and forest conservation. In sub-Saharan Africa where health care is predominantly a forest-based service, wild foods or forest resources are used to: improve health, detoxify the effects of AIDS-related drug treatments, and enable an afflicted person and their household to control and adapt to HIV/AIDS. The complex interactions between the health and wellbeing of an HIV/AIDS-affected population and environmental resources mean that solutions cannot be sought from a purely medical standpoint. Instead, an interdisciplinary approach based on integrating ecological, sociological, and health perspectives is required. In this presentation, I first characterise how household dependence on the most important forest resources (firewood, medicinal plants) in four Malawian study sites changed through three phases: the period before HIV became a problem in the household, the period during HIV-related morbidity, and after AIDS-related mortality. I then explore several of the most promising agroforestry interventions (including planting seedlings of fast-growing species of firewood trees on homesteads; creating community medicinal plant herbaria) identified by local respondents as a means to meet forest-resource needs while alleviating the disease burden of HIV/AIDS-affected households. I include preliminary results from my research focused on the development impacts of these types of agroforestry interventions in rural Malawi. Given that research on the environmental dimensions of HIV/AIDS remains limited in spite of the global impact of the disease, particularly its increased prevalence in India, this presentation should be of interest to a wide array of conference attendees.

Keywords: *agroforestry interventions, complex problems, HIV/AIDS*

PP4.1.13. Medicinal plants: a viable option for diversification of poplar based agroforestry systems in Haryana

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Poplar has gained popularity among the farming communities of the northwestern parts of India because of its fast growth rate and commercial uses. It has been extensively grown in agroforestry systems. Diversification in terms of inclusion of some perennial medicinal plants, after the 3rd year, will not only reduce the risk but also diversify farm income while conserving natural medicinal plants resource. With these objectives the present experimentation was carried out by including four medicinal plants viz. mulathi (*Glycyrrhiza glabra*), aloe (*Aloe vera*), shatawari (*Asparagus racemosus*) and giloe (*Tinospora cordifolia*) in poplar (*Populus deltoides*) based agroforestry/silvo-medicinal system, planted at three different spacings i.e. 5x4 m, 10x2 m and 18x2x2 m (paired row). Mulathi and aloe were planted between the rows of poplar and giloe, shatawari being climbers were planted in one metre radius of poplar and allowed to climb on the trees in all the three spacings.

A marked decrease in pH and electrical conductivity of the soil was observed in all the spacings of poplar after three years of poplar planting. In mulathi the increase in dry yield was 32 percent in 5x4m, 21 percent in 10x2m spacing than control and the quality in terms of crude glycyrrhizin content was

significantly high in 5x4 m (7.4%) than 18x2x2 m spacing (7.0%). The yield of aloe was significantly more (145 t/ha in 5x4 m spacing, 102 t/ha in 10x2 m and 99 t/ha in 18x2x2 m spacing) than control (58t/ha) and aloe gel content has been found to be more in the closer spacings. Similarly the yield and saponin content of shatawari was significantly more in closer spacings than in control. The dry yield giloe increased to more than double of control in the closest spacing of 5x4 m and the yield increased significantly as compared to control with the decreasing spacings of poplar. The total bitter content was also significantly more.

Income generated in all of the silvo-medicinal plant systems tried was markedly better as compared to control. It increased as the poplar tree spacings decreased i.e. best in 5x4 m, followed by 10x2 m and 18x2x2 m in all the cases. Cultivation of shatawari was found to be the most profitable (INR113 500/ha/year), in spite of the high cultivation cost (INR120 000/ha), followed by aloe (INR 66 000/ha/year), mulathi (INR 34 000/ha/year) and giloe (INR 20 000/ha /year) and hence can be recommended for improving the overall income of the tree-based system.

PP4.1.14. Does building technical capacity of smallholder farmers lead to adoption of agroforestry based conservation practices?

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Agroforestry related practices are seen as effective natural resource management approaches that increase farmers' resilience to climatic variability and address environmental degradation resulting from poor agricultural practices that lead to nutrient mining. One such approach is agroforestry based conservation agriculture, which involves the integration of trees into conservation agriculture (CA) practices. Due to aspects of the approach, the practices are knowledge-intensive and too complex for farmers to learn and implement. The complexity of the technology increases the time lag between technology awareness and uptake among resource-poor farmers. Consequently, many government and non-governmental organizations are promoting agroforestry (AF) and CA practices in various parts of sub-Saharan Africa (SSA) through capacity building of smallholder farmers with a view to improving adoption and hence sustainable agricultural productivity at low costs. Yet there is paucity of empirical evidence on the extent to which training enhances adoption of agroforestry-based conservation practices (CAWT). The objective of this study is to quantify the effects of training on adoption of CAWT. The study uses data obtained from 198 households in Machakos County in Kenya from selected farmer groups. Owing to the lack of data on the control group, we use propensity score matching method to construct controls and measure the effect of training on adoption of CAWT. Results show that participation in trainings, number of trainings attended, training provider and distance to the farm trials significantly affect the adoption of CAWT. Farmers who attended the training had higher yields and diverse crops compared to those that did not attend the training. A major policy implication of the study is the need to increase the capacity of farmers and extension providers through training in order to significantly improve the adoption of soil conservation practices.

Keywords: adoption, agroforestry-based conservation agriculture, propensity score matching

PP4.1.15. Performance of soybean-wheat cropping sequence under clonal eucalyptus plantation

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India is looking forward to overcoming the challenges induced by high human and livestock population, change in demographic structure, poverty in forest fringe areas and climate change with policy and legislative interventions along with capacity building of community and R&D for high productivity in future. About 76.2% of the total farming community belongs to marginal and small farmers who possess only 29% of the total operated area while per capita land availability has reached to only 0.14 ha. There is no further scope for horizontal expansion of land for cultivation. Agroforestry, a land management system, is gaining popularity among the farmers of Satpura Plateau and Kymore Zone in Madhya Pradesh. In selecting tree species and agricultural crops for intercropping and other association, climatic consideration is of prime importance. Besides the agroclimatic factors, compatibility of tree species in the farming system of a given area is also a considerable factor. The little work has been done on clonal eucalyptus-based agroforestry model with respect to compatibility and profitability.

Keeping the above points in view, a trial was conducted at Mushkara village in the Sihora block of Jabalpur district in three consecutive seasons from 2009 to 2012 to assess performance of cropping sequence of soybean (var. JS 97-52) - wheat (GW-273) under agrisilvicultural model. The plants of clonal eucalyptus were planted (8 m x 1.5 m- paired rows) in July 2009 as alley cropping and the soybean and wheat were grown respectively in kharif and rabi season. Recommended package of practices were followed to get the yield of crops and the best quality of poles from the clonal plantation. The harvesting of trees gave a yield of 90 tonnes/ha after three years during 2013 and it was sold as a pole in the local market @ INR 4500/t. There is a reduction in the yield of soybean and wheat up to 9% and 14% respectively but the net return of INR 298 310/ha was recorded from soybean-wheat cropping system under plantation as compared to sole cropping of soybean and wheat.

Keywords: *agroforestry, eucalyptus clones and cropping sequence*

PP4.1.16. Role of agroforestry in watershed management for sustainable development in India

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Natural resources like land, water and vegetation are nature's gift to mankind and most important for the country's growth and development. The availability of resources for future generations depends on their sustainable management. In the last four decades sustainability of natural resources has been threatened due to misuse and mismanagement of natural resources for developmental activities. The problem has been further aggravated due to the high rate of population growth, both human (1210 million) and livestock (529.70 million), resulting in indiscriminate exploitation of natural resources to meet the ever-increasing demand for food, fodder, fuel, fibre and fertilizers. The areas under food crops and forest were declining due to diversion of good fertile lands for non-agricultural and forest land for non-forest land use purposes, respectively. Natural resources are best managed on a watershed basis with their conservation and optimal utilization through management of watershed components. The role of agroforestry is highlighted in upland and lowland watershed management to achieve the principles and objectives of watershed management. Traditional agroforestry systems in the mountains are similar to natural ecosystems as they provide ecosystem services similar to the forests and profit farmers 5.7 times more compared to rain-fed agriculture. Alternate land use practices like agri-silviculture, silvo-pastoral,

agro-horticulture, dry land horticulture are suggested for efficient utilization and sustainable management of natural resources. Agroforestry systems also help to meet the fuelwood and fodder requirements with decreasing crop failure risk from hot-arid tracts of India. Agroforestry research and development is creating a much wider array of practical solutions that reduce the tension in achieving both the environmental services of watershed and productivity functions essential to the livelihood of the dense rural populations that inhabit them. Agroforestry has proved to be a useful approach in watershed management to promote the sustainable use of various resources and to improve the economic well-being of local people. Properly designed and managed, agroforestry can provide various benefits and has potential to meet environmental and socioeconomic requirements.

Keywords: agroforestry, watershed management, sustainable development, resource conservation and utilization

PP4.1.17. Utilizing shallow vertisols in the Indian semi-arid Deccan for fruit, fodder and firewood production

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Vertisols and vertic associates occupy 72 m ha in peninsular India which is equal to 23.2% of India's geographical area. These areas are characterized by soils of varying depths, low annual precipitation (<750 mm) and frequent occurrence of droughts of moderate intensity. Absence of conservation measures in arable lands has led to high soil erosion rates. An excess of 15t/ha/yr has been recorded in many districts of the Deccan. Besides the declining soil depth, sub-soil salinity, poor aggregation and high sodium content pose severe limitations for plant growth.

Shallow vertisols were evaluated for various land use combinations using hardy fruit trees, fruit yielding trees and firewood yielding species with varying degrees of success. Fruit plans like ber, sapota, guava and lemon were grown along with *in-situ* moisture conservation practices. The performance of lemon in a cup and saucer shaped basin was the best followed by guava and sapota. Among the fruit yielding trees, the performance of tamarind and wood apple was satisfactory. Silvi-pastoral systems using *A.nilotica* and fodder grasses like *Cenchrus ciliaris*, *Dicanthium annulatum* and *Chloris gayana* were evaluated, although sub-soil salinity led to poor average grass yields of 2.6, and 0.8t/ha/yr over a 10 year period. Production of firewood from *Acacia nilotica*, *Eucalyptus* hybrid, *Azadirachta indica* and *Leucaena leucocephala* (var.K 8) raised at three spacings (3x1m, 2x1 m and 2x2 m) was evaluated. After a period of 6 years, *L. leucocephala* proved to be the best by recording maximum biomass of 62.5 t/ha under 2 x 1 m spacing followed by 39.5 t ha⁻¹ in *A. nilotica* and *Leucaena* 38.6 t ha⁻¹ at 3 x 1 m spacing.

There is an urgent need to identify, test and popularize technologies that are resilient to climatic changes and are able to withstand periods of soil and rainfall related stress; these may include land use combinations of suitable trees and associations of medicinal, aromatic and dye yielding plants which can provide resource-poor farmers alternate sources of income during periods of crop failure and other climatic vagaries.

Keywords: firewood, fruit, semi-arid, vertisols

PP4.1.18. Fodder production from woody perennials in mountains of Uttarakhand through management practices

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Agriculture, animals and forestry constitute an integrated part of the mountain farming system. In the plain regions of the state, animals mostly feed on cultivated fodders while in mountains green fodder is mainly obtained from forests. Woody perennials form the chief source of green fodder due to less per capita agricultural land holdings and difficult environmental conditions that prevails in the mountains. Farmers prefer those species which provide palatable, nutritious and digestible fodder during lean periods when green fodder is not available from other sources. The leaves of tree species such as *Bauhinia* spp, *Celtis australis*, *Ficus* spp, *Grewia optiva*, *Melia azedarach*, *Morus* spp, *Quercus* spp. etc. and shrubs like *Desmodium elegans*, *Debregeasia longifolia*, etc. are traditionally used as fodder. Leaves of these species are rich in nutrients i.e. crude protein, crude fibre, ether extracts, nitrogen free extractives, calcium and phosphorus. From the point of view of sustainable fodder production, it is essential to standardize the fodder production techniques of these species. Fodder harvesting methods such as coppicing, lopping, pollarding, etc. promote the lateral growth that results in increased fodder yield in the consecutive years. As most of the fodder trees are deciduous in nature and shed their leaves during the winter season and thus fodder harvesting one or two months before leaf fall is in practice. Therefore, optimisation of the fodder harvesting at optimum height and time is also an important consideration as there is a seasonal variation in terms of quality and quantity of fodder throughout the year.

Keywords: fodder, shrubs, trees

PP4.1.19. Agroforestry for biodiversity, conservation, food and nutritional security and adaptation to climate change

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Forests and trees play a vital role both in climate change mitigation and adaptation, biodiversity conservation, livelihoods enhancement and income generation for the Pacific Islanders. However, forests and trees are only able to do this effectively if these valuable resources are conserved, managed and utilized in a sustainable manner.

Better-managed and healthy forests are able to adapt better to climate change and therefore contribute to the improved resilience of the communities that rely on these important resources. However, we know very well that achieving or even moving closer to this ideal state is easier said than done considering the number of challenges we are facing now.

Unsustainable logging practices, inadequately planned human developments and the unregulated conversion of forested areas into agriculture are few examples of some of the challenges that most in the Pacific face today.

In many Pacific island countries, especially on the smaller islands and atolls, agroforestry and tree crops provide most of the food, medicines, construction materials, firewood, tools and myriad of other products and services that cannot be replaced with imported substitutions. For the larger countries, forests have contributed significantly into their economic development, employment and infrastructure development. Thus, a major challenge for the Pacific is to ensure sustainable management of their scarce and diminishing forest and tree resources, taking into account demands for economic development and the social and environmental needs of their growing population. The Secretariat of the Pacific Community (SPC) through its Land Resources Division (LRD) is working with SPC

member countries in addressing these issues.

Despite these challenges, there are also many opportunities that can be explored as well and agroforestry system is one such opportunity that provides a range of opportunities to improve soil health, attain biodiversity, and undertake conservation especially of indigenous tree species, providing resilience to climate change and above all improving food and nutritional security.

Despite having so many activities to manage our forest well, we still continue to face degradation of our forest resources and the practice of monocropping over an agroforestry concept. Therefore we need to be innovative and ‘think outside the forest’ to maintain our forest and adopt innovative agroforestry models.

Keywords: *agroforestry models, biodiversity, conservation of indigenous tree species and building resilience to climate change, soil health and food and nutritional security*

PP4.1.20. Silvopastoral agro-forestry system: a sustainable model for shifting cultivation management and livelihood improvement

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Silvopastoral agro-forestry system has been piloted on shifting cultivation areas of two sites (Jhirubas and Hupsekot) in western Nepal. The government has leased a total of 408 hectares of shifting cultivation areas to small groups of poor households for a period of forty years with the goal of poverty reduction through sustainable use of natural resources. A total of 35 user groups were formed involving 408 poor households of ethnic *Magar* community. Silvopastoral agro-forestry (cut n carry) model has been practiced in the leased lands. As it is native to the area and generates multiple benefits in a short period, broom grass was chosen for first year intervention. Multiple use tree species such as *Cinnamomum tamala*, *Zanthoxylum armatum*, and *Fraxinus floribunda* were planted as an intercrops from second year onwards. It has been able to bring back the greenery in the Landscape which until recently was devastated and degraded and was of little use to the local people. Moreover, it has succeeded in improving the livelihoods of the local communities. The leasehold group members have been benefited right from the second year of intervention from the sale of inflorescence of broom grass. In addition, the group members are benefited from the forage produced in the lease land. Improve in the livestock feed has also increased the production of milk and meat providing additional income. Being very good raw material for paper pulp, huge quantity of the broom stalk produced (8 ton per ha) in this model fetches good price. These two sites have proved as a show case example in leasehold forestry in merely less than three years of project intervention. All is happening largely from villager’s own efforts, of course with technical back up and bare minimum amount of financial support on the part of FAO. There are enough reasons to believe that the whole endeavour is nicely owned by local communities and the chances of their sustainability are fairly high. These sites have already been centre of attraction to many visitors and received series of supports from development partners ranging from infrastructure development to health and sanitation.

Keywords: *silvopastoral agro-forestry system, shifting cultivation, leasehold forestry, livelihoods, broom grass*

PP4.1.21. Sustainable enhancement of yield potential of dual purpose sorghum through INM in legume based cropping system

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The introduction of forage legumes in a crop rotation can add greatly to soil fertility through biological nitrogen fixation of freely available atmospheric nitrogen thereby reducing expenditure on nitrogenous fertilizer for the succeeding crop. To study the effect of INM on the yield and quality of sorghum – cowpea cropping system, the present study was undertaken

The field experiment was carried out at Livestock Research Institute, Rajendranagar, Hyderabad from 2005-2009 to study the effect of INM on the performance of dual purpose sorghum – cowpea cropping system under protective irrigated conditions. Treatment combinations were nine, replicated thrice, the experiment was laid out in randomized block design. The research results over five years of experimentation revealed that application of 75 % of recommended dose of nutrients through inorganic fertilizers + 25 % N through poultry manure sorghum crop received significantly higher grain yield (27.94 q/ha) and crude protein yield (10.14 q/ha), and it was on par with 100 % RDN through inorganic fertilizers. Whereas dry matter yield (150.47 q/ha) was higher with 100 % RDN through inorganic fertilizers and it was on par with 25 % substitution with poultry manure (149.72 q/ha). These two treatments were significantly superior over other treatments. Green fodder yield (180.34 q/ha), dry fodder yield (37.87 q/ha) and crude protein yield (6.39 q/ha) of forage cowpea raised as sequence crop of sorghum was higher with 25 % substitution of RDN with poultry manure and it was on par with 100 % RDN through inorganic fertilizers.

Gross and net returns (Rs. 29930 and 20430/ha) were higher with 25 % substitution of RDN with poultry manure followed by 100 % RDN through inorganic fertilizers, whereas B: C ratio was higher with 100 % RDN through inorganic fertilizers. Though, the gross and net returns were higher with VAM application, B: C ratio was decreased due to the increasing cost of cultivation.

Keywords: *yield potential, sorghum, INM*

PP4.1.22. Potential medicinal herbs as elements of agroforestry systems in cold desert regions of Himachal Pradesh

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Cold deserts in India come under the Trans Himalayan zone which is confined to Ladakh in Jammu & Kashmir, Lahaul & Spiti, Kinnaur and Pangi in Himachal Pradesh. These areas are ecologically very fragile with very harsh climatic conditions. Since, in cold desert traditional cropping systems, agriculture is not sustaining the livelihood security of farming communities and even growing fruit crops is often proving uneconomical owing to unfavourable conditions like climate change, disease epidemics, transportation problems, market fluctuations and lack of postharvest processing to avoid losses in agricultural and horticultural produce. Diversification of the present cropping system is needed to cope up with the ever-increasing demand of the variety of products. There is a great potential for development of sustainable models for intercropping of commercially medicinal crops with horticultural crops for the farmers of the area. The region has rich medicinal plant diversity and is considered as a

treasure house of these valuable natural resources. Economically viable and highly demanded medicinal herbs like, *Saussurea costus* (Kuth), *Inula racemosa* (Pushkarmool), *Bunium persicum* (Kala Zeera), *Dactylorrhiza hatagirea* (Salam Panja), *Nardostachys grandiflora* (Jatamansi), *Picrorhiza kurroo* (Kutki), *Humulus lupulus* (Hops) are the potential herbal elements which are suitable for incorporation in the different horti-silvi and agri-silvi systems. The present paper is an attempt to assess the traditional agroforestry practices of the region and developing of integrated agroforestry models based on medicinal herbs to provide sustainable livelihood and environment security to the farmers living in these ecologically most fragile regions.

Key words: cold deserts, medicinal herbs, agroforestry, crop diversification

PP4.1.23. Soil organic carbon and available nitrogen under different agroforestry systems

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The soil, an important natural resource, is influenced greatly by the tree plantations in many ways. This study was conducted to find out the impact of different agroforestry systems on soil organic carbon and available nitrogen. Seven agroforestry systems viz *Psidium guajava*, *Azardirachta indica*, *Jatropha curcas*, *Hardwickia binata*, *Bambusa vulgaris*, *Eucalyptus tereticornis* and *Acacia senegal* were selected for assessment of organic carbon and available nitrogen. The associated crops were chickpea (*Cicer arietinum*), wheat (*Triticum aestivum*), Barley (*Hordeum vulgare*), lentil and mustard. From each agroforestry system, soils were analysed at different depths 0-15, 15-30 and 30-60cm. It was found that the soil organic carbon and available nitrogen were higher under the canopy when compared to outside the canopy. The *Jatropha* based agroforestry system recorded 315.59 kg ha⁻¹ nitrogen followed by *Hardwickia binata* (314.12), *Acacia senegal* (288.32) and the lowest was noticed in control (250.67). At different depths the nitrogen was found to be (281.54 kg ha⁻¹ (0-15 cm), 267.65 kg ha⁻¹ (15-30 cm) and 216.16 kg ha⁻¹ (30 – 60 cm) and after the canopy 281.68 kg ha⁻¹ (0- 15 cm), 255.50 kg ha⁻¹ (15-30 cm) and 254.82 kg ha⁻¹ (30-60 cm). In case of soil organic carbon, *Psidium guajava* recorded highest (4.4 g/kg), followed by *Bambusa vulgaris* (3.9 g kg⁻¹) and *Jatropha curcas* (3.5 g kg⁻¹). The lowest was noticed in control (2.1 g kg⁻¹). At different depths under the canopy it was 3.8 g kg⁻¹ (0-15 cm), 3.4 g kg⁻¹ (15-30 cm) and 3.5 g kg⁻¹ (30-60 cm) and outside the canopy it was 4.0 g kg⁻¹, 4.0 g kg⁻¹ and 3.6 g kg⁻¹ respectively. Soil organic carbon and available nitrogen decreased with the depth and were found higher under the canopy than outside the canopy as compared to control.

Keywords: agroforestry systems, available nitrogen, organic carbon, tree canopy

PP4.1.24. Effect of different level of Indol Butyric Acid (IBA) on rooting and sprouting of semi hard wood cutting of Olive (*Olea europaea* L)

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Olive is ever green Mediterranean tree which belongs to the family oleaceae. Olive tree perform well in hot and dry climate of North Gujarat. The propagation of Olive tree is most commonly done with hard wood cutting, in which cuttings are taken from mature branches. This is the promising technology of vegetative propagation. Olive cultivation has been done in 31.80 ha area under substation of SDAU jurisdiction during 2012. The saplings were supplied by Asia Everest Pvt. Ltd. Israel during 2010-11. Still the commercial propagation technology is miner in Gujarat. Therefore the vegetative propagation through stem cutting has been tried to get superior plants and multiplication can be done easily, cheaply and more conveniently through cuttings.

The present investigation was conducted in net house at Centre for Agroforestry, Forage Crops & Green Belt, S.D. Agricultural University Sardarkrushinagar (Gujarat) during July 2012 to determine the effect of seven concentrations of Indol Butyric Acid i.e. control, 500, 1000, 1500, 2000, 2500 and 3000 ppm, with two potting mixture soil:clay:FYM (1:1:1) ratio and coco-pit, with 5g N:P:K fertilizer (19:19:19). Pencil size semi hard wood cuttings were taken comprised of 4-6 nodes, 10-12 cm in length. The cuttings were dipped in above IBA solutions for 1 minute as “quick dip” method before planting in rooting media. Among IBA concentrations 3000 ppm concentration reset maximum percentage of rooting (25%), shoot length (67.88cm) and number of shoot/cutting (3.50). Significantly maximum number of root/cutting (9), length of root (58.63cm) and fresh weight (8.03g) was recorded with 3000 ppm IBA solution. Among the growing media examined coco-pit with 5g NPK fertilizer (19:19:19) was recorded 25 percent rooting while there was no rooting in (soil:clay:FYM) media and in control (untreated cuttings).

Keywords: *Oleae europaea*, IBA, Auxin, propagation, soft wood cutting

PP4.1.25. Evaluation of Dalbergia sissoo Roxb. progenies at field stage under semi-arid regions of Punjab

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Dalbergia sissoo Roxb. commonly known as shishm/Tahli is an important timber species of India and is a state tree of Punjab. Its heartwood is durable and is used in the furniture and was grown in the fields across the state. Punjab Agriculture has undertaken tree improvement work since last two decades. Plus trees from different zones of Punjab, Haryana and Himachal Pradesh were selected for growth and stem straightness on the basis of 'base line method'. The survey was conducted along roads, railway lines, canals and from the scattered trees in fields. Open-pollinated seeds from the thirteen plus trees were raised under nursery and were planted at Regional Research Bathinda by following RBD and three replications. Significant differences were found for diameter at breast height (DBH), tree height and D²H at all the ages i.e. 4, 6 and 10 years. After 10 year growth in the field, progeny No 6, 11 and 8 were found to be the superior most with respect to tree volume. Considerable variation was noticed for stem straightness, clear bole and branch traits. Heritability for DBH, tree height and D²H were found to be 0.54, 0.46 and 0.76, respectively. The vegetative propagules from the superior genotypes from progeny trials have been used to establish the hedge orchard. Moreover, the introductions from Nepal and selections from other progeny trial have been used to develop the new clones which are under investigation. The future thrust is breeding for tolerance to root rot, stem straightness and wood traits

Keywords: *Dalbergia sissoo*, heritability, open-pollinated, vegetative propagules

PP4.1.26. Impact of sustainable agricultural land management practices on smallholder farm productivity and livelihood

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The Kenyan Agricultural Carbon Project (KACP) is the first African agricultural soil organic and biomass carbon sequestration project. It provides advisory services on sustainable agricultural land management practices (e.g. reduced tillage, mulching, composting, manure and fertilizer application, water harvesting, terracing, tree planting), farm enterprise development and village saving and loaning. KACP is led by Vi Agroforestry, a non-profit, non-political, non-religious organisation set up in 1983 envisioning a sustainable environment that enables people in poverty to improve their lives through agroforestry and support to farmer organizations.

The aim of KACP is to address climate change adaptation and mitigation, in particular among smallholder farmers, and to improve agricultural productivity. The objectives are to (i) provide advisory services, (ii) restore agricultural production so that there is increased farm productivity as well as diversified food sources, (iii) increase farmer resilience to climate change, (iv) contribute to greenhouse gas emission reduction, and (v) selling emission reduction. From 2009 to 2012, the project included 26,535 farmers within 1,555 farmer groups, and it targets to have recruited 60,000 farmers within 3,000 groups by end of 2014. Monitoring and evaluation systems have been set up and control farms included.

Adoption and effects of project implementation on farm productivity and livelihood are being evaluated. Preliminary results show that the two annual maize yields were 50 (y1) and 30% (y2) higher on the KACP farmer than the controls. Compared to baseline 2009, yields were higher 2010-2012 also on the control farms showing the importance of including controls in addition to a baseline. The on-farm food sufficiency was <6 month on 16 and 35% of the KACP and control farms, respectively, whereas it was 10-12 months on 37 and 17% of these farms. In 2012, 73% of the KACP farmers were saving 3-5 USD/month compared to 44% of the control.

Keywords: *carbon sequestration, farm productivity, farmer groups, livelihood*

PP4.1.27. Sustainable Development through Integrated Watershed Management Programme: Case Studies from Jharkhand (India)

Integrated Watershed Management Programme has been initiated in watersheds of Jharkhand with the objective of conservation and sustainable management of natural resources. It also intends to enhance agriculture productivity, improve livelihood options and restore ecological balance in degraded and fragile rainfed ecosystem. A Study was conducted in thirty villages in different watersheds of Chotanagpur and Singhbhum area of Jharkhand to assess the results of projects under IWMP. The major methods employed were household survey and meetings with watershed committees, Village Forest & Management Committees and Self Help Groups (SHGs). Secondary data were collected from literature and interpretation in GIS Cell. The paper aims to examine various aspects of activities and results of IWMP based on this study. The study revealed that the communities actively participated in planning and implementation of the activities. Overall technical and financial support has been provided by Forest and other government departments and NGOs. Construction of earthen and loose boulder check dams, terracing, contour trenching, construction and renovation of ponds and wells are some of the measures adopted for soil and water conservation. For promoting agroforestry, plantations of Cashew

nut (*Anacardium occidentale*), Mango (*Mangifera indica*). Gambhar (*Gmelina arborea*). Bamboo (*Dendrocalamus strictus*), Teak (*Tectona grandis*), Jackfruit (*Artocarpus heterophyllus*) etc. have also been taken up. For capacity building, SHGs, User Groups, villagers and members of Watershed committees were imparted training. Health and literacy camp have also been organized. In most of these watershed areas encouraging results have been registered with regard to silvi-pasture practices and production of different agricultural crops. There has been increase in biomass production and improvement in soil and water conservation. These results have positive impact not only on environment and livelihood of the people, but also on their social and cultural domain.

Keywords: *Jharkhand, sustainable development, watershed*

PP4.1.28. Potential of Multipurpose Trees for Soil Quality Maintenance in Tropical Agro-ecosystems

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Soil quality, the capacity of a soil to function within ecosystem boundaries to sustain biological productivity and to maintain environmental quality, is an invaluable tool in determining the sustainability and environmental impact of agricultural ecosystems. It is more meaningful under present scenario of climate change and global warming. Tropical deforestation and forest degradation are considered to be an important source of greenhouse gases (GHG) contributing to 17.4% of the global emissions. The importance of agroforestry as a land-use system is most preferred not only in terms of agricultural sustainability but also in issues related to climate change. Multipurpose trees (MPTs) form an integral component of different agroforestry interventions and models. MPTs significantly improved soil quality, particularly by decreasing bulk density and erosion ratio by 15.9 and 39.5% respectively and increasing soil organic C by 96.2%, porosity by 10.9%, aggregate stability by 24.0% and available soil moisture by 33.2% under tropical eco-system. Higher stability of soil aggregates under *Pinus kesiya*, *Michelia oblonga* and *Alnus nepalensis* might be due to their impressive root system and root biomass (497, 462 and 436 gm⁻², respectively) resulting from accumulation of higher organic carbon, proliferation of rhizosphere and micro floral and faunal activities and root exudation below ground. *Michelia oblonga* plantation had the significantly higher SMBC (478 mg kg⁻¹) as compared to other MPTs tested upon. The SMBC as a percentage of SOC were higher in the surface soil due to greater C and N inputs, which might have stimulated in greater soil microbial biomass production, into the surface soil. Inclusion of MPTs is a viable option for eco-restoration and maintenance of soil quality and could sustain long-term soil productivity and improve the food security of the resource poor farmers. Thus, assemblage of MPTs provides a base for ecologically sound and environmentally safe agriculture in tropical agro-ecosystem.

Keywords: *multipurpose trees, soil quality, tropical ecosystem*

4.2 The gender dimensions of applying agroforestry innovation

PP4.2.1. Gender roles, responsibilities and spaces: Implications for agroforestry research and development in Africa

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Throughout Africa, roles and responsibilities are gendered. Men are responsible for productive work while women are responsible for both reproductive and productive work. Furthermore, women and men have different spaces in which they have authority over. In some communities, certain fields, trees and tree products are reserved for women. In certain parts of Africa, certain trees are considered men's or women's trees. For example, indigenous fruits are considered a domain for women and children. In Mali, men maintain shea trees in the cropland because they are a key source of income for their wives. Different parts of the same tree may be gender specific in use e.g. *G. robusta* (men benefit from poles and timber while women use branches for fuel wood). Understanding these roles, responsibilities and spaces is therefore necessary if agroforestry research and development is to benefit both men and women. This paper discusses the importance of understanding gender roles, responsibilities and spaces in agroforestry research and development. I use data from different parts of Africa to show how roles and responsibilities influence choices men and women make in regard to agroforestry. In addition, I show how women are more likely to derive personal benefits from agroforestry if spaces in which they have control over resource management are reinforced by researchers and development professionals.

Keywords: *gender, responsibilities, roles, spaces*

PP4.2.2. Gender, species priorities, and domestication in South and Southeast Sulawesi, Indonesia

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Tree domestication includes any activity that brings trees into wider cultivation to provide people food, building materials, medicine, other tree products, or income from the sales of tree products. It may also positively influence the conservation of endangered species or the provision of environmental services. Research on tree domestication is not merely focused on integrating trees on to farm or community land, but also most consider socio-cultural-economic factors and institutional aspects that influenced the domestication process. Gender is an important factor in tree domestication that has not been sufficiently researched to date. Women and men have different sets of knowledge, experiences, and strategies in addressing tree propagation, management, utilization and marketing. This study investigated the effect of gender roles and decision making (by men and women) on the domestication of economically important species in south and southeast Sulawesi. Focus group discussions were held with 300 community members (45% women) of 19 villages in four districts in south and southeast Sulawesi province, Indonesia. Results demonstrate that women are keen to domesticate vegetables and other annual crops that contribute directly to household food security and nutrition. Women focus those domestication activities on land near the home. Men and women give priority to tree species with high economic value. The management of those species is a priority for men but shared by women. The study supports the premise that identifying gender roles and knowledge related to tree domestication is important in the planning program on tree-based livelihood enhancement and sustainable environmental management.

Keywords: *domestication, gender, Sulawesi, decision making, species prioritization*

PP4.2.3. Understanding the role of gender in the behaviour of users of Ricinodendron heudelotii kernel extraction machine

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The world and Africa in particular face an explosive population growth which puts considerable pressure on natural resources. With this pressure, it is urgent to find solutions by developing innovative

strategies for the rational management of natural resources available to improve the living conditions of rural people and protect the environment at the same time. One solution is the exploitation of agroforestry tree products (AFTPs) through improving harvest and post-harvest techniques and technologies. In this line, *Ricinodendron heudelotii* kernel extraction machine, designed as an alternative to traditional manual extraction, is viewed as a tool to assist producers to gain more time and produce large quantities of kernels with increased market demand. However, there is a gap in the research on utilization and adoption of the machine as a human dimension. In this research, we attempt to study the behaviour of users of njansang extraction machine in pilot sites in southern Cameroon. We examine users' intention to use and adopt the machine by building upon studies in the exploitation and commercialization of the product. Particularly, the role of gender is explored; a focus group discussion is conducted followed by a survey. Findings confirm that users' intention to use and adopt the machine is strongly associated with three factors: main source of income, price of the machine and producers' age. The implications of these results on the dissemination of the machine and for further studies is that both researchers and manufacturers should take into account users' needs as a co-development process, which is important to boost the value chain development of AFTPs.

Keywords: *AFTPs, Cameroon, post-harvest, innovative technology, small-scale farmers*

PP4.2.4. Creating livelihood opportunities for women through simple household interventions for saving trees

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The rural and less income earning households use traditional open fire 'chulhas' or stoves for cooking and on an average each household annually consumes about 2.94 tonnes of fuelwood. These stoves burn the biomass inefficiently and contribute negatively to climate change at local, national and global levels. It also destructs the environment and ecology as more and more trees are logged for fuelwood. Arranging fuelwood (tree branches, pruned twigs, shrubs and roots, dried dung cakes and crop residues) for cooking is one of the main responsibilities of women. They spend substantial time daily to collect fuelwood from the common property resources and have to travel long distances to meet the daily family requirement. With the shift to low cost and energy efficient stoves, a household can reduce on an average 3.1 kg of fuelwood per day and save up to 40% of their annual fuelwood consumption. These stoves improve health, saves trees from felling for fuelwood, contribute towards lowering emissions and reduce forest degradation and deforestation. Thereby significantly reducing the drudgery of women and providing opportunities to enhance their livelihoods. About 1000 households at three ecological grids (arid in Mavli, Rajasthan; semi-arid in Jaffergudum, Andhra Pradesh; and humid in Athagarh, Orissa) have shifted to energy efficient stoves. For the last two years the participating women have experienced reduced wood consumption, a cleaner environment and less cooking time due to efficient burning of wood in these stoves. They save a lot of trees from felling and contribute positively towards lowering emissions. With this, they also save time that was earlier used in collecting wood daily. During the experience-sharing interviews, these women expressed willingness to utilize this saved time productively so as to contribute to household income. The details of this study are given in the paper.

Keywords: *livelihoods, income, energy, fuel*

PP4.2.5. The role of women in agroforestry: nursery-raising activity by self help groups

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In India, over 85% of rural families are dependent on agriculture for their livelihood. Women contribute 65-70% of the labour in agriculture and do a lot of work on their farms. But women lack formal agriculture training as they are not considered farmers and have domestic responsibilities. Women trail in adopting new technologies and in taking advantage of modern scientific information and technologies. BAIF Development Research Foundation was established in 1967 for promoting sustainable livelihood in rural India. It now works in 16 states of India. The deprived rural poor, particularly those belonging to secluded castes and secluded tribes, having small and marginal land holding, and living in drought prone areas are the major target groups. The programmes aim at sustainable livelihood, empowerment and clean environment.

In 1982, BAIF initiated the wadi model in tribal areas in Gujarat on the wastelands with fruit plants in the main field and fuelwood and fodder species on field bunds. A typical orchard, covering 0.4 ha, had 40-80 fruit plants and 500-600 other plant species. Under the KfW and Nabard supported project in Dharampur block of Gujarat, many families have adopted the wadi model since 1993. Women self help groups were also promoted of wadi holding families for women empowerment. For the wadi programme a lot of saplings for fruit and forestry had to be procured for plantation. It was difficult to get these saplings in time and of the required quality in the nearby villages or nurseries.

BAIF decided and discussed with the groups to take up nursery raising activity. Nursery raising activity was acceptable to many groups. Then women from the interested self help groups were trained to undertake mango grafting and nursery of many forestry trees. Nursery raising was taken up as a group activity by women. This activity gave them an opportunity to increase their knowledge, skill and income. There has been a significant increase in the confidence of women. They have developed mutual trust, social security, skills and access to technology and credit. The income earned from the nursery was kept by the women and the women could take decisions on how to use it.

Keywords: *women, agroforestry, nursery, drought*

PP4.2.6. The role of gender in decision making on agroforestry: A case study from Malawi

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The success of agroforestry innovations is largely determined by the degree to which agricultural decisions are made within households. Traditionally, decisions are made by the male household head or husband, raising questions as to the role of the wife in the decision-making process. This paper examines household decision-making and gender dimensions in agricultural activities, including tree planting, for farming families in Malawi. Survey questionnaires were administered to 141 household heads in two districts with ethnic groups that practice both patrilineal/patrilocal and matrilineal/matrilocal marriage. The study found that although husbands are the main decision-makers, there is considerable joint decision-making with their wives for many agricultural activities. Decisions regarding tree planting and tree management however, are more often made by the husband alone. In patrilineal households, decisions were made more often by the head of the household alone compared to matrilineal families where there was more joint decision-making by husbands and wives together.

Notably, joint decision-making by husbands and wives resulted in a higher density of planted trees on farms compared to when a household head decides alone. This points to the need for enhancing joint decision-making by the husband and wife within a household. The study recommends further understanding on the local context that impinge upon gendered decision-making for tree planting in Malawi

Keywords: *decision making, gender, Malawi, matrilineality*

4.3 Adapting to climate change

PP4.3.1. Gliricidia intercropping boosts maize yields in southern Africa even under severe drought

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"Fertilizer tree" systems such as Gliricidia intercropping show promise for boosting maize yields and improving food security in southern Africa, but their performance under drought conditions is not well described. This three-year experiment (2008-2011) used rain exclusion shelters to test the effects of drought on a mature Gliricidia-maize intercropping system at a long-term field site at Makoka Agricultural Research Station in southern Malawi. It was hypothesized that Gliricidia might improve the drought resilience of maize production via effects on soil moisture and microclimate.

The drought manipulation reduced overall maize yields by 61% and 39% in 2009-2010 and 2010- 2011, respectively. Gliricidia plots (which, at this site, tend to yield 50-100% more than maize monoculture plots) experienced yield reductions that were proportionally similar to those of maize monoculture plots. This suggests that Gliricidia continued to confer yield benefits under drought conditions and that Gliricidia did not interact with the drought treatment either positively or negatively.

Yield benefits from Gliricidia accrued at each stage of the maize's reproductive development: maize in Gliricidia plots had more ears per plant, more kernels per ear, and greater thousand-kernel weights. This was not due merely to improved nutrient status, as plots receiving full doses of inorganic N did not show such pronounced benefits. Nor was it due to enhanced soil moisture, as Gliricidia had no effect on soil moisture throughout the growing season (though it did reduce soil and air temperature at the end of the growing season). More work is needed to determine the underlying mechanisms.

These results, along with long-term yield data (1993-2006) from this field site, indicate that absolute yield increases from Gliricidia are greatest under conditions of adequate rainfall but that Gliricidia still outperforms monoculture maize even in drought conditions. These findings suggest that Gliricidia intercropping will remain a useful tool for improving maize yields in adverse and uncertain climatic conditions. Much more research is needed to optimize agroforestry soil fertility technologies for current climate variability and future climate change.

Keywords: *drought, Gliricidia, maize, physiology*

PP4.3.2. Potentiality of biochar production from agricultural and homegarden wastes to ensure multiple benefits

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An exploratory survey was conducted in coastal areas of Bangladesh to investigate potentiality of biochar production from agricultural and homegarden wastes to ensure multiple benefits to climate resilient Bangladesh. A semi-structured questionnaire survey was conducted among 180 sampled households of ten coastal districts of Bangladesh (Bhola, Patuakhali, Barguna, Jhalokathi, Pirojpur, Barisal, Bagerhat, Khulna, Satkhira, Jessore) following multistage simple random sampling to identify sources and amounts of agricultural and homegarden tree wastes; to compare agricultural wastes with tree wastes of homegardens; to identify major tree species of homegarden contributing wastes; to identify present mode of utilization of wastes; and to assess farmers' perception about biochar using agricultural and homegarden tree wastes for farm productivity. A literature review was conducted to find out suitable kilns for low cost biochar production in Bangladesh with potential multiple benefits of biochar. For surveyed coastal households, agricultural residues (56%) dominated over homegarden tree residues (44%) in terms of biomass production. In agricultural residues, paddy straw comprised the highest percentage (45%) followed by rice husks (24%) and bean plants (18%). For homegarden tree residues, *Albizia saman* contributed the highest amount (43%) of woody residues annually followed by *Leucaena leucocephala* (22%) and *Albizia procera* (18%). Tree residue comprised pruned branches (48%), lops and tops (31%), leaves (14%) and others (7%). A major part (82%) of agricultural and homegarden waste was disposed of by dumping, burning in-field, burning for cooking or throwing away. Among various kilns designed for biochar production worldwide, the SuperChar 100 Mk II from Carbon Gold seemed the most promising for Bangladesh. Literature envisaged that the use of agricultural and homegarden wastes in biochar production can address soil fertility and agricultural productivity in Bangladesh as well as other tropical countries with mitigation of climate change by reducing green house gas emissions.

Keywords: *agricultural waste, biochar, climate change, homegardens*

PP4.3.3. Agroforestry and climate change: an empirical study in drought and mountain regions of west Bengal, India

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Agroforestry systems sequester carbon and produce a range of economic, environmental, and socioeconomic benefits. In India agroforestry is the only alternative to meet the target of increasing forest cover to 33 per cent. This study has three objectives. First is to examine the carbon sequestration potential of agroforestry in different regions of India. Second, the paper attempts to examine how agroforestry contributes to the livelihood improvement of the people which helps to enhance resilience against climate change. Lastly, the paper tries to examine plantation programmes of the Government of India.

The paper is an empirical study based on data collected through field surveys and secondary sources in 2011. The field survey covers two villages consisting of 191 households in the drought-prone district of Bankura and two other villages in the mountain area of Darjeeling district of West Bengal, India. The results of the study showed that agroforestry systems have impacted on raising income,

employment and livelihood security while on the other hand the average sequestration potential in agroforestry has been estimated as 25tC per ha. The paper has important policy implications for forest conservation, environmental sustainability and enhancing rural landscape.

Keywords: *agroforestry, carbon sequestration, livelihood security, environmental sustainability, plantation programs*

PP4.3.4. Effects of 20-year of livestock grazing, prescribed early fire and selective tree cutting on below ground biomass

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Below-ground biomass is an important component of terrestrial ecosystem carbon stock. Understanding its size and the influence of disturbance on its level is essential for carbon evaluation in savanna ecosystems. We studied root biomass after twenty years (1992-2012) of application of early fire, grazing and selective tree cutting on two factorial experimental sites characterized by deep and shallow soils in Sudanian savanna-woodland ecosystems of Burkina Faso. Coring methods have been used. At each sampling point, a block of soil 25x25x50 was taken and the roots (fine and coarse) quantified at two levels (0-20 and 20-50 cm). We found no significant difference ($p > 0.05$) in root biomass between site and between top (0-20 cm) and sub soils (20-50 cm). Grazing, selective wood-cutting and fire did not affect ($p > 0.05$) root biomass. Nevertheless, interactive treatment effect was observed ($P=0,001$). Total amount of biomass dry weight ranged from 8.7 t.ha⁻¹ on plots treated simultaneously with grazing, fire and wood cutting to 18.3 t.ha⁻¹ on plots protected from grazing but subject to fire and wood cutting. The result suggested that vegetation of dry savanna ecosystems are adapted to the investigated disturbances since below-ground root biomass is not affected by any of the treatment applied alone. Therefore, projects which aim to mitigate climate change by increasing soil carbon stocks in dry savanna ecosystems should pay more attention to this part of below-ground biomass, taking care to avoid occurrence of the three disturbance factors (grazing, fire and tree cutting) in the same landscape.

Keywords: *below-ground biomass, climate mitigation, fire, grazing*

PP4.3.5. Enclosures – a productive, C sequestering and sustainable alternative to pastoralism?

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Since 1960 population increased 5-10fold in pastoral areas resulting in reduced per capita livestock assets that underpin traditional pastoralism. This population pressure triggered encroachment of cropland, concentration of livestock and constrained seasonal migration resulting in overgrazing and land degradation. This increased land degradation was followed in West Pokot district by the emergence of community-based institutional change aiming at sustainable land management. This innovative land management, which includes trees and enclosures, has been adopted widely. Trees and natural grasses do not only offer products but also ecosystem services such as reduced erosion and significant carbon sequestration in woody biomass and the soil. In a checker-board pattern of fences, farmers now rotate their grazing animals between paddocks which are interspersed with cropfields. Concurrently there has been a change in land tenure towards privatization and individual land use rights.

The above chronosequence of population pressure leading to land degradation, land use change and a subsequent emergence of institutions to support greater land care is a trajectory common to many semi-arid areas and offers excellent scope for research. We have started multidisciplinary research aiming at documenting and analyzing this development. Analysis of the role of population pressure in driving this trajectory reveals that land use changes in West Pokot with lower initial population occurred several decades later in more densely populated districts such as Machakos. Further, we evaluated experiences with enclosures from Kenya, Ethiopia and Tanzania, in relation to the West Pokot site. We conclude that population density is the prime driver of land use change and the emergence of bottom up natural resource management in semi-arid districts of East Africa.

Keywords: *climate change adaptation, demographic pressure, enclosures, pastoralism*

PP4.3.6. Silvopastoral systems and climate change: Proyect scolel' te in chiapas, Mexico

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The transformation of natural forest to secondary forest and pastures has been the most common process of land use change in tropical countries in recent decades. In Chiapas, Mexico, since 1994, the Scolel' te project ('tzeltal' means "growing trees"), has sold carbon credits in the voluntary market. The aim of this study was to show silvopastoral strategies for mitigation and adaptation to climate change in the framework of the Scolel' te. The research was carried out in 2010 in cattle farming communities (Marques de Comillas) within the Lacandon rainforest, Chiapas, México. Interviews, transects and participative workshops (Plan Vivo, 2006) were used in order to design and show advances in silvopastoral strategies. The following two approaches were suggested by livestock community members and selected for project development: 1) management of secondary vegetation and forest conservation and 2) establishment of agrosilvopastoral and agroforestry systems in open and grazing areas. As a result, secondary vegetation was managed by pruning and thinning trees to eliminate competition and favour growth of the most commercially valuable species. The establishment of 45.5 km of live fences (Ejido La Corona) was carried out in accordance to the silvopastoral work plan using "cocoite" forage trees (*Glyricidia sepium*) and other timber species. All of the forage trees were native species produced in communal nurseries. Other activities included the use of forage grasses from the *Brachiaria* genus, promotion of cattle-feed supplementations with multinutritional blocks, improvement of cattle breeds, establishment of livestock infrastructure, establishment of technical training and creation of the farmer-to-farmer exchange.

Keywords: *Lacandon Rainforest, livestock, small farmers*

PP4.3.7. Tools for estimating below-ground biomass of coffee bushes growing in monoculture and agroforestry systems

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Coffee plantations, in monoculture and agroforestry systems, are strategies to mitigate climate due to their capacity to capture atmospheric CO₂ in biomass and soils. However, research about above-ground biomass (*Ab*) is now more available than that for below-ground biomass (*Bb*). The development of tools for estimating *Bb* is a key for studies of carbon capture. A total of 40 plants from two cultivars (Caturra and Castilla) were sampled in the most dominant coffee production system in Líbano, Tolima, Colombia. Sampled bushes were measured (diameter of trunk at 15 cm height -*D15*- and total height -*th*), cut at ground level and their root systems (diameter >2 mm) manually excavated. Plants were separated in components (roots, branches, trunks, leaves and fruits) and their biomass was estimated gravimetrically (fresh weight and dry matter content). *Ab* and *Bb* was estimated for each plant. Analysis of correlation (*r*) was carried out between *Bb* and independent variables (*D15* and *th*). Generic models, with lineal and logarithmically transformed variables, were tested through lineal regression analysis. A *Bb/Ab* ratio was also estimated for each plant. The best-fit models were selected based on the highest coefficient of determination (*R*²) and adjusted *R*² (*AdjR*²), and lowest root mean squared error (RMSE), quadratic mean error of prediction (ECMP), and Akaike and Bayesian information criterion and biologic logical. The sampled bushes varied between 0.46 – 3.00 cm in *D15*; 0.60 – 8.00 m in *th* and 0.01 – 2.33 kg/plant in *Bb*. The *Bb* was better explained by *D15* than by *th*, with an *r* of 0.66 and 0.85, respectively. The best-fit models use *D15* or *D15-th*: $Bb = 0.10 + 0.02 * D_{15}$ and $Bb = 0.04 + 0.01 * D + 0.23 * D * th - 0.0038 * D * th$ where *Bb* (kg/plant), *D15* (cm) and *th* (m). These tools allow to estimate *Bb* in coffee bushes non-destructively.

Keywords: allometric equation, carbon sequestration, root to shoot ratio

PP4.3.8. Estimation of above-ground carbon: a modelling approach for Acacia woodlands in Meatu, Tanzania

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At present, methods for estimation of carbon (C) stocks in terrestrial ecosystems are very important worldwide. Use of allometric models for tree C estimations is therefore increasing due to their high levels of precision. This study was undertaken to develop allometric models for estimation of above-ground C in different tree components of *Acacias*.

We collected data from *A. nilotica*, *A. polyacantha* and *A. tortilis* in the woodlands of Meatu, Tanzania. We employed a destructive sampling technique, where several separate C prediction models for different tree components were developed. We used diameter at breast height (DBH), height (H) relationship as predictor variables and above-ground C as dependent variable. We log transformed all the linear regression models, then logarithmic units were converted to arithmetic units to obtain the realistic C content and equalize the variances over the entire range of C values. The best fit models based on accuracy measures (higher coefficient of determination and low standard error) were

selected for prediction of above-ground carbon.

Nine tree specie-specific allometric models were developed. The accuracy measures indicated that C in *Acacias* is explained well using diameter at breast height. The best fit models for *A. tortilis* and *A. polyacantha* were those that used DBH as predictor variable. However, the best model for total C in *A. nilotica* used DBH and H as predictor variables. These models are potentially useful for prediction of above-ground C and estimation of C stocks in *Acacias*.

Keywords: *allometric models, carbon stocks, DBH, destructive sampling*

PP4.3.9. Climate smart land management for improved food security and Climate Resilient Green Economy (CRGE) Strategies in Ethiopia

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There has been increasing attention in climate smart landscape management in Ethiopia over recent years. The new climate resilient green economy (CRGE) strategy for Ethiopia has given an impetus for sustainable land-related productive systems. The wake of climate smart land management/agricultural development has translated into higher support for forestry, livestock and crop-based development pathways. More recent efforts to foster resilience tend to focus on livelihood dimensions that revolve around the principles of green economy. Although there are many local climate smart agricultural practices that support the sustainable livelihoods of smallholder farmers in the country, there is scattered knowledge and limited insight in the role of climate smart agriculture in achieving more resilient agricultural development. To address this knowledge gap, World Agroforestry Centre together with national partners organized a consultative process in Ethiopia to compile existing information and best practices in order to prepare practical guides for various stakeholders including parliamentarians, government officials, NGOs, women, farmers, pastoralists, etc., to ensure that climate smart agricultural practices are managed and used to strengthen people's resilience to the shocks of climate change. This consultative process involved various practitioners including women and policy makers engaged in climate smart land management/agriculture initiatives. Policy makers and experts with in-depth knowledge of climate smart land management/agriculture in Ethiopia were engaged to consolidate knowledge on climate smart policies that could be mainstreamed into agriculture, forestry and agroforestry systems. The study considers biophysical and socioeconomic aspects (including livelihoods, gender and institutional arrangements), and identified available technologies and best practices as important to the body of knowledge that is converted into a range of information and communication products.

Keywords: *climate smart land management, climate resilient green economy, climate change adaptation, rehabilitation*

PP4.3.10. A multifunctional rotational system practiced for Mayan small farmers in Mexico

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The Taungya system consisting of an association of corn to high-valued trees has been proposed as an

alternative to shifting cultivation. This study aimed to evaluate the performance of the Taungya established by small indigenous Mayan farmers in Chiapas, Mexico. 27 farmers' plots were selected in a chronosequence (2-13 years of establishment). Interviews to each owner were applied. Structure and function indicators were assessed in each plot. Land and trees were owned by farmers who decided the amount of land, species and management to be involved. The species preferred were: cedar (*Cedrela odorata*), mahogany (*Sweitenia macrophylla*), “maculis” (*Tabebuia rosea*), “bojón” (*Cordia alliodora*) and “guanacastle” (*Enterolobium cyclocarpum*). Maize was harvested twice annually with a total average of 3600 kg ha⁻¹ decreasing about 200 kg ha⁻¹ annually. 17 edible species and 43 woody species were recorded. Crops and trees associated for a 3-7 year period favoured by tree phenology (drop leaf) in winter.

Tree diameters, complexity, total biomass, aboveground carbon stock, timber volume and value significantly increased with age. The first turn comes around the ninth year whereupon 320 trees and 465 saplings ha⁻¹ were left on the plot, showing a successional potential. The total tree height in the oldest plantations (10-13 years) was 11.8m. Farmers received a payment for carbon sequestration during the first ten years of the plantation. Nonetheless soil organic matter was high; the amount of soil nitrogen and phosphorus can be a limiting factor. Some farmers establish coffee and palms after the ninth year or pastures for cattle, shifting to perennial or silvopastoral schemes, adding economic value to the system.

Taungya offers a high potential for climate change mitigation and adaptation, offers food, timber and shows potential for restoration as avoids the use of fire, and reduces degradation occurring with frequent cycles of maize cultivation.

Keywords: *climate change adaptation, climate change mitigation, Mayan indigenous people, Taungya*

PP4.3.11. Carbon stock potential and economic benefits of community-managed dry afromontane forests in Gergera watershed, Ethiopia

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Sustainable community management of forests has met people's subsistence needs and plays a major role in reducing deforestation and degradation and can enhance carbon sequestration. The study was conducted to quantify the potential significance of community-managed forests in enhancing carbon sequestration and bring additional income to the local people. 24 plots were randomly selected from managed natural forests, disturbed natural forests, exclosures and grazing land. Tree and shrub biomass was estimated using a regression model while herbaceous biomass was determined using a total harvest. The impact of community forest on total income of the community was studied by taking 150 sample households. A Propensity Score Matching (PSM) was conducted to measure the impact of the community forest on total income of the community. The estimated total biomass for managed natural forest, disturbed natural forest, exclosure and grazing land were 92.9 Mg ha⁻¹, 33.4 Mg ha⁻¹, 33.8 Mg ha⁻¹ and 12.5 Mg ha⁻¹, respectively. There was a significant difference in total biomass between the community forests and the grazing land ($P < 0.05$). The carbon content of the living biomass for managed natural forest, disturbed natural forest and exclosure were estimated as 43.6 Mg ha⁻¹, 15.7 Mg ha⁻¹, 15.9 Mg ha⁻¹, while for open grazing the estimated carbon were 5.8 Mg ha⁻¹. The carbon trading potential for managed natural forest, disturbed natural forest and exclosure was USD of

439 ha⁻¹, 158 ha⁻¹ and 160 ha⁻¹, respectively. The overall average gain of using community forest in total income ranges from USD 854 to 900 year⁻¹. The intervention has resulted in positive and significant effects on total income on the treated households ($p < 0.05$). This study confirms that successful participation can enhance carbon sequestration and income benefits to the community.

Keywords: *biomass, carbon sequestration, carbon trading, community forest, income, northern Ethiopia*

PP4.3.12. The status of local experience in the restoration practices in degraded landscapes of Eastern Africa

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An analysis was conducted in order to document local experiences in restoring degraded forests and woodland areas in some countries in Eastern Africa. The findings showed that natural regeneration through active involvement of local communities supported by enabling policies such as clear forest and land tenure is the most successful and promising option for restoration of the large areas of degraded land in East Africa. Enclosures are prevalent in livestock farming areas where they are used to encourage rehabilitation of grazing land. Artificial regeneration through woodlots or farm forest is prioritized for outgrowers in Uganda, energy production in Rwanda and reforestation of bare hills in Ethiopia. Opportunities also exist of promoting forest restoration through tree planting for carbon markets in rural communities in the form of community-based REDD mechanisms for sustainable forest management. Agroforestry is also recognized as an important avenue for rehabilitation of degraded areas especially to improve soil fertility and soil conservation. In future, there is need to relook at the forestry and environmental policies in some countries to make them more enabling to forest restoration and land rehabilitation and promote up-scaling of forest and land restoration/rehabilitation in association with forest enterprise development such as farm forestry and/or out-growers and payment of environmental services.

Keywords: *degradation, natural regeneration, policies, restoration*

PP4.3.13. Trees suitable for carbon sequestration in agroforestry system at Sivaganga district, Tamil Nadu

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A field experiment was conducted to study the benefit of carbon sequestration in important agroforestry trees for adopting climate change at Nattarasankottai Village (N 9°52'13.37'' and E 78°33'06.80''), Sivaganga district in Tamil Nadu during 2009 - 2013. The species selected for the experiment viz., *Tectona grandis*, *Gmelina arborea*, *Dalbergia sissoo*, *Bambusa vulgaris* var. *vulgaris* and *Swietenia macrophylla* in randomized block design with four replication. The soil of the study area was red sandy clay, acidic in nature, low in nitrogen, medium in phosphorus, high in potassium with average rainfall of 400 - 600 mm per annum. The species were compared in terms of biometric, biomass production, carbon accumulation and soil organic carbon. Among the five species, *Dalbergia sissoo* recorded maximum biomass (14 970.82 kg ha⁻¹) and biomass carbon (6593.55 kg ha⁻¹) followed by *Bambusa*

vulgaris var. *vulgaris* with a biomass of 9611.58 kg ha⁻¹ and biomass carbon of 4078.87 kg ha⁻¹. The minimum biomass (1799.13 kg ha⁻¹) and biomass carbon (771.80 kg ha⁻¹) was observed in *Gmelina arborea*. Soil organic carbon was maximum in *Bambusa vulgaris* var. *vulgaris* (11.32 t ha⁻¹) followed by *Tectona grandis* (11.24 t ha⁻¹), *Dalbergia sissoo* (11.07 t ha⁻¹) and minimum was recorded in *Swietenia macrophylla* (11.00 t ha⁻¹). From this study it was concluded that *Dalbergia sissoo* and *Bambusa vulgaris* var. *vulgaris* are the suitable agroforestry trees for mitigating climate change by getting maximum biomass, biomass carbon and soil organic carbon in southern region of Tamil Nadu.

Keywords: *Bambusa vulgaris*, biomass carbon, *Dalbergia sissoo*, soil organic carbon

PP4.3.14. Developing market to reward diversity in horticulture crops: a case study of mango in India

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Mango (*Mangifera indica*) is the king of fruits and a native species to India. It is estimated that there are nearly 1000 mango varieties grown in India. Based on "consultation market based approach" in one of the major mango producing regions in India - Malihabad, Uttar Pradesh, the authors found that more than 90% of mango orchards are now under cultivation for four major commercial varieties: Dushehri, Lucknow safeda, Chausa and Langra. This restricts more than 400 domestic/indigenous varieties in less than 10% of the orchards' land. Unfortunately, mango diversity all over India including Malihabad region is facing threats and regional challenges such as commercialization, urbanization, loss of & changes in traditional knowledge & management systems. Such loss exists despite huge germplasm collections in gene banks by ex-situ conservation. To tackle these challenges, there is an urgent need for "on-farm conservation" of diversity. This can be done by providing some rewards and incentives to the diversity conserving farmers through a Payment of Agrobiodiversity Conservation Services (PACS) approach, which will benefit the society as a whole. The mango varieties which are having good shape/size/colour/taste, longer shelf life, and hardy should be selected and conserved. This will not only help in conserving agrobiodiversity, but will also help in enhancing resilience of produce in the face of natural disasters, climate change, and other factors that impact socioecological production of mango in India. This in the long term contributes to securing the livelihoods of the farmers who are completely financially dependent on mango plantation and it will also revitalize their local businesses. The authors present the design of such an approach for the Malihabad region.

Keywords: agrobiodiversity, climate change, farmers, PACS (Payment for Agrobiodiversity Conservation Services)

PP4.3.15. Studies on carbon sequestration by the nitrogen-fixing species in subtropical climate

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Nitrogen-fixing trees are an integral part of the indigenous agroforestry plantations on farms. The nitrogen-fixing species accumulate more C due to their efficient system of fixation of nitrogen and the

carbon in their parts. Increased N inputs most likely increase soil C storage by increasing biomass diversity and production. The maximum tree height and diameter was recorded in *Acacia albida* (Hissar collection). It was closely followed by *Dalbergia sissoo* and *Bauhinia variegeta*. *Acacia nilotica* was the poor performer with 20 percent survival and 6.86 m height per tree. It was most affected by the diseases among all the species. The *Dalbergia sissoo* sequestered 145.24 and 42.12 t/ha carbon in above and below ground parts, respectively. It was closely followed by *Acacia albida*. Carbon potential of *Dalbergia sissoo* was again maximum at 28.42t/ha per year. The 18.42 t/ha carbon was sequestered by the soil over 24 years which was almost double the carbon level at the time of plantation in 1989. The mean annual increment was higher in the first six years among all the NFT species. The maximum mean annual increment in height was recorded to be 0.57 m per year whereas the maximum mean annual increment in DBH was recorded in *Leucenaena leucocephala* to the tune of 1.03 cm per year. The study concludes that *Dalbergia sissoo* is the highest carbon sequestering species with maximum survival.

Keywords: *nitrogen-fixing trees, carbon sequestration, agroforestry species subtropical*

PP4.3.16. Domestication of potential agroforestry fruit/oil tree Jaitoon (*Olea cuspidata*) for wasteland amelioration

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India is a nation with a wealth of forest resources that provide benefits to local communities on both subsistence and commercial levels. Olive is sought for its best oil available in the world for edible purposes. Some significant results have been obtained for possibilities to exploit olive production. It can be grown in marginal and waste land where the soil is unsuitable for other crops. It provides employment opportunities to the rural population and thus helps in poverty alleviation. It contributes to establish agro-industries for manufacturing filter discs, olive crushers, packaging materials, etc. The olive oil has twice energy value than that of sugar. The fruits contain around 20% oil and have very less cholesterol. It contains 80% unsaturated fatty acid against 20% saturated ones. It contains oleic acid in high percentage which is very essential for our body. The Indian olive oil market pegged at Rs 52 Crores until 2006 is now at Rs. 380 Crores. With this expected boom to reach Rs. 550 Crores by the end of 2013 and as per the Indian Olive Association hopes to reach 2, 5000 MT in 2020.

The development of a viable Olive based agroforestry industry therefore requires a means to increase the availability of planting material and build farmer capacity for appropriate tree management. There are still considerable shortages of planting material to meet smallholder planting goals, which has resulted in significant price increases for planting materials. Olive shows high level of genetic segregation causing problem in propagation through seeds. This paper outlines a domestication strategy that includes provision for rapid deployment of improved germplasm through both clonal and asexual propagation, inter-island exchange and extension and awareness activities.

Keywords: *agro-industries, genetic segregation, domestication, poverty alleviation, communities.*

PP4.3.17. Homegarden agroforestry for socio-Economic, ecological and environmental sustainability in Sri Lanka

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Home gardens in Sri Lanka have been described as the oldest land use activity, next only to shifting cultivation. It is one of the major forms of land use in the island that has been evolved through generations within the available resource frontiers to suit the socio-economic, cultural and ecological needs. Though, this land use system existed in Sri Lanka for centuries, and claimed to account for 13.1% of the total land area of the country, it started receiving the national recognition only recently. During the past two decades, numerous studies have been conducted on home garden systems by researchers from various disciplines. Having realized the importance of home gardens, the national development plan has now included strategies to expand and improve food and timber productions in such landscapes of Sri Lanka. Development of home gardens in Sri Lanka has been the priority of many development programmes implemented over the past few years; among them strengthening of 1.5 million home gardens was the target of “*Divi Neguma*” (Livelihood Development) programme in order to achieve self-sufficiency in vegetables and to reduce vegetable prices. Hence, Sri Lanka is a country to declare a national program for improvement of home garden agroforestry. Parallel to such development, this paper shows how home garden land use system plays a critical role in agricultural, ecological and environmental sustainability of the country and how beneficial home gardens are to socio-economic development of the human well-being. Strategies to achieve such goals of the country and the critical gaps exist and mechanisms to overcome such gaps are discussed in detail.

Keywords: *home gardens, sustainability, Sri Lanka*

PP4.3.18. Adaptation to climate change in agroforestry: Evidence from the Nile basin of Ethiopia

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This paper presents an empirical analysis of adaptation to climate change in an agroforestry in a typical low-income developing country. Specifically, it provides an empirical estimation of the determinants of adaptation to climate change in agroforestry vis-a-vis other (non-agroforestry) adaptation measures. Key questions involved include what are the factors that enhance farmers adopt agroforestry as an adaptation strategy to climate change? How do these compare to adoption of other adaptation strategies (measures)? What are the barriers to agro-forestry adaptation? The analysis relies on primary data from 1,000 farm households in the Nile Basin of Ethiopia. The analysis also involves use of seasonally disaggregated climate (temperature and rainfall) data. Based on monthly collected meteorological station data, the thin plate spline method of spatial interpolation was used to interpolate the specific rainfall and temperature values of each household. A bivariate probit model is used for the empirical estimation. Results suggest that agro-ecology and climate variables are most important factors that determine (or have significant impact on) farmers’ adoption of agroforestry as an adaptation strategy to climate change among others.

Keywords: *climate change, adaptation, agroforestry, bivariate probit model, Ethiopia*

PP4.3.19. Assessments of the carbon storage potential of forestation in Southern Africa

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Forestation, which can be afforestation or reforestation, is recognized as a potential climate change mitigation option because of the forests' capacity in capturing and storing atmospheric carbon. Hence, there are global efforts to engage the developing countries in Climate Change mitigation using forestation. One of such efforts is carbon credit and trading through the Carbon Development Mechanism (CDM). Among the world's forest, tropical forests in developing countries like Southern Africa have been identified to have the greatest potential for carbon sequestration, but the carbon potential and cost-benefits of such forestation in South Africa remain unknown for various tree species. The present study uses IPCC Tier 1, 2, and 3 (CO2FIX v3.1 model) in assessing the carbon sequestration capacity of most tree species that grown in Southern Africa under various feasible scenarios. Our preliminary results show that *Acacia* spp, *Portulacaria afra* (Spekboom) and *Faidherbia albida* (Anaboom) are among the species with greatest economic potential for carbon storage. Results of this study will help in the long term mitigation scenarios in Southern Africa and will contribute to the third national communication in some Southern African countries.

Keywords: *climate change, agroforestry, mitigation*

PP4.3.20. Human security or resilience? The role of trees for climate change adaptation in the Burkina Faso parklands

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In the landlocked, West-African state of Burkina Faso, a majority of the population derive their livelihood from diverse and multifunctional agroforestry systems, often referred to as the parklands. Characterized by mature trees occurring scattered in cultivated or recently fallowed fields, the Burkina Faso parklands have been described as a highly dynamic and resilient socio-ecological system, developed over generations as a reflection of and adaptation to changes in the physical and socio-economic environment. There is a considerable body of literature that highlights the importance of trees for communities in Burkina Faso and the wider Sahel region to adapt to climate variability on intra- and inter-annual, as well as longer time-scales.

However, at the same time, the rural population dependent on parklands is often claimed to be among the most vulnerable in the world due to a combination of high levels of poverty and food insecurity, high natural resource dependence, high climatic risk, and low natural resource endowment. Such evidence echo findings from other parts of the world, showing that high levels of vulnerability and low adaptive capacity are often associated with high levels of poverty in combination with a high reliance on natural resources.

Based on results from extensive fieldwork during 2010 – 2012, we show how these two very different interpretations of the Burkina Faso Parklands (the first emphasizing socio-ecological resilience, the second human security) guide assessments of the role of trees in climate change adaptation to very different results and subsequently provide fundamentally different platforms for climate change adaptation policy. While almost all literature on differences in the framing of climate change vulnerability in general, and the role of agroforestry in climate change adaptation in particular, is based on comparison between different cases and/or different studies; this paper will discuss such differences within the context of one single research project and one single case.

Keywords: *adaptation to climate change, Burkina Faso, human security, resilience*

4.4 Bridging science and technology

PP4.4.1. State of the art of agroforestry research, development and scaling up in Vietnam

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Agroforestry research in Vietnam has been conducted based on scientific and local ecological knowledge. However, sustainable implementation of agroforestry practices, which constitutes an important component in natural resource management, still faces many challenges. Thorough evaluation of the current state of agroforestry research and development in Vietnam is indeed necessary to re-orient its future direction. However, evaluating agroforestry research and development in Vietnam is a difficult undertaking for four reasons: i) many agroforestry studies in the past were at best documented only in ‘grey literature’ form; ii) there was no system to document agroforestry practices developed by farmers; iii) agroforestry pilots were not scientifically evaluated in terms of their extrapolation domains, and hence, were not recommended for scaling up; and finally, iv) the temporal and spatial dimensions of agroforestry vis a vis the multiple factors that influence change make it harder to predict their sustainability. This paper attempts to summarize existing research on agroforestry, analyze research gaps, and presents priority research topics that need to be addressed to unleash the potential of agroforestry in Vietnam.

Keywords: *agroforestry research and development, scaling up, sustainability*

PP4.4.2. Radio as mass media in agroforestry extension in Sulawesi, Indonesia: challenges and potentials

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Availability of information on agroforestry is crucial to help farmers to improve their livelihoods. In Indonesia the information only reaches a limited number of communities due to limited numbers of extension agents. Furthermore, agroforestry is a new field which most of the agricultural extension agents have limited knowledge and experience of. To address such gaps, the use of communication media is potential for facilitating the spread of knowledge. A survey on preferred media was conducted in south and southeast Sulawesi involving 146 farmers in November 2012.

The study revealed that the most preferred communication media in south Sulawesi was television and mobile phones, while in southeast Sulawesi it was radio and mobile phones. Television and radio as mass media will help to spread information to wider audiences, yet television requires more budget compare to radio. Radio in most of the world is still the medium of choice and offers the greatest potential for serving farm and rural populations. In the two provinces, radio has the potential as it can reach villages with poor infrastructure. The paper describes the experiences, challenges and also potentials of utilizing a community empowerment program that belongs to a state-owned radio and using local radio to broadcast information to support agroforestry extension in south and southeast Sulawesi.

Keywords: *communication, farmers’ information, knowledge*

PP4.4.3. Integrating agroforestry and sheep feeding for increased food security in Mali

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Sheep herding and fattening play a significant role in the livelihoods of rural households in Mali and other semi-arid countries of West Africa. Although they could improve the incomes of rural women and men, their potential is not completely realized. Lack of forage, mainly during the dry season, reduces the meat production of sheep. Agroforestry offers the potential for better herd management, as it can supply nutrients not otherwise available especially through fodder production of trees and shrubs species.

This project aimed at improving incomes for poor rural women in Mali by investigating the contribution of woody species that can serve both as sheep fodder and as the backbone of a productive agroforestry system. Whereas residues from crops and other herbaceous species are generally unavailable during the dry season, woody species are available all year-round and can supply valuable feed during this period.

The project tests different species of fodder trees for nutritional content, sheep preference, and sheep growth rates, and investigates how these species can be incorporated into agroforestry practices to increase the production of both human and animal foodstuffs. Social and economic considerations and impacts are also covered. Research is performed in station and in the fields within a participatory process in which NGOs, national and international research centres, tertiary education institutions and civil society organizations take part. Ensuring the participation of potential users is a key issue in this approach. The results emphasize the important potential of using tree fodder in sheep herding and fattening for improving the livelihoods of rural households, especially of women, in Mali.

Keywords: *participatory approach, sheep fattening, socioeconomic issues, tree fodder*

PP4.4.4. The role of the communication process in enhancing agroforestry projects' sustainability: a Burundian case study

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Literature and empirical experiences have pinpointed for decades the importance of building on farmers' knowledge and open communication processes for developing sustainable agroforestry initiatives. However, the influence of the communication process on farmers' knowledge integration within agroforestry projects is not yet fully understood. Using an exploratory approach, our study aimed at constructing a grounded theory on the influence of the communication process between farmers and extension agents on farmers' knowledge integration. Our systemic framework focused on four key elements of the communication process: the communication approach, the perceived value of knowledge, the compatibility between farmers' and extension agents' knowledge, and interpersonal relationships between farmers and extension agents. The study took place in the province of Ngozi (Burundi), where local, non-governmental and national stakeholders pilot the implementation of treed

hedgerows on steep cultivated hill slopes. Semi-directed interviews were conducted with the extension agents as well as with 48 farmers involved in these projects. Results show that the incompatibility between farmers' and extension agents' knowledge on trees and pasture management caused some projects to fail. Interestingly, farmers' knowledge on task division and execution had been integrated even if it was incompatible with extension agents' guidelines. Farmers' knowledge that was not consistent with the projects' objectives, enhancing the projects' efficiency or valued by both farmers and agents was ignored or rejected by the extension agents. The top-down communicational approach and the higher value given to extension agents' knowledge as opposed to farmers' knowledge had a stronger influence on farmers' knowledge integration than compatibility and interpersonal relationships. Our findings reinforce previous conclusions on the key role played by farmers' knowledge in the success of agroforestry projects, and highlight the importance of considering the communication approach and the perceived value of knowledge to facilitate farmers' knowledge integration and enhance the sustainability of agroforestry projects.

Keywords: *communication, extension strategies, grounded theory, local knowledge*

4.5 Increasing food production through trees on farms

PP4.5.1. Evaluation of livestock management strategies of farmers participating in the agroforestry practices to enhance resources

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An evaluation was carried out in 2012 to determine the perception of farmers about introduced agroforestry technologies, the feeding systems and health of livestock, and the constraints that are associated with livestock management in three communities; Fiapre, Dumesua and Ayakomaso in the Sunyani West District, Brong Ahafo Region of Ghana. The Agroforestry Practices to Enhance Resource Poor Livelihood (APERL) Project trained and provided resources for these farmers. The project was implemented by KNUST and the University of Guelph in Canada. The data was collected through the administration of questionnaires, interviews and observations and was quantitatively analysed using Statistical Package for Social Sciences (SPSS) version 16. Respondents' perceptions about the introduced agroforestry technologies were diverse. 19% of the 72 respondents indicated it provides quality fodder, 14% said it reduces stress on livestock and 22% reported it promotes growth and development of livestock. The study also revealed that respondents selected for the project actively participated and applied most management techniques in terms of feeding and disease management, which implies that production levels of the livestock would improve since all the necessary management techniques are adhered to and that the number of animals would continue to increase steadily. 95% of the 72 respondents said agroforestry technologies should continue to be introduced to support the health and feeding of livestock to boost growth and development. From the evaluation, the APERL should continue and extend to other communities outside the project area to educate, encourage capacity building and reduce the burden placed on natural resources and improve the livelihoods of rural communities.

Keywords: *agricultural production, cut and carry fodder, resource poor, rural livelihoods*

PP4.5.2. Policy adoption and strategy for taungya agroforestry land use in Ondo State, Nigeria

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Policy adoption and strategy for taungya agroforestry system and the participation of smallholder farmers in tree planting in southwest Nigeria were assessed. The contributions of these farmers to tree planting was also assessed through field inventory of *Tectona grandis* established by them in 2000, 2002, 1999 and 1997 under this system in five government forest reserves in the state. Information on policy and strategy of adoption were obtained through questionnaires that were administered on randomly selected taungya farmers in five fringe communities of reserves namely Obada, Agopanu, Oyinmo, Idoani/Ipele and Oniseere where smallholders are involved in tree planting through the approved taungya system and the Director of Forestry Department in the state. Additional information on rules and regulations of taungya were collected from government documents, files, annual reports and records. The results show that taungya was active in eleven forest reserves in the states. It involved a total of 950 smallholders and between 1 and 4ha of land were allocated to each farmer annually. An average of 3800ha of plantation was raised by the farmers. The stands growth parameter ranged between 34.01 and 42.88cm for mean DBH, 10.74 and 13.03m for mean height, 2.27 and 3.29m² for basal area/ha and 18.74 and 5.33m³ for volume/ha. The majority of taungya farmers were males, married, non-indigene, landless people and within the working age. They were generally without formal education and have no access to agricultural inputs and loans. The cost for plantation establishment under taungya system was discovered to be less than under non-taungya system and taungya famers had more income, farm produce and better access to wood and wood products than the non-taungya farmers. Adherence to rules by the participating famers guarantees their stay for the three-year period on the allocated plots.

Keywords: *taungya, smallholders, forest reserves, income*

PP4.5.3. Evaluation of agroforestry systems planted in North of Mato Grosso Btate, Brazil

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The Amazon Portal is located at the initial Amazon forest frontier, in Mato Grosso State, Brazil. It involves municipalities structured in the 1970s which passed by many economic cycles, accumulating deforestation indexes. The discussion about agroforestry systems (AS) emerges from social movements as an alternative for the soil occupation model. Since 2008 experiences with successional AS have begun, featuring the “Sementes do Portal” project supported by Amazon Fund/ BNDES and coordinated by Instituto Ouro Verde (IOV), a local NGO, supporting the sowing of 720 AS areas in 06 municipalities.

This paper documents the final evaluation of this initiative, involving all the areas planted between 2010 and 2013. This evaluation was based on five dimensions: soil quality, seed distribution, plants density, spontaneous plants interference and seeds germination/ survival plants. The final step was a survey with all the families involved in the project. All the results were submitted for statistical analysis to identify the main factors related to the AS quality.

The AS planted could be characterized as small areas (70% less than 1.5 ha) with the main objective to improve the environment, located specially at deforested riparian and spring areas. The main

factors associated with AS quality were: management intensity, green manure management, mowing and participation on the capacity and management activities. The high density, soil recuperation, water protection, incomes and food production possibilities were indicated points as AS advantages by the families, apart from easier planting techniques (direct seeding).

For future challenges, the farmers pointed out the need to improve sensitization and knowledge to manage the forest species and the need of a regional organization for commercialization support with focus on the AS products. This action has already been developed by local NGOs and community groups as an emergent force from “Sementes do Portal” project.

Keywords: Amazon, family farmers, social capital, sustainable development

PP4.5.4. Optimising the value of carbon forests using local knowledge in West Africa

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West Africa has experienced a substantial decline in tree cover since the 1950s. Forest carbon projects have a potential for increasing tree cover again, which can improve biological diversity, resilience, climate change mitigation and subsequently local people's food security and income. In order for forest carbon projects to contribute towards poverty alleviation, a careful selection of the best native tree species for planting is crucial. Within a forest carbon project, Arlomom, in Senegal, tree planting was carried out by local people and species selection was based on local preferences evaluated by qualitative interviews and quantitative ethnobotanical questionnaires involving 120 informants. There was a very strong highly significant correlation between use value and planting interest of 55 species ($r = 0.93^{***}$). Women rank use value and planting higher than men for 20% of the species, especially fruit species and shrubby species for firewood. Men tend to rank construction wood higher. There is a weak significant correlation between declining trend and planting interest of 55 species ($r = 0.33^*$) meaning that local knowledge based species selection does not necessarily lead to increase in declining species. Among the tree species finally selected for planting in Arlomom were many fruit trees, eg *Parkia biglobosa*, *Adansonia digitata*, *Cordyla pinnata*, *Detarium senegalense*, *Tamarindus indica*, *Ziziphus mauritiana*, *Detarium microcarpum*, *Saba senegalensis* and *Neocarya macrophylla*.

Keywords: Africa, carbon sequestration, ethnobotany, local knowledge

PP4.5.5. Production potential of finger millet and carbon sequestration of oil seed tree-based agroforestry system

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Tree-borne oil seeds (TBOs) are gaining importance under agroforestry system because of their multipurpose use. Field experiment was conducted during 'kharif' 2011 under rainfed situation at Gandhi Krishi Vignana Kendra, Bangalore with the objectives to know the production potential of finger millet as an intercrop under TBOs and to assess carbon sequestration potential of TBOs under

agroforestry system, laid out in RCBD with eight treatments replicated thrice. The site was located between 12°51' north latitude and 77° 35' east latitude at an altitude of 930 m. above MSL. The normal rainfall is 930 mm with bi-modal distribution from May to November. The mean monthly maximum and minimum temperature ranged between 26.1° C and 33.7° C, 14.0° C and 20.5° C respectively. The relative humidity ranged from 72 to 88 percent. The sunshine hours were maximum during March (9.7 hours) and minimum during November (4.8 hours). Results revealed that higher growth and yield parameter of finger millet were recorded under *Madhuca latifolia* followed by *Calophyllum inophyllum* and attributed to higher number of productive tillers hill⁻¹, total dry matter hill⁻¹, earhead weight and 1000 grain weight. The percent reduction in yield of finger millet was 12.1, 15.0, 19.6, 24.7, 30.0, 31.84 and 50.6 in *Madhuca latifolia*, *Calophyllum inophyllum*, *Pongamia pinnata*, *Simarouba glauca*, *Melia azedarach*, *Azadirachta indica* and *Melia dubia* agroforestry system. Finger millet yield reduction was attributed to reduction in light availability due to shading and competition for soil moisture.

Melia dubia as a fast growing tree recorded higher biomass (39.95 t ha) resulting in higher carbon sequestration (21.43 t ha⁻¹). Soil fertility in terms of organic carbon, available nitrogen, phosphorus and potash was significantly better in association with trees. In addition, *Melia dubia* agroforestry system found superior in terms of net returns INR 58 397 ha⁻¹ and B: C ratio 3.60.

Keywords: agroforestry system, carbon sequestration, finger millet, tree-borne oil seeds

PP4.5.6. The influence of agroforestry planting pattern on productivity and quality of tuber Canna Edulis Ker on community forest

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Canna edulis Ker shows its potential when planted under tree stands to utilize dry areas within community forests. The increase in production of this particular tuber may contribute to the increase in food security at the smallholder level. The objective of this research is to identify the influence of agroforestry planting patterns on the productivity and quality of tubers *Canna edulis* Ker on dry community forest land. Randomized Complete Block Design was used as the research methodology. It used four treatments, i.e. agroforestry on three types of planting space using *Manglietia glauca* BI tree (2 m x 2 m, 2 m x 3 m dan 3 m x 3 m) and *Canna edulis* Ker monoculture. The planting of *Canna edulis* Ker was implemented on 33 months old *Manglietia glauca* BI using agroforestry system. The research showed that there are significant influences of agroforestry treatment on productivity of *Canna edulis* Ker. The average of tubers of *Canna edulis* Ker harvested and that of its leave's stem under the *Manglietia glauca* BI tree are shown as follows: the highest result was produced using 2 m x 3 m planting pattern (2362,5 gram/1276,8 gram), 3 m x 3 m (2021,5 gram/988,1 gram), 2 m x 2 m (1768,3 gram/863,8 gram/) and on *Canna edulis* Ker monoculture (1946,6 gram/662,0 gram). The quality of protein, fiber and carbohydrate of *Canna edulis* Ker harvested under *Manglietia glauca* BI are shown as follows: using the planting pattern of 2 m x 2 m the results are 0.9608, 0.7074, and 19.3009, respectively. The 2 m x 3 m *Manglietia glauca* BI spacing pattern resulted in 0.8690, 0.7992, and 20.1235, respectively. The 3m x 3m *Manglietia glauca* BI spacing pattern resulted in 0.9004, 0.6992, and 24.2108, respectively. And on monoculture *Canna edulis* Ker resulted 1.2641, 0.7200, and 31.7635, respectively. With the tradeoff between weight and carbohydrate content when planted using agroforestry system, it is recommended to plant *Canna edulis* Ker under *Manglietia glauca* BI stands in 2m x 3m to obtain the optimum tuber weight.

Keywords: agroforestry, *Canna edulis*, community forest, dry land

PP4.5.7. Comparison between biomass yield and SOC in young agroforestry systems of varying chronosequence in Sergipe, Brazil

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Soil organic carbon is an important physical property of soil that influences several soil parameters such as nutrient and moisture content and support habitat for soil flora and fauna. Agroforestry systems are important components of ecosystem sustainability as they have a large role in sequestering carbon in soil and thus combat climate change and global warming. The objective of the study was to quantify the biomass production of accumulated litter in 3- and 4-year-old agroforestry trials in rural central Sergipe. The estimation of biomass and organic carbon was done in duplicate located in the county Itabaiana-SE. For biomass estimation of tree and shrub (understory) vegetation consortium, the accumulated litter and roots were evaluated in both 3 and 4 years of established agroforestry systems. For the collection of litter layer we used a 0.25 x 0.25 m² square frame. Results obtained show average production of total biomass (above and below ground) of 86.48 Mg ha⁻¹ (278 trees/ha) in the 3-year-old agroforestry system, while it was 76.11 Mg ha⁻¹ (204 trees/ha) for the 4-year-old system. The soil organic carbon was 55.55 Mg ha⁻¹ and 53.47 Mg ha⁻¹ for the 3- and 4-year-old systems respectively. Biomass production in agroforestry systems and the amount of accumulated litter were significantly different probably because the 4-year-old trials had 26% fewer trees than the 3-year-old system. Similar trend was also observed for soil organic carbon. Our findings show that tree density can be an important factor in determining the amount of biomass production and soil organic carbon accumulation in the early stages of establishment.

Keywords: agroforestry, allometric equation, biomass, C-sequestration, organic carbon

PP4.5.8. Short-term effects of agroforestry-shrubs green manure on nutrients uptake and maize yield in the highlands of Rwanda

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Field trials were designed to investigate the effects of *Calliandra calothyrsus* and *Alnus acuminata* green manures as sources of N and P on nutrients uptake and maize grain yields in northwestern Rwanda. Green manures at 0.5 and 10 tonnes ha⁻¹ dry matter were incorporated in split application at planting and four weeks after planting, DAP +urea and the absolute were included in the treatments. A factorial experiment in a randomized complete block design (RCBD) with three replications was carried in two sites in Busogo and Kinigi. The effects of green manures on main soil chemical properties were not significant.

In intercropping system, the study showed that green manure increased maize yield by 20.7% and 24.1 % respectively for *C. calothyrsus* and *A. acuminata* at Busogo while at Kinigi site *C. calothyrsus* reduced maize yield by 9% and *A. acuminata* increased maize grain by 4.8%. For beans,

A. acuminata increased beans yield by 66.7% while *C. calothyrsus* increased beans by 50% at Busogo and Kinigi sites. DAP +urea increased maize yield at 25% and 56.8% over the absolute control at Busogo and Kinigi sites respectively while green manure applied at 5 t D.M. per ha reduced maize yield for both species over the control. Application 10 t D.M per ha of green manures of *C. calothyrsus* and *A. acuminata* increased maize grain yield at 12.5% and 18.7% at Busogo site.

It is therefore advisable to incorporate green manures some weeks before sowing or compost them before application in order to synchronize nutrient release with crop nutritional needs. In addition, inorganic P fertilizer application is needed to correct the low soil available level to meet crop P requirements. The results from this experiment will be used to design the participatory trial for Tree for Food Security in Gishwati which has similar agroecological conditions.

Keywords: *biomass mineralization, evergreen agriculture, hedgerow*

PP4.5.9. Dietary influence of dry Carica papaya leaf meal on growth performance of African giant land snail, Archachatina marginata

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Availability of acceptable food materials at affordable prices and at the required time is a necessity for livestock enterprises in any functional economy. Investigations into the influence of dry pawpaw (*Carica papaya*) leaf meal on the growth performance of African giant land snail *Archachatina marginata* were conducted for 56 days in the quest to provide acceptable feed for farming of the snail. A control diet (diet I) was formulated without dry pawpaw leaves meal; other test diets were formulated to contain dry pawpaw leaf meal at different inclusion levels, namely diets II (25% inclusion), III (50% inclusion), and IV (75% inclusion). Juveniles of *A. marginata* (n=72; 12±0.8g) raised at the Teaching and Research Farm of Federal University of Technology, Akure were selected, randomly allotted into four treatment groups, in triplicate, and stocked in plastic baskets lined with top soil (10cm thickness). Growth performance indices, such as body weight gain, shell length, shell width increase and survival of the snails were assessed. The snails in each treatment were fed 5% body weight of the specific diet. Body weight gain of snails fed diet II treatment was significantly different (p<0.05) than the body weight of snails fed with the other diets. The morphological parameters and other indices of the snails followed the same trend. No mortality was recorded in all the diet treatments indicating that the diets were acceptable to the snails.

Keywords: *Archachatina marginata, growth performance, land snail, pawpaw leaf meal*

PP4.5.10. Effect of tillage practices on production of mustard in 10-year old Dalbergia sissoo based agroforestry system

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An experiment was conducted to test the effectiveness of two methods of tillage viz., deep ploughing

(carried out with disc plough) and normal ploughing (carried out with cultivator), and the distance from the tree row (0.5m, 1m, 2m, 3m and 4m) on production behaviour of mustard crop raised under 10-year-old *Dalbergia sissoo* based agrisilviculture system and under open field conditions at National Research Center for Agroforestry, Jhansi, India. Growth and yield attributes were recorded for both components viz., tree and crop, and were analyzed using randomized Block Design by applying technique of analysis of variance ($P < 0.05$). It was observed that the yield of the mustard crop under deep ploughing ($260 \text{ Kg}^{-1} \text{ ha}$) was significantly higher (6.51 %) than under normal ploughing practice ($246 \text{ Kg}^{-1} \text{ ha}$). The yield was 182.24 % ($713 \text{ kg}^{-1} \text{ ha}$) higher in monocropping than under agrisilviculture. It was also observed that mustard yield showed an increasing trend with increasing distance from the tree row. From this study, it was concluded that mustard crop is not compatible with the *Dalbergia sissoo* trees.

Keywords: *agrisilviculture, Dalbergia sissoo, methods of tillage, mustard*

PP4.5.11. Effect of integrated nutrient management on productivity of turmeric grown under poplar based agrisilviculture system

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A trial was carried out to study the effect of integrated nutrient management practices and tree spacing ($4\text{m} \times 4\text{m}$ and $4\text{m} \times 6\text{m}$) on the production behaviour of turmeric. The trial was laid out in a 6-year-old plantation of *Populus deltoides* (G-48) established in 2006 at Nauni, the sub humid-mid hill zone of Himachal Pradesh, India. The five treatments applied were (i) recommended dose of fertilizers; (ii) FYM + PGPR; (iii) Vermicompost + PGPR; (iv) 75% recommended dose of fertilizers + PGPR; and (v) 50% FYM + PGPR calculated on nitrogen equivalent basis. The plant height, yield and root size of the crop was significantly affected due to tree spacing and nutrient management practices. Plant height was observed maximum (103.88 cm) under $4\text{m} \times 4\text{m}$ spacing and nutrient combination of vermicompost + PGPR, whereas, the yield was also observed maximum (142 t ha^{-1}) under tree spacing of $4\text{m} \times 4\text{m}$ and nutrients applied through FYM + PGPR (141 t ha^{-1}) which however was at par with T₃ (Vermicompost + PGPR). The root size and PAR was significantly affected by the tree spacing, the maximum being under $4\text{m} \times 4\text{m}$ and $6\text{m} \times 4\text{m}$ respectively.

Keywords: *tree spacing, farmyard manure, vermicompost, PGPR*

PP4.5.12. Soil microbial dynamics influenced with pasture species and growth stage in Bauhinia based silvipasture system

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Silvipasture systems have been promoted as win-win technologies to enhance productivity from degraded land in semi-arid and arid regions of India besides providing environmental services. Biological diversity plays an important role in ecosystem stability. Soil microorganisms (fungi and bacteria) play a fundamental role in driving nutrient cycling and carbon turnover in all terrestrial ecosystems and are very much influenced by changes in land use, soil cover and

management practices. Plant productivity, which is mainly governed by crop genetic potential and agronomical management, may also influence microbial structure and functional process of soil microorganisms through modification in the quality and type of organic matter inputs (primary production). The introduction of plants in any silvipasture system affects the physical–chemical properties and the biological parameters of the soil environment close to the growing roots. The rhizo-deposition of nutrients by plant roots supports increased microbial growth. Soil microorganisms, mainly bacteria and fungi, are key agents involved in litter breakdown and mineralization. Keeping in view the above facts, a study was conducted under *Bauhinia* (*Bauhinia variegata*) based silvipasture system at Central Research Farm of Indian Grassland and Fodder Research Institute, Jhansi during 2011-12. Cropping season exhibited that monthly microbial population of rhizosphere soil varied with pasture species as well as their growth stage. Higher rhizospheric population of fungi and bacteria (9.94 and $86.61 \times 10^5/\text{g}$ soil) was recorded with *Cenchrus ciliaris*, followed by *Chrysopogon fulvus* (4.03 and $41.48 \times 10^5/\text{g}$ soil) in the month of July. However, higher microbial population (3.65 and $31.3 \times 10^5/\text{g}$ soil) with *Stylosanthes seabrana* were observed in the month of September. Increased trend in rhizospheric microbial population was recorded when increase in crop growth started from July up to November. The increase in microbial population and community structure was associated with active pasture growth stage.

Keywords: degraded land, microbes, pasture, silvipasture

PP4.5.13. Evaluation of performance of multi-tier crops under agroforestry system in Chhattisgarh

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The benefits of agroforestry systems are mostly realized by large farmers where the land resources and critical inputs are not limited, but multi tier agroforestry system is most suitable for small farmers. The multi-tier agroforestry systems are most common in high rainfall humid tropics. Looking at the same climatic status of Chhattisgarh province of southeast part of India, such multitier agroforestry systems for alleviating the poverty of tribes was established and studied with *Acacia mangium*, *Emblia officinalis*, *Jatropha curcus* and *Murraya koeinghii* with cover crop of turmeric.

The performance of MPTs at different tiers and ages showed that *A.mangium* was promising top storey tree component followed by *E.officinalis* and *J.curcas* with more than 90% survivorship. The height growth of trees measured maximum in *A.mangium* (15.7m) followed by *E.officinalis* (7.2m) and minimum in *M.koeinghii* (2.5m) at 7th year of growth, while in sole tree crops it was 0.5, 1.9 and 0.3m less respectively. *Jatropha* was removed at 7 years for lack of flowering and fruiting; turmeric was found more favourable for cultivation.

The plucking of edible leaves in *M.koeinghii* was done weekly from July to April every year from the 4th year and the production of leaves in sole and under groforestry was 432.7 and 460.5 kg ha⁻¹ respectively during early years and it reached to 1476 and 1430 kg ha⁻¹ respectively during the 7th year. The yield of turmeric was recorded at 38.2 and 33.5qha⁻¹ under trees and in open respectively in the 7th year. The economics of multi-tier agroforestry system for 7 yrs of cultivation are also worked out and presented in the paper.

Keywords: multi-tier, agroforestry

PP4.5.14. Fruit-based agroforestry: a suitable model for alternative land use system in red and laterite zone of West Bengal

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Productivity of crops under red and laterite soil in rainfed condition is low and unstable; and often optimum yield cannot be achieved because of aberrant monsoon behaviour and severe land degradation. Therefore, some alternate land use systems are to be developed for such lands. Fruit-based agroforestry system is an alternative land use system that integrates the cultivation of arable crops, fruit trees and silvi components. To enhance the production, capacity experiments on fruit-based agroforestry were conducted at Regional Research Station of Red and Laterite Zone (22°5'N, 87°0'E, 78.77m above MSL), Bidhan Chandra Krishi Viswavidyalaya, Jhargram, West Bengal to find out the suitable components for agroforestry model with production potential on marginal/degraded lands under rain-fed conditions. Hardy fruit crops like mango (*Mangifera indica*), guava (*Psidium guajava*), sweet orange and silvi species of gamhar (*Gmelina arborea*) were established on staggered contour trenches. The fruit plants and *Gmelina arborea* were planted at a spacing of 10m × 10m. Six arable crops viz., pigeon pea, black gram, lady's finger, bottle gourd, sesame and maize were cultivated during kharif and a single crop viz., mustard in rabi season of 2011-2012 and 2012-2013 to identify the superior model for attaining the maximum returns and improving soil fertility. Experimental results revealed that all the growth characters of *Gmelina arborea* and production of mango were at a higher side where the crops were cultivated under intercropping system as compared to their sole planting. The maximum gross income of INR 139 200 was recorded during the fourth year of the ongoing experiment when lady's finger (kharif) was intercropped with *Gmelina arborea* + mango. Studies on soil fertility revealed that improvement of soil health was higher under all fruit-based agroforestry systems and found to be the best when intercropped with pigeon pea.

Keywords: fruit-based agroforestry system, intercrop, soil fertility

PP4.5.15. Underutilized fruit trees in agroforestry systems in Central and North Sumatra: opportunities and challenges

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Indonesia is widely known as a source of tropical fruit tree germ-plasm. However, many tropical fruit trees are underutilized, although they are important sources of livelihood. Many fruit tree species occur in the wild and some fruit trees are cultivated. We assessed production of underutilized fruit trees in agroforestry systems in Jambi and North Sumatra. 34 food tree species occurred in agroforestry systems in Jambi and nine underutilized fruit tree species were identified as having economic value such as *Artocarpus integra*, *Artocarpus heterophyllus*, *Dimocarpus longan*, *Lansium domesticum* var. *domesticum*, *L. Domesticum* var. *pubescens*, *Durio zibethinus*, *Mangifera foetida* and *Nephellium lappaceum*. *Durio zibethinus* is very well known among others. The fruits can be consumed fresh and can be processed (e.g. dried and cooked) and fermented as 'tempoyak' (e.g. a traditional cuisine of Sumatran dishes). Fruit production of *D. zibethinus* in different ages in Jambi ranged from 15 to 800 fruits per tree per year, while in North Sumatra they ranged from 1 to 600 fruits per tree per year. In 2009, production value of *Durio* in Jambi ranged from IDR 100 000 to 14 000 000 per year. Indonesia produced 6.13 mt *Durio* in 2011, however, impor value of *Durio* was higher than its export value

(deficit USD 28 9 million). The high demand of *Durio* is one opportunity to improve fruit production from agroforestry system. Despite the economic value, many obstacles such as cultivation and domestication techniques to improve yields, economy (market and marketing), technology of post harvesting, and infrastructure challenge fruit production in Central and North Sumatra.

Keywords: *Durio zybethinus*, food, Sumatra

PP4.5.16. Do frequency and coppicing height affect fodder production of *Gliricidia sepium* and *Pterocarpus erinaceus* in the Sahel?

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Livestock plays an important role in food security strategies but the changing contexts in which pastoralists operate raise the issue of the sustainability of pastoral systems in dryland Africa. Therefore, more intensive periurban livestock breeding may constitute a credible alternative to pastoralism. However, the success of such a system might be subjected to good feed delivery systems for which woody species play a critical role during the dry season in the Sahel. Therefore the present research was designed to test the viability of intensive woody fodder production of planted and frequently pruned trees. Various frequencies and heights were applied to trials established back in 1995 at Samanko Station in Bamako, Mali with *Pterocarpus erinaceus* and three varieties of *Gliricidia sepium* (ILG 50, ILG 70 and Reuthaluleu) planted within randomized bloc designs. Two cutting heights (0.5 m and 1.3 m) with three fodder evaluation frequencies (3, 4 and 6 times a year) were applied to *P. erinaceus* whereas two frequencies (6 and 4 times a year) were retained for *G. sepium* cut at a single height at 0.5 m. The results revealed no significant difference between the frequencies for *P. erinaceus* but marketable fodder (branch > 50 cm) was more important in 3- and 4-month intervals. Coppicing at 1.30 m (0.38 kg tree⁻¹) gave significantly ($P < 0.05$) higher fodder biomass than 0.5 m (0.30 kg tree⁻¹). No significant difference was between varieties for all measured parameters whereas that was the case for the frequency with 2-month interval coppicing (35.41 kg tree⁻¹) outperforming the 3-month (32.68 kg tree⁻¹). Intensive production using *G. sepium* may help optimize the role played by woody species in fodder production during the dry season in Sahel while reducing the pressure on the natural resources. Applying irrigation to *P. erinaceus* may improve its performance.

Keywords: agroforestry practice, fattening, livestock, management, peri-urban, woody fodder

PP4.5.17. Does early decapitation affect growth of control-pollinated *Dacryodes edulis* seedlings? Makueti Josephine Therese¹, Tchoundjeu Zac¹, Antoine Kalinganire², Ebenezer Asaah³, Bernard Aloys Nkongmeneck⁴

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Success in breeding for yield superiority of indigenous fruit trees is still constrained by the lack of availability of improved germplasm. *Dacryodes edulis* is one of a number of high-valued indigenous fruit trees under domestication in West and Central Africa. Controlled-cross-pollination was used to combine some desired characters in fruits traits between superior trees to increase the inter-tree

variability between selected superior genotypes. The resultant seeds were germinated and pot-grown in a shade house over 39 weeks before being decapitated by removing the shoot apex or the uppermost node, while leaving shoots of uniform height of 40 cm. The pot-grown *D. edulis* seedlings originated from 13 control-pollinated progenies from four provenances. The original stem size (height and diameter) and leaf number were assessed weekly for a period of 39 weeks, whereas coppiced lateral shoot (twigs) length and number were measured over eight weeks after decapitation. Neither progeny nor provenance significantly affected height ($P>0.05$) among the seedlings evaluated after 39 weeks. However, seedling collar diameter and number of leaves varied significantly ($p<0.05$) with provenance or progeny. Eight weeks after decapitation, the number of vigorous twigs development varied significantly ($p<0.05$) with both progeny and provenances. The number of weeks after decapitation is a strong predictor of shoot elongation. Surprisingly, no sprouting and dominance phases were observed in the present study. This suggests a synchronal shoot growth after decapitation by *D. edulis* which could be used as a predictive test in the relations between branching habit and harvest index. Hence, early decapitation can help breeders to produce *D. edulis* dwarfed trees in order to satisfy farmers' need for better tree management.

Keywords: *branching habit, dwarfed trees, germplasm, harvest index*

PP4.5.18. The effect of lopping intensity on tree growth and forage yield under *D.sissoo* based silvipastoral system

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The present investigation entitled “Effect of lopping intensity on tree growth, forage yield and periodic change in leaf nutrient under *D.sissoo* based silvipastoral system” was carried out in the main experiment station (M.E.S.) of forestry at Narendra Deva University of Agriculture and Technology, Kumarganj, Faizabad during 2011-2012. The silvipastoral system selected for the study had *Dalbergia sissoo* (forest tree species) in association with three forage crops (grasses): *Pennisetum purpureum*, *Brachiaria mutica* and *Panicum maximum*. Tree growth was significantly affected in silvipastoral system (*Dalbergia sissoo*). Tree growth (tree height, dbh and canopy width) across different lopping intensities (0-100% lopping) showed a consistent decline along increasing lopping stress. Amongst different seasons, rainy season indicated maximum tree growth, whereas winter showed the minimum growth in all the treatments. Interestingly, the leaf area showed consistent increment from initial (summer) period till the winter season. Amongst different seasons, leaf specific weight of *D.sissoo* was highest in winter (19.50mg cm^{-2}) before approaching senescence. Seasonal changes in leaf nutrient concentration of *Dalbergia sissoo* showed that maximum nutrient concentration during summer was significantly higher over rainy and winter seasons. Forage yield (green herbage) for three grasses under *Dalbergia sissoo* based silvipastoral system on sodic land was found maximum in case of *Pennisetum purpureum* (40.54 t ha^{-1}) and minimum for *Panicum maximum* (23.92 t ha^{-1}).

Keywords: *growth yield, silvipastoral, Dalbergia sissoo, grasses*

PP4.5.19. Impact of different clones of poplar (*Populus deltoids*) and moisture conservation practices on sustainable crop production

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Sustainable development through scientific agroforestry interventions has a huge potential in meeting the various demands of fuelwood, fodder and timber in conjunction with agricultural crops on non-forest land, apart from providing economic and environmental security. Keeping in view the ever increasing demand of poplar wood and the interest of farmers in poplar culture, the study was conducted at Kanpur during kharif and rabi 2007-2009 in Factorial Randomized Block Design with 14 treatment combinations comprising 42 plots covering 36 plots under poplar based agroforestry system (6 clones of poplar x 2 moisture conservation practices x 3 replications) and 6 plots without poplar i.e. control with and without mulch to evaluate growth performance of different clones for suitable poplar clones in relation to maize-mustard crop sequence; to ascertain the moisture depletion pattern; change in soil properties in relation to different treatments; and to estimate the economics of the poplar based cropping system. Among all the six clones selected for the study, G-48 clone acclimatized better and performed excellently with maize as well as mustard crops in Central Plain Zone. The results showed that periodic poplar management through pruning during kharif has reduced competition for light, moisture and nutrients of associated agricultural crops. The aerial part of poplar provided nutrient rich leaf litter when used as mulch and/or green manure, which conserve moisture, maintain soil productivity and improve physico-chemical properties of soil. So, *Populus deltoids* based intercropping is a superior alternative to sole cropping system by virtue of its economic feasibility and sustainability.

Keywords: *Populus deltoids*, moisture conservation practices, maize, mustard

PP4.5.20. Effect of different pruning intensities on wood biomass and yield of wheat varieties in *D. sissoo* based agrisilviculture

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The present experiment was carried out continuously for three years during the rabi season of 2010-2011, 2011-2012 and 2012-2013 under AICRP on Agroforestry, Department of Forestry, JNKVV, Jabalpur. *Dalbergia sissoo* was planted in 1988 with spacing of 5m x 5m. There were five main treatments i.e. four pruning treatments (0, 25, 50 and 75% pruning) + one open and three late sown wheat varieties (viz; MP-3020, GW-273 and GW-366) in sub plot design with four replication. On the basis of mean data of three year it was observed that, open condition recorded higher plant height (84.7 cm), number of effective tillers per meter row length (85.9), length of earhead (9.18 cm), number of grains/earhead (42.6) and 1000 grain weight (35.15 gms) as compared to no pruning which recorded the lowest plant height (78 cm), number of tillers per meter row length (68.4), length of earhead (7.54), and 1000 grain weight (28.5 gms). Higher grain yield⁻¹ (26.99 q ha⁻¹) was recorded in open condition followed by 75% pruning (23.99 q ha⁻¹), 50% pruning (21.09 q ha⁻¹) and 25% pruning recorded lowest yield (15.16 q ha⁻¹). The reduction in grain yield under no pruning, 25% pruning, 50% pruning and 75% pruning as compared to open condition was 43.8, 28.3, 21.9 and 11.1 percent, respectively. Variety GW 273 recorded higher grain yield (23.65 q ha⁻¹) followed by MP 3020 (21.07 q ha⁻¹) but superior to GW 366 (19.25 q ha⁻¹). In morphological growth characters of *D. sissoo*, 25% pruning gave highest dbh (21.53 cm), cylindrical volume (164.57 m³ha⁻¹) and stand biomass (1285.5 tha⁻¹) as compared to no pruning, 50% and 75% pruning. 75% pruning recorded lowest dbh (14.99 cm), crown spread N-S (3.67 m) E-W (4.21 m), cylindrical volume (70.28 m³ha⁻¹) and stand biomass (54.19 tha⁻¹). Managed agroforestry

system i.e. wheat + *D. sissoo* in 25% pruning gave higher monetary return (INR 40 018 ha⁻¹) as compared to 50% pruning (INR 35 237 ha⁻¹) tree alone crop alone (INR 26 882 ha⁻¹) and unmanaged agroforestry system i.e. no pruning, which gave lower monetary return (INR. 29 112 ha⁻¹). Variety GW-273 gave highest monetary return (INR 35 123 ha⁻¹) followed by MP-3020 (INR 34 259 ha⁻¹) and GW-366 (Rs. 28163 ha⁻¹). GW-366 recorded lowest monetary return.

Keywords: *agrisilviculture, D.sissoo, monetary return, pruning*

PP4.5.21. The distribution of sustainable development through agroforestry in an Atlantic rainforest Biome in southern Brazil

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The rebuilding of the ecosystem in a Mixed Ombrophilous Forest or Araucaria Forest, located in an Atlantic Rainforest Biome of a specific mountain region in the state of Santa Catarina, is at its full restoration and conservation. In this context, in 2011, the Social Network Carbon Project sponsored by Petrobras through Petrobras Environmental Program planted 500 000 native plants in areas of permanent preservation and legal reserve, forming agroforests in approximately 1000 family farm properties in 18 cities. This study had the objective to analyze the sustainable development of the family farms using agroforestry. In the properties that joined the project, only native regional species (approximately 100 species) with food and economic potential for family subsistence were planted. The results/experiences that we had were that agroforestry has been accepted by a lot of farmers as a revolution for sustainable production. Farmers had a considerably more economical and productive production while they were dealing with the complexity of agroforestry integrating animals with plants in areas that should be preserved. Many of the farmers reported that this system enabled a more ecological production between their crops and livestock, becoming sovereign with their productions. We conclude that the use of agroforestry improved the production of about 1000 farm families that made part of the project, working on a sustainable-basis producing fruits, grains, honey, meat and milk in a more ecological and productive way compared to the traditional system. This study is going to be displayed on a poster and its theme is to promote development based on agroforestry systems.

Keywords: *family farms, sustainable development*

PP4.5.22. Performance of summer groundnut (*Arachis hypogaea*) with *Jatropha curcas* under agroforestry system in semi arid region

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The field experiment was conducted at Kanpur on *Jatropha curcas*, which was planted during August 2004 on sandy loam soil having average fertility. The experiment was laid out with 8 cultivars of summer groundnut in RBD with three replications. The groundnut cultivars Dh 86 (1.85 t ha⁻¹) and ICGV 93468 (1.84 t ha⁻¹) produced significantly higher pod yield in the filler cropping system of *Jatropha* + summer groundnut. The result showed that the check cultivar JL 24 produced 0.72 t ha⁻¹. The performance of the cultivars was in order of Dh 86 (1.85 t ha⁻¹) and ICGV 93468 (1.84 t ha⁻¹)

> NRCG 2063 (0.79 t ha⁻¹) > NRCG 12082 (0.74 t ha⁻¹) > TG 26 (0.73 t ha⁻¹) > JL 24 (0.72 t ha⁻¹), B 95 (0.72 t ha⁻¹) and NRCG 7150 (0.72 t ha⁻¹). ICGV 93468 and Dh 86 are high-yielding cultivars and most suitable for cultivation during summer season. These were found suitable under nutrient deficient and limited irrigation condition.

Keywords: *summer groundnut, Jatropha curcas, semi arid, ICGV 93468 and Dh 86*

PP4.5.23. Preferred niches of agroforestry practices for sustainable management of highlands in Western and Northern Rwanda

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Agroforestry practices have been effective in Rwanda for many decades but their efficiency is constrained by obstacles such as lack of proper tree establishment and management and hence reducing the benefits accrued from them. Identification of farmers' needs in terms of species and niches for agroforestry using specific criteria is critical for sustainable agriculture in Rwandan highlands. This paper examined the preferred tree species currently used by farmers for agroforestry systems. A baseline survey was conducted in four sectors namely Rwaza, Mukamira, Kagogo and Karago in the respective districts of Burera, Musanze, Ngororero and Nyabihu in the northern and western provinces. The choice of these districts was made on the basis of levels of land degradation as well as on that of land management interventions. 30 farmers in each sector were interviewed on tree species and niches for tree establishment. Information from soil conservation as related to the presence of hedgerows and gaps according to slopes categories was also collected. Preliminary results show that tree species used as hedgerows are *Calliandra calothyrsus*, *Grevillea robusta*, *Alnus acuminata* and *Leuceana diversifolia*. Indigenous species are still abundant (up to 78%) closer to Gishwati forest area while exotic agroforestry species are the most preferred from 10% to 24%. Their niche ranking varies from one site to another but the main niches identified are trenches, bench trenches and contour of farm compound. For fruit trees, avocado was selected as the most preferred in all sites among other fruit species. The preferred niche for avocado is at the homestead for all sites. The trade-off for different benefits like soil nutrient or quality of fodder needs to be established between agroforestry species and grasses, considering that more than 66% of farmers planted grasses in the same niches.

Keywords: *agroforestry species, farmers, preferred niches, sustainable agriculture*

PP4.5.24. Post-ex evaluation of agroforestry based sustainable land management in northwest Rwanda

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Agroforestry (AF) has been seen as a key element particularly where mechanical measurements for conserving soil are perceived difficult. Unfortunately few post-ex economic analyses have been made to support efforts of increasing public investment in AF systems. This paper presents post-ex benefit valuation. To evaluate post ante economic value of the AF system of Nkuli sites, biophysical and socioeconomic data were collected. The biophysical data were related to soil erosion change, soil

quality change, tree biomass production and crop yield. The biophysical trial was laid in randomized completely block design with control and *alnus acuminata* double line at 50 cm spacing hedgerows as treatments and replicated five times. Socioeconomic investigation gathered information related to inputs and outputs related to fruit trees production. The results showed that the adopted hedges reduce 27% to 76% of soil erosion. The trends of soil deposition, reduction of bulk density and soil organic matters confirmed the positive effects of hedgerows. The hedges produced 1.5 to 2.7 kg of biomass per plant. Other benefits are slope reduction for improved soil suitability. The eroded soil deposition above the hedge reduced the slope by raising the terrace by 3 to 7cm each year and improved soil organic matter by 0.01 to 1%. Furthermore maize and potato yields increased by 212.5% (from 0.8tons/ha to 2.5tons/ha) and 57% (from 10 tons/ha to 15.7tons/ha). Also, the production of tamarillo improved from 20kg/tree/year to 50kg/tree/year in 3 years. The increase of income per household per year ranged from USD 249 to USD 1780. Nutrient retained by hedgerows compared to control were 8-19 kg of nitrogen; 4-10kg of phosphorus and 8-15 kg of potassium ha⁻¹ year⁻¹. The use of AF green manure, hedgerows and fruits is effective in soil fertility enhancement, soil erosion control, increased food security and enhanced incomes.

Keywords: *Alnus Acuminata*, cost-benefit analysis, impact assessment, land degradation

PP4.5.25. *Gmelina* based agroforestry system in Madhya Pradesh: potential and prospects in tree business

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Gmelina arborea Roxb. commonly known as white teak is a viable substitute for *Tectona grandis* L.(teak) under the present socioeconomic scenario. In the mid 1990s, teak-based farm forestry became a phenomenon worldwide. But the absence of standard managerial practices, inadequate government support and the government's restrictions on harvesting coupled with losses due to theft had shaken farmers' confidence in tree farming. Small and marginal farmers switched over to subsistence farming whereas big farmers opted for other viable options including high value cash crop based production system and others preferred to lease their land to MNC's for sustained income. *G.arborea* is a multifarious tree with drought resistance, fast growing, with a capacity to recover from frost within a short period making it most suitable to grow under a wide range of agroclimatic conditions, not only in Madhya Pradesh but throughout India.

The present study deals with *Gmelina*-based agroforestry system to assess the compatibility with oli and medicinal plants in the tropical region of Madhya Pradesh (India). An experiment was conducted at Tropical Forest Research Institute, Jabalpur (M.P.) and data on growth and yield of trees as well as intercrops indicates higher economic returns from the *Gmelina*-based agroforestry system as compared to sole plantation. Traditionally it is harvested after 15 years of age under monoculture; when intercropped with oli & medicinal plants it provides 0.3m³ wood volume per tree after 10 years. Thus *Gmelina* based short rotation agroforestry system is a boon in tree business.

In this context, the government of M.P. has taken a positive step by removing the restrictions on transit pass during transportation of *Gmelina* in the state and observed 2012 as "**Gmelina Year**". A number of workshops were conducted to promote and create awareness about the species. The forest department has also distributed *Gmelina* seedlings on subsidized rates.

Keywords: agroforestry, *Gmelina arborea*, medicinal plants

PP4.5.26. Production potential of soybean (*Glycine max* L. Merrill)- Wheat (*Triticum aestivum* L.) cropping sequence with young aonla

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Least attention has been given on an integrated self-sustaining system which involves the deliberate introduction/growing of trees, shrubs or fruit trees etc. with agricultural crops in a sequence or simultaneously on the same unit of land in order to meet the ecological as well as the socioeconomic needs of the people (Deb Roy 1993 and 1994). Crop yield reduction (yield penalty) in a tree-crop mixed system is invariably ascribed to competition for resource pools of light, moisture and nutrients (Loomis and Whitman 1983). The competition for light between trees and crops is also dependent on the tree and crop species, tree density, age of trees and spatial arrangement of trees (Basavaraju and Gururaja Rao 2000). Normally, fruit trees are planted on wider distance and there is no assured income for the initial 4-5 years during their establishment period. A number of studies have been made on suitability of companion crops which can be grown in association with aonla under rainfed conditions. The performance and profitability of soybean-wheat cropping sequence under the plantation of fruit crop of aonla was not studied thoroughly under rainfed situation. Keeping the above points in view, the present study was therefore conducted to study the suitability and profitability aspects of intercrops in bearing orchard of aonla to assess the performance of soybean (var. JS97-52) and wheat (var. JW3173) in a sequence under five years old aonla plantation during 2007-2008 and 2008-2009. The aonla varieties NA7 and chakaiya were planted at 8m x 8m on sandy loam soil. Sowing of soybean during rainy season (kharif) under aonla plantation of variety NA-7 and chakaiya recorded the reduction in yield by 13.3% and 23.6%, and wheat during rabi season (October to February) 11.3% and 18.9%, respectively. Soybean followed by wheat as companion crops under aonla plantation (NA-7) fetched a net return of INR 56 030/ha/annum whereas aonla alone and soybean-wheat cropping sequences gave only INR 16 875/ha/annum and INRs47 235/ha/annum, respectively.

Keywords: fruit trees, aonla, soybean

PP4.5.27. Effect of three *Grewia* species on soil characteristics under semi-arid environment

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This study was carried out to assess the effect of three *Grewia* species namely *Grewia mollis*, *Grewia tenax* and *Grewia villosa* on soil characteristics and their fine root distribution under semi-arid environment. The main objective was to assess their potential as multipurpose trees/shrubs suitable for agroforestry under semi-arid conditions. The three species are indigenous to Sudan. Randomized Complete Block Design was used. The soil samples were taken at the beginning and the end of the experiment for assessing the effect of the trees/shrub on soil characteristics and at the end of the experiment to measure root distribution. The results revealed that the 19-month-old *Grewia*s exhibited no considerable effect on soil characteristics. This is attributed to their young age. Lateral spread of roots and root biomass distribution were not significant ($P = 0.05$) among the species but there was significant difference ($P = 0.05$) in root biomass among depths with most of the roots found on the upper soil layer (0 - 20 cm). It is concluded that the three *Grewia* species have the potential to improve soil properties. The fruits of *G. tenax* are available in Khartoum market due to their nutritive value, but they are imported from outside Khartoum state. This study is an attempt to introduce these species in

Khartoum state as cash crops and at the same time contribute to soil fertility improvement and fodder production as they have potential to produce valuable fodder.

Keywords: *cash crop, fruits, root distribution, soil characteristics*

PP4.5.28. Reproduction abilities and potentials for silvicultural promotion of *Dalbergia melanoxylon* in Burkina Faso

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Dalbergia melanoxylon Guill. & Perr. is a multipurpose shrub mainly used for pharmacopoeia, fodder, fuel and woodcarving. The degradation of the vegetation has caused the species' decline in the Sahelian zone of Burkina Faso. The rare individuals are subjected to intensive exploitation, which could jeopardize the species survival. This study aims at assessing the natural regeneration of *D. melanoxylon* across different phytogeographical zones of Burkina Faso and testing the germination capacities of seeds as well as the seedlings' early growth. Quantitative inventories were used to describe the natural regeneration stands and monitoring was carried out in permanent plots to assess the recruitment dynamics. Seeds from different provenances were used for germination tests and to assess the seedlings growth. The results revealed a scarcity of regeneration individuals that was traduced by comparable ($p = 0.28$) low densities in both Sahel (3 individuals / 25m²) and sub-Sahel (1.8 individual / m²) stands. Regenerating individuals originated exclusively from root sprouting and exhibited multistratum population structures. The spatial distribution pattern of recruitments revealed grouping trends around the mother trees. The survival rates of recruitments were relatively good but their growth was unpredictable. *D. melanoxylon* had a relatively high rate of damaged fruits by pests (44-88%), which largely account for its poor rate of natural regeneration by seedlings. However, the experiments revealed average to high germination rate (52-77%) according to the time of conservation. The speed of germination (5.3 -12.8 days) and the longevity of healthy seeds are an advantage for sexual reproduction. Even though seedlings have poor resilience ability in the natural stands, the good capacities of germination as well as the high growth and survival rates in nursery are assets for the silvicultural promotion of *D. melanoxylon* among local populations since the species contributes to the soil's fertility.

Keywords: *Dalbergia melanoxylon, natural regeneration, silvicultural ability, threatened species*

PP4.5.29. Performance of soybean varieties under poplar based agroforestry system in mollisol of tarai region of Uttarakhand

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Poplar (*Populus deltoides*) based cropping system is the most prevalent agroforestry system in tarai region of northern India due to a higher net return. Soybean is the important oilseed pulse crop of this region but no specific soybean variety is known for poplar based agroforestry system. This research was carried out at Agroforestry Research Centre of G.B. Pant University of Agriculture and Technology, Pantnagar during the winter season of 2012-2013. The soil of the site was silty-clay loam with mollic-epidon classified as mollisols. The research was carried out to study the changes in soil

properties and the performance of both soybean and poplar intercropped. Soybean varieties viz., PS 1042, PS 1225, PS 1347 and PS 1024) were grown under poplar plantation. The results clearly revealed that there was an improvement in the soil physico-chemical and chemical properties viz. pH, EC, organic carbon and available N, P and K as compared to open system. The pH of the soil was lowered to 7.68 from 8.1. There was marked improvement of 19.8 (O.C), 14.2 (available P) and 6.6%, respectively (available K). Growth parameters of poplar viz. collar diameter, height and volume were also considerably increased by 43.3, 58.2 and 86.6%, respectively. Among soybean varieties PS 1225 was found superior closely followed by PS 1042 with respect to nodulation behaviour, growth and yield attributes (germination count, trifoliolate leaves, number of primary branches, number of pods plant⁻¹ and grains pod⁻¹). Soybean varieties PS 1225 recorded highest biological yield (74.6 q ha⁻¹), straw yield (44.6 q ha⁻¹) and grain yield (29.9 q ha⁻¹) under poplar based agroforestry system and open system. There exists a significant and positive correlation between soil properties, growth and yield attributes of soybean and poplar intercropped. Soybean varieties superiority followed the order PS 1225 > PS1042 > PS1024 > PS1347.

Keywords: *soybean, poplar, agroforestry system, mollisol*

PP4.5.30. Influence of tree species and spacing on wheat yield and soil properties in terai region of Northern India

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A field experiment was conducted during the winter season of 29 November 2008 to 15 April 2009 on a plantation established from 2007 at the Agroforestry Research Centre, Haldi, G. B. Pant University of Agriculture and Technology, Pantnagar to evaluate the effect of four tree species (*Eucalyptus cameldulansis*, *Populus deltoides*, *Melia azedarach*, *Leucaena leucocephala*.) and their spacing (3m×1m, 3m×1.5m, 3m×2m, 3m×2.5m) on the yield of intercrop wheat (variety PBW-502) and soil properties. The experiment was laid out in split-plot design with 3 replications. The fertilizer was applied as N: P₂O₅:K₂O @ 150:60:40 kg ha⁻¹. Half of the N, full P₂O₅ and K₂O were applied as basal dressing, remaining half N through top dressing at 30 days after sowing. The highest grain yield (36.0 q ha) was obtained under open farming system. The reduction in grain yield was in the range of 16% to 62% under different agroforestry system as compared to control. The poplar-wheat system performed better as compared to other agroforestry systems. The highest wheat yield was recorded in 3m×2.5m spacing under poplar, melia, and leucaena based agroforestry system but in eucalypt at 3m×2m spacing was found best. Organic carbon (1.31 %) was highest under poplar (3m×1m) as compared to control (0.6). Highest available N, P₂O₅ and K₂O content (180.53, 17.74 & 169.66 kg ha⁻¹, respectively) were observed in the soil under leucaena (3m×2m). The overall results demonstrated that poplar-based agroforestry system (3m×2.5m) performed better as compared to others in the terai region of Northern India.

Keywords: *tree species, spacing, fertility levels, wheat yield, soil properties*

PP4.5.31. Intercropping of rabi crops with *Jatropha* (*Jatropha curcas* L.) based agroforestry system

In agrisilviculture system, trees and crops compete inevitably for light, nutrients and other sources that affect the growth performance of the crops. Inclusion of fast growing oil-bearing trees in the already existing farming system under agrisilviculture is one option to tackle the alarming situation of increasing energy demand. Among the tree borne oilseeds, *Jatropha curcas* L. has evoked much interest globally as a potential biodiesel plant in addition to its traditional medicinal, illumination and lubricating properties. Oil from jatropha seeds seems to be an available option as an alternative to petroleum fuel.

Keeping the above points in view, an on-farm trial was conducted at Sorghum Research Station, S D Agricultural University, Deesa (Gujarat) to assess the performance of different rabi crops viz; mustard (GM-3), wheat (GW-496), amaranthus (GA-1) and chickpea (GC-2) under jatropha plantation during the rabi season of 2009-2010 and 2010-2011. The jatropha variety Nanadan-1 was planted at 3 x 3 m spacing on loamy sand soil. Jatropha plant did not offer any competition with associated arable crops up to the first year of plantation. But the yield of the intercropped crops reduced from 11 percent (chickpea) to 89 percent (wheat) during the second year of plantation. Maximum mustard equivalent yield (17.66 q/ha) was recorded in mustard associated with jatropha (mean of two years). Minimum height (154.6 cm), primary branches (7.1), secondary branches (10.7) and plant canopy (162.4 cm at N-S and 167.1 cm at E-W) noted when the jatropha was intercropped with mustard crop at the end of the second year of jatropha plantation.

Keywords: *jatropha, mustard, wheat, equivalent yield*

PP4.5.32. Provenance variation for pod and seed germination parameters of Cassia fistula L. in agroclimatic zones of N. Karnataka

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Increase in forestry planting activities is often restricted by adequate supply of quality seeds. *Cassia fistula* L. is an important medicinal-valued ornamental tree species that has the potentiality to be used in a large-scale afforestation programme. Studies were conducted on the physical attributes of pods and seeds *Cassia fistula* L. and germination parameters from five different agroclimatic zones of northern Karnataka. The seed size, weight and germination are the important traits considered for early selection of provenances and improving seed production. Seed weight can be used as one of the useful criteria for early selection of superior provenances. Results revealed that pods and seeds collected from hilly zone showed better pod and seed characteristics and germination parameters such as germination percentage (64.81%), mean daily germination (3.36), peak value of germination (1.91) and germination value (6.85). Hence this seed source can be used for mass multiplication of the species for large-scale wasteland afforestation programme.

Keywords: *Cassia fistula, medicinal, germination, seed*

PP4.5.33. Biomass accumulation and carbon sequestration in Tectona grandis Linn. f

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Carbon management is a serious concern confronting the world today. Since the beginning of the industrial revolution, carbondioxide concentration in the atmosphere has been rising alarmingly. In spite of the increasing interest of ecologists in the production of organic matter in different ecosystems, work of this nature in forests of tropical region is scanty due to great biological richness and diversity of species. Selection of ideal species for carbon sequestration is very important step in improving the ecosystem. *Tectona grandis* belonging to the Verbenaceae family is a widely distributed and economically important timber species in India. In the present paper, attempts were made to work out biomass accumulation and carbon sequestration of teak grown in agroforestry systems of a transitional tract of Karnataka, India.

The experiment was initiated at the Main Agricultural Research Station, University of Agricultural Sciences, Dharwad on medium black soil during 2001. Teak was planted at 8x2m and four legumes viz., soybean, redgram, greengram and blackgram were grown in alleys of teak. The silvicultural practice for teak was applied to get good structures; both observations in height and DBH for teak were measured annually. At the age of 12 years, volume estimation was made for standing trees and converted in to biomass, carbon sequestration etc. The growth of teak was significantly higher in teak grown with soybean as compared to other legumes. Wood volume and wood biomass were significantly higher in sole teak followed by teak + soybean as compared to other treatments. The carbon sequestrated by teak alone was higher than teak + soybean as compared to other treatment. Similarly carbon sequestrated per year was higher in teak alone than teak + soybean as compared to other tree agroforestry system. The biomass production and carbon sequestration was better in sole teak and teak grown in agroforestry system.

Keywords: biomass, carbon, teak

PP4.5.34. Effect of different pre-sowing treatments on seed germination parameters of *Cassia fistula* L.

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Cassia fistula L. is an important medicinal-valued ornamental and avenue tree species. Matured pods of the species were collected from healthy trees from five agroclimatic zones of Northern Karnataka, India and treated with 12 pre-sowing treatments to determine the effect of various treatments such as sulfuric acid scarification, mechanical scarification, hot water soaking, cow-dung and growth regulators on seed germination. In all the experiments, daily observations were recorded for 45 days after sowing. Results reveal that pre-sowing treatments influence a significant increase in the percentage germination compared with those in control (46.60%). Among the pre-sowing treatments, seed germination under cold water soaking for 24 h and dipping in H₂SO₄ for 1 min performs significantly better than others. The mean daily germination, peak value, germination rate and value also differed significantly among twelve different treatments among five provenances. Hilly zone proved to be best in germination attributes among all provenances.

Keywords: *Cassia fistula*, germination, growth regulators, seed scarification

PP4.5.35. Evaluation of tamarind selections under agroforestry systems for transitional tract of Karnataka

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Tamarindus indica is an indigenous species grown throughout India for its edible pulp, which is mainly used for culinary purposes. The planting stock currently available for establishing plantation of *Tamarindus* mostly comes from unimproved sources. The planting agencies and farmers prefer high-yielding tamarind clones for early and increased fruit production. Tamarind pulp is frequently used as a low cost souring agent. It has variations regarding colour, length, pulp and other physical and chemical characteristics. The variations are possible due to clones, soils, temperature, rainfall and other climatic conditions in which the trees are established. In this direction an effort is made to evaluate identified vegetatively propagated 14 selections of tamarind under agroforestry system. The grafts were planted at 6m x 6m spacing. The site for the experimentation is red soil. In the initial 6 years agricultural crops (*Sesamum* and *Niger*) were raised in the inter space.

Several quality parameters have been recorded for the clones under study. Among 14 selections the higher tree height was observed in NTI-5. In respect of DBH, NTI-14 have higher DBH as compare to others. Crown area was significantly higher in NTI-84 (18.64 m²/plant). Regarding yield it was higher in SMG-13 (33.44 kg/plant) followed by NTI-14 (32.45 kg/plant). Tamarind fruits can also be considered as nutritive as it has high acidic content in terms of tartaric acid which can be used as an acidulant in Indian cuisines. Titrable acidity was significantly higher in NTI-14 followed by SMG-13 & PKM-1. Total sugar (51.97mg/100g) and non-reducing sugar (36.42mg/100g) was more in NTI-79 followed by PKM-1. Good markets are also available for these processed products both in domestic as well as international circuits. So product development and diversification are also required for commercial exploitation.

Keywords: *Tamarindus indica*, agricultural crops, quality parameters

PP4.5.36. Performance of Cucurbits under established teak plantation of transitional tract of Karnataka

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Agroforestry is often designated as a sustainable system wherein the tree species are planted at a wider spacing. In the initial years, annuals/arable crops are raised in the interspace as long as possible i.e. till the canopy closes and the yield levels of the inter crops are economically not profitable. Blending of shade-loving species in an established plantation can generate additional income to the farmers for an extended period and will transfer low productive farms into well managed, diversified and ecologically robust agroforestry systems. In addition there are some vegetables and annual crops known to perform better under shade in an established wide-space tree plantation. Growing plants under trees is always a bit of a tricky situation, especially where there may be a lot of surface roots as

it is always noticed in the established plantation. The top 15-25cm of the soil offers brutal competition for nutrients and water. Under established plantation, the spread of roots is the main problem and contributes competition. However, the annuals with deep roots are known to perform better under such a system. Among the cucurbit vegetables (ridgegourd, bottlegourd, pumpkin, spongegourd, bittergourd and cucumber) are reported to perform better under shade. With this background an experiment was initiated in established teak plantation of 11 years (8x2m). These cucurbits were hand dibbled at a spacing of 2x2 m following all package and practices. Care was taken to control insects and disease infestation through appropriate measures. Among the six cucurbits evaluated, growth of bottlegourd, pumpkin and ridgegourd was better as compared to the other three species. However, their performance was not as satisfactory as that in open field.

It is inferred that the performance of cucurbits which perform better can be still further enhanced by reducing the competition by way of thinning the tree species.

Keywords: *vegetables, teak, cucurbits, plantation, competition, brutal*

PP4.5.37. Vana Mahotsava: an ideal tool to promote agroforestry in Central India

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The population in India is increasing at an alarming rate and will consume most of the natural resources. One of the alternatives to overcome this is afforestation. National Research Centre for Agroforestry has been promoting agroforestry since its establishment. The ideal way to promote fruit and timber trees in farmland is through the festival of tree planting i.e Vana Mahotsava. This movement was initiated in 1950. It is annual event and is celebrated from July 1 to 7 during monsoon season. During 2012 and 2013 a series of *Vana Mahotsava* were organised at Parasi-Sindh Watershed in collaboration with ICRISAT, Hyderabad, along with active participation of the watershed committee, farmers, farmwomen, children and various SHG. Farmers' choice for seedlings were recorded through various PRA excersises. As per their choice, seedlings were distributed. During 2012 and 2013: 3061 & 8230 seedlings were planted of which *Tectona grandis* (1500 & 1800) *Citrus sinensis* (250 & 454), *Psidium guajava* (250 & 200), *Emblica officianalis* (150 & 400), *Artocarpus integrifolia* (225 & 300), *Carica papaya* (100 & 0), *Bambusa vulgaris* (400 & 713), *Carisa karonda* (25 & 100), *Pomegranate* (61&0) and rose (60&0), *Mangifera indica* (250 & 180) *Annona squamosa* (0&16), *Dalbergia sissoo* (0 & 100), *Eucalyptus tereticornis* (0 & 50) *Syzygium cumini* (0 & 50) were planted. Data recorded on survival revealed that there was 70 – 80% survival for various species. The impact of movement was that women and children have come to the forefront to save these saplings. It is expected that fruit plants will start yielding fruits within three years that will fulfil the nutrient requirements of the children. The teak seedlings planted at the site fetch INR 3000 rupees per tree at a 5-year of rotation. This results in overall socioeconomic upliftment of the community.

Keywords: *afforestation, agroforestry, rotation, watershed*

PP4.5.38. Horti-pasture system for sustaining productivity and livelihood improvement in rainfed area

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In India, about 60 percent of the net sown area is rainfed, contributing 40 percent of the total food production, supports 40 percent of human and 60 percent of livestock population. However, aberrant behaviour of monsoon due to climate change, land/soil degradation with multiple nutrient and water deficiencies declining the ground water table and poor resource-base of the farmers are principal constraints for low and unstable yield in rainfed areas. Little attention towards fodder production resulted in acute fodder scarcity leading to poor livestock health, production and productivity. In this context, there is need to utilize rainfed areas by incorporating fruit plantation and animal husbandry to improve livelihood and sustain fodder production.

Hortipasture system, integration of fruit trees with pasture species in the same unit of land acts as one of the best and economic alternatives for class IV and V type of land. A number of experiments were conducted at Indian Grassland and Fodder Research Institute, Jhansi, India during 1990 to 2013 with different fruits viz. ber (*Zizyphus mauritiana*), aonla (*Emblica officinalis*), custard apple (*Annona squamata*), guava (*Psidium guajava*), tamarind (*Tamarindus indica*) and bael (*Aegle marmelos*) based hortipasture systems under rainfed situation. On average, production potential of these systems ranged from 7-15 t fruit/ha, 3-8 t DM forage/ha and 4-5 t fuel wood /ha, besides soil improvement and preventing soil erosion. These systems were also recorded with higher cost:benefit ratio (1:3.7-6.24) alongwith more employment opportunities (64.9 man days/ ha/year).

Keywords: fruit species, horti-pasture system, productivity, rainfed area

PP4.5.39. Argan [*Argania spinosa* (L.) Skeels] in Morocco: importance, multiple use tree, access and benefit sharing (ABS)

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The argan constitutes an important source of revenue for the local population to a total value of 25% to 45% according to the zones. It thus ensures the subsistence of approximately 3 million people, of which roughly a million are in a rural environment. Within the argan ecosystem, various productions provide more than 20 million days' work, including 7.5 million primarily female days for the only argan oil extraction. The argan constitutes an important example for access and benefit sharing rising from its resources exploitation. However, the argan ecosystems are currently subjected to many pressures of destruction with the most important being demographic pressure, agriculture development, excessive pasture and climate changes.

Keywords: argan, importance, use, access, benefit sharing, Morocco

PP4.5.40. Temporal and spatial differences in corn and soybean yields in a temperate silver maple alley cropping system

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Although alley cropping practices improve ecosystem services, they can reduce crop yields especially at the tree-crop interface and progressively at increasing distances from that interface with time. The objective of this study was to evaluate temporal and spatial yield differences in no-till corn (*Zea mays* L.)-soybean [*Glycine max* (L.) Merr.] rotation in a mature (11-19 years) silver maple (*Acer saccharinum* L.) alley cropping system in the claypan region of the temperate climatic zone. Silver maple saplings were planted in 20 m wide rows at 3.6 m spacing between trees in 1990. Crop yields were measured at 3.3, 6.7, and 10 m distances from the tree row from 2001 to 2008. Corn yields in 2002, 2004, 2006 and 2008 and soybean yields in 2001, 2003, 2005, and 2007 were determined using a small plot combined and analyzed in a split-plot in space and time design. Corn yield was 86 and 24% lower at 3.3 and 6.7 m compared to 10 m. The greatest reductions were recorded in 2006 when the site recorded the greatest yields. Late planting significantly affected the corn yield despite 156% of the normal rain in 2008. Soybean yield was 77% and 24% lower at 3.3 and 6.7 m, respectively, compared to yield at 10 m. Soybean yields declined over time at all three measured distances. Results of this study indicate that reduction of competition and selection of drought and shade tolerant crops may help increase productivity while providing ecosystem services of the perennial tree rows.

Keywords: claypan, competition, soil moisture

PP4.5.41. Bio-amelioration of alkali soils through agroforestry systems in central Indo-Gangetic plains of India

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A long-term field study was initiated during 1995 at Central Soil Salinity Research Institute, Regional Research station, Lucknow (26° 47' 58'' N and 80° 46' 24'' E) to analyze the effect of different agroforestry systems on amelioration of alkali soils. Three different agroforestry systems (pastoral, silvipastoral and silvicultural) were compared with the control where no agroforestry system was introduced. Tree based silvicultural and silvipastoral systems were characterized by tree species of *Prosopis juliflora* and *Acacia nilotica* along with grass species of *Leptochloa fusca*, *Panicum maximum*, *Trifolium alexandrinum* and *Chloris gayana*. Tree growth of ten years old *Prosopis juliflora* and *Acacia nilotica* planted in combination with grasses was significantly higher over the silviculture system with the same species. Tree biomass yields of *P. juliflora* (77.20 Mg ha⁻¹) and *A. Nilotica* (63.20Mg ha⁻¹) planted under silvipastoral system were significantly higher than the sole plantation of (64.50 Mg ha⁻¹ and 52.75 Mg ha⁻¹). Fodder yield under pastoral system was significantly higher than the silvipastoral system during initial years but it was at par with that of silvipastoral systems after eight years of plantation. The microbial biomass carbon in the soils of silvipastoral systems was significantly higher over the soils under silviculture and control systems. *Prosopis*-based silvipastoral system proved more effective in reducing soil pH, displacing Na⁺ from the exchange complex, increasing organic carbon and available N, P and K. Improvement in soil physical properties like bulk density, porosity, soil moisture and infiltration rate was higher in *prosopis* based silvipastoral system than the silviculture and control. On the basis of biomass production and improvement in soil health due to tree + grass systems, silvipastoral agroforestry system could be adopted for sustainable reclamation of highly alkaline soils.

Keywords: agroforestry systems, alkali soils, biomass yield, soil microbial biomass, soil amelioration

PP4.5.42. Integrated use of organics and inorganics in different intercrops in Pongamia based on agri-Silviculture system in the semi-arid region of Andhra Pradesh, India

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The field experiments on integrated use of organics and inorganics was conducted in sweet sorghum, castor, pearl millet in *kharif* 2009 and 2010 in the alleys of young Pongamia plantation at the agroforestry research block, Acharya N.G. Ranga Agricultural University, Rajendranagar campus, Hyderabad, A.P. All three experiments were laid out in randomised block design, replicated thrice with nine different treatment combinations in sweet sorghum and eight in castor. The sources of organic manures were FYM, vermicompost, poultry manure, neemcake, biofertilizers as Azospirillum, Azotobactor, VAM and urea, single super phosphate, muriate of potash as chemical fertilizers. The experimental soil was red sandy loam in texture, neutral, non-saline and medium in organic carbon, low to medium in available N, P, K. The grain and stover yield (3078 and 9225 kg ha⁻¹) of sweet sorghum was significantly affected by the application of 100% RDF (80-60-40 kg ha⁻¹) followed by conjoint use of 75% RD N + 25% N through poultry manure (2850 and 8465 kg ha⁻¹). Regarding quality parameters the highest brix content (12.14%) was recorded in 75% RD N + 25 % N through poultry manure and on par with 100% RDF (11.8%). In case of sucrose the highest content (9.86%) followed by 75% RD N + 25% N through Vermicompost (9.29%). Highest soil organic carbon content (0.63%) was resulted in 75% RD N + 25% N through poultry manure. Regarding available N, P, K, the maximum content was found when integration of 75% RD N + 25% N through poultry manure practice was followed. In case of castor, the results revealed that highest seed and stalk yield (658.4 and 1359 kg ha⁻¹) was recorded with conjunctive use of 75% RDF + Vermicompost 2 t ha⁻¹ followed by 75% RDF + Neem cake 4 t ha⁻¹ (619.0 and 1191 kg ha⁻¹). Regarding soil parameters the same nutrient management practice recorded the highest organic carbon content (0.74%) and available N, P and K (183.7, 24.8 and 230.5 kg ha⁻¹).

Keywords: agrisilviculture, sweet sorghum, castor, pearl millet, nutrient management

PP4.5.43. Development potential of Agroforestry systems with son tra (*Docynia indica*) in the Northwest Vietnam

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Son tra- *Docynia indica* (Wallich.)Decne. belongs to the plant family *Rosaceae*, along with well-known fruit tree species such as the apple (*Malus domestica* Borkh.), pear (*Pyrus* spp.) and quince (*Cydonia oblonga* Mill.). Son tra is a tree indigenous to Vietnam and the subtropical mountains of neighbouring countries from Nepal through to southern China and it occurs naturally at elevations above 900 masl in the North of Vietnam. It is increasingly used as a reforestation species for environmental services and is also planted for commercial purposes on a small scale as a fruit tree. Today, son tra is increasingly recognized as an important source of income for local households and the production area and market value chain for Son tra has grown over the last years.

Despite the environmental and economic benefits of son tra, little attention has been paid to the sustainable development of son tra production and improvement of its added value.

To address the above-mentioned issues and to promote son tra planting in the hilly region in northwest Vietnam, the “Agroforestry for Livelihoods of Smallholder Farmers in North-West Vietnam” project funded by the Australian Centre for International Agricultural Research (ACIAR), is conducting research on: i) improving availability of high-quality germplasm of son tra; ii) enhancing market access for, and opportunities to add value to son tra products and iii) developing agroforestry model of intercropping son tra with short term crops to increase the benefits of the system while protecting the environment.

Initial results of our research show that better market access and collective marketing of son tra increased income for son tra producers, which encouraged local farmers to plant more son tra trees on farm. High quality grafted seedlings produced by smallholder nurseries have been provided to interested farmers.

Keywords: *son tra, Docynia indica, agroforestry in Northwest Vietnam*

PP4.5.44. Agroforestry option for smallholder farmers in Northwest Vietnam – Late fruiting longan with grass strips and short term

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The North Western uplands of Vietnam are characterized by monocropping systems with short term crops in steeply sloping lands. Maize is an important crop for the burgeoning animal feed industry not only in the region but in the entire country. Maize is planted without soil and water conservation measures on up to 70% slopes, resulting in severe soil erosion and declining yields overtime. Since maize can be grown during summer, or only once a year due to weather conditions, farmers optimize their production by using chemical fertilizers and herbicides. There is thus a challenge in sustaining maize production for income while at the same time, protecting soil erosion.

The integration of late fruiting longan and grass strips in maize fields was recommended to improve overall productivity of maize system, increase the ground cover of the system and thus help to protect the soil from soil erosion. Longan is a high-yielding fruit tree with fruits that command a higher price during the late season and it. Longan trees are grafted for early fruiting.

This study is part of the ‘Agroforestry for Livelihoods and the Environment for Smallholders in Northwest Vietnam’ (AFLI) project, funded by the Australian Centre for International Agricultural Research (ACIAR) which aims to improve the performance of smallholder farming systems and environmental conditions in Northwest Vietnam through agroforestry.

Keywords: *agroforestry in north western Vietnam, intercropping, late fruiting longan, maize system*

PP.4.5.45. Value chain development of agroforestry species for ensuring sustainable livelihood in India

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Increasing demand for fodder and forest products from the growing population, is posing a threat to forests, which are necessary for mitigating global warming and enriching the atmosphere. This can be

addressed through agroforestry on non-forest lands, while generating additional benefits to farmers. Profitability of agroforestry is dependent on choice of tree species and cropping system. Among different categories of trees, farmers prefer trees producing fruits, nuts and minor forest products over timber, fuel and fodder, because of assured annual income without cutting trees. BAIF, a Civil Society Organisation, promoted agroforestry in semiarid regions, through introduction of Multi-Purpose Tree Species (MPTS) as shelterbelt plantations under rain-fed farming, but farmers in hilly terrains preferred drought tolerant fruit species like mango, cashew, Indian gooseberry, tamarind, custard apple, etc., as there was ready market for the produce, while there was no demand for wood, resulting in poor price realization. Other factors which influenced cultivation of fruit species were easy availability of good quality plants, adequate soil moisture and opportunity for food security through inter-cropping. Planting various MPTS on field bunds could serve as wind breaks and meet the household needs. There was scope for cultivating trees which produce edible and non-edible oil seeds, medicinal herbs, bio-pesticides, etc., provided aggregation, processing and marketing of produce were planned to realize higher price. As women contributed 60 - 70% labour, their empowerment could accelerate progress. Farmers' Organisations at village and block levels and Producer Company for processing and marketing could facilitate value chain development and programme sustainability. This programme which has benefitted over 0.2 million poor tribal families, is being replicated by the Government of India across the country for Tribal Rehabilitation.

Keywords: fodder, value chain, farmers

PP.4.5.46. Long term strategy against emerging new pests threatening agroforestry in Haryana State of India

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Haryana is an agrarian state of India with 80% of its land under cultivation. It is not bestowed with bounty of natural forests and only 3.52% of its geographical area is under forests. However, farmer and industry friendly agroforestry atmosphere has turned a forest deficient state into a wood surplus state and made it national leader in agroforestry. There are no restrictions on felling and transport of agroforestry trees from private areas. This has helped to set up a number of wood-based industries in Yamunanagar district of the State. *Eucalyptus* and *Populus* are major players of agroforestry. However, emerging new pests are threatening agroforestry prospects in the state. While Gall Wasp (*Leptocybe invasa*), Little Leaf Disease caused by *Phytoplasmas*, Gummosis and *Cylindrocladium* Leaf and Twig Blight are challenging *Eucalyptus* cultivation; Stem Borer, Defoliator (*Pygaera fulgurita*) and foliar diseases are discouraging poplar cultivation. Evaluation of pest tolerant/resistant germplasm, introduction of superior genetic material, standardization of propagation techniques, diversification of the species and starting of public liaison cell, are some of the comprehensive strategies chalked out to face the challenges. *Eucalyptus* germplasm has been evaluated for *Leptocybe invasa* and the resistant/tolerant genotypes have been identified. Bhadrachalam clones of *Eucalyptus* namely 288 and 7 have been found tolerant and *Corymbia* hybrid-6 has been found resistant to Gall Wasp and these clones are propagated in mist chambers. Unfortunately, no *Eucalyptus* germplasm has been found free from Little Leaf Disease. As regards diversification of species *Melia dubia* is being encouraged as it is emerging as a very good agroforestry species. It produces instant greenery and is the delight of researchers, farmers, foresters and carpenters. Package and practices for growing *Melia dubia* under Haryana conditions has been developed. *Ailanthus excelsa* has been found suitable species for agroforestry under arid and semi-arid areas of the State.

Keywords: *Leptocybe invasa*, *Corymbia*, *Phytoplasmmas*, *Melia dubia*

PP4.5.47. Structure and functioning of traditional agroforestry system in selected villages of Leh Laddakh, India

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The present study reports structure and functioning of a traditional agroforestry system in Phey and Nang villages of Leh district of Laddakh, India. Farmers grow food crops, vegetables, raise trees on the bunds of crop-fields and cultivate trees as woodlots and keep animals since generations, which together form a traditional agroforestry system (TAS). In Phey and Nang village, members per household are 7 and 4, respectively and livestock 8 and 6, respectively. Croplands (44% land), orchards (3%), CPRs (19%), permanent woodlands (18%) are crop component of the system. Wheat and barley are main staple food crops and alfalfa (*Medicago sativa*) a main fodder crop. Farmers grow potato, cauliflower and pea as vegetables. Orchards are comprised of apple and apricot and woodlots include poplar and *Salix*. Cow contributes maximum 79 to 81% to the livestock population. Dio and Dzomo are another important (9 to 15%) livestock in the villages, which farmers use for ploughing crop fields. Crop production (wheat 696-1083 kg ha⁻¹ and barley 766 kg ha⁻¹) is low, below national average, because they grow local cultivars. Production of tuber, pea, cauliflower, onion, carrot and spinach is 1438 -2857 kg ha⁻¹, 429 kg ha⁻¹, 716-800 kg ha⁻¹, 700-1000 kg ha⁻¹, 606-750 kg ha⁻¹, respectively. Household members do labour for growing, caring and harvesting of crops and keeping livestock. Household members consume almost all food grains, but sell surplus products like fodder, vegetables, milk and tree logs and branches in the local market for running household affairs. During planting season, a stick of *Salix* is sold for Rs. 25 to 40. The TAS in Leh is similar to that found in central Himalaya. Each component of the system is independent structurally, but work together in an interactive manner and makes the system efficient functionally and viable economically though at subsistence level.

Keywords: *agroforestry, fodder crop, Leh, tree-crop- animal interaction*

PP4.5.48. Productivity evaluation of fruit based two-tier system for livelihood security through integration of nutrient and moist

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The study was initiated from April, 2008 in Doon Valley in four year old mango - flower based two-tier horticulture system to improve livelihood security through integration of nutrient and moisture management under rainfed situations” started. The jasmine flower was introduced as an intercrop in two tier system in rainy season of 2008-09 with recommended package of practices. There were seven treatments of organic and inorganic amendments with two mulches in addition to control were laid out in factorial randomized block design with three replications. Performance of mango (cv. Dashehari) under different amendments and mulches was recorded and analysed. Integrated nutrient management (organic manures combined with chemical fertilizers) and mulches improved vegetative growth, productivity of mango and jasmine as well as moisture conservation under rainfed conditions. Based on 5 years of fruiting (2009-2013), the mean fruit yield of 25.7 kg tree⁻¹ or 4.0 t ha⁻¹ harvested from

mango plants, which received nutrients from vermi-compost + chemical fertilizer (50% each) was 19.6% higher than pure chemical fertilizer application followed by poultry manure and chemical fertilizers (50% each). Likewise, mean flower yield of jasmine (205.8 g plant⁻¹ or 0.36 tha⁻¹) was harvested from vermi-compost + chemical fertilizers (50% each) in comparison to sole chemical fertilizer treatment under Sunhemp mulch with pure chemical fertilizer during (2010-2013). The moisture conservation was also recorded higher in vermi-compost + chemical fertilizer (50% each) + sunhemp mulch by 12.7% and 23.8% as compared to weed mulch and control (no mulched) treatments, respectively. Net economic returns from mango + jasmine planted under vermi-compost + chemical fertilizer (50% each) + sunhemp mulch was realized * 5000.0 ha⁻¹.

*1US\$ = 60

Keywords: fruit yield and quality, in-situ moisture conservation, mango-jasmine, rainfed, two tier systems

PP4.5.49. Response of selected indigenous dryland agroforestry tree species to salinity and their implication to soil fertility management

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Salt tolerant indigenous plants are known for salinity mitigation and removal of soluble salts from salt affected soils. The research was conducted to study the response of *Acacia tortilis*, *Balanites aegyptica* and *Tamarindus indica* to salinity and their implication to soil fertility management. Three experiments were conducted; germination test in laboratory, seedling performances in a Lath house and multipurpose trees effect on soil productivity index at field condition. A mixture of salts composed of chlorides and sulfates of Na, K, Ca, and Mg were prepared at a ratio of 3:3:1:1 for chlorides and 1:1:1:1 for sulphates in order to maintain five treatment levels and five replicates of 4.1, 6.2, 8.1, 10.2 and 12.2dS/m for the germination and lath house experiments. A randomized complete block experimental design was used. Seedling root collar diameter and height were measured at two weeks interval. Soil samples were collected from randomly selected pots to examine the effect of salinity on soil properties. The tree species contribution to soil productivity enhancement were studied by collecting 72 soil samples at different radii and soil depth. The soil productivity index was computed. There was a significant decrease in the final germination percent and germination rate with increased salt concentration ($p < 0.05$). The effects of the three species on soil properties were significantly different at 12dS/m salinity level than control soil. The tree species had a significant effect on soil productivity enhancement. *Acacia tortilis* was the least salt sensitive followed by *Balanites ageyptiaca* and *Tamarindus indica*. The tree species could be integrated as a parkland agroforestry system or irrigated fields to mitigate the problem of salinization and increase productivity of salt affected soils.

Keywords: germination, productivity index, *Balanites ageyptiaca*, *Acacia tortilis*,

PP4.5.50. Nutritive value, associative effects and ruminal dry matter degradability kinetics of whole fruit meals in five tropical

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The objective of this study was to evaluate the associative effect and ruminal kinetics of the dry matter degradability of whole fruit flour from “tepame” *Acacia pennatula* (Ap), “cascalote” *Caesalpinia coriaria* (Cc), “guacima” *Guazuma ulmifolia* (Gu), “vainillo” *Senna atomaria* (Sa) and “asmol” *Zizyphus mexicana* (Zm), collected in the State of Colima, Mexico. At the same time it was assessed the nutritive quality and fractions of fibre: neutral detergent fibre (NDF), acid detergent fibre (ADF), cellulose, hemicellulose and lignin of the tropical native trees. The kinetics test was performed for each of the diets of the five arboreal species, introducing in the rumen for each one of the 5 g of flour of the fruits of the tree species evaluated. The periods of incubation were: 4, 8, 12, 24, 36, 48 and 72 hours. The experimental design was completely randomized, with a split plot arrangement where the different flours of the tree species were evaluated. The mean comparison was conducted with the Tukey’s test ($P < 0.05$). Chemically fruits ranged from 85.2 to 89.9% of dry matter (DM), 6.0 to 12.0% crude protein (CP), 46.8 to 54.9% of neutral detergent fibre (NDF), and from 11.0 to 33.2% of acid detergent fibre (ADF). The highest potential DM degradability (a+b) was observed for Cc of 95.8% when in the diet was the flour fruit of Cc, increasing a little when in the diet was included Ap of 96.96%. The degradability of Gu was the lowest of 40.1%, however, when the diet was with the others species had a little increase in its degradability. The rate of degradation of DM ranged from 0.152 h^{-1} for Gu to 0.03 h^{-1} for Cc. Associative effects were detected for the kinetics of ruminal degradability of DM between the meal present in the ration and the meals incubated *in situ*

Keywords: dry matter, fruits, native tropical species, protein crude

PP4.5.51. Effect of shade and nitrogen levels on production and quality of bajra napier hybrids

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Bajra napier hybrids are the most promising perennial fodder crops widely popular in India. Being a hybrid between the bajra and napier grass this hybrid tends to express accumulation of oxalates. However, owing to intensive cultivation of this hybrid especially in shade and in temperate conditions, besides nitrogen fertilization after every cut could lead to accumulation of anti-nutritional factor i.e., nitrates and oxalates. An experiment was hence conducted in an orchard to study the effect of nitrogen levels and shade on the production of the crop, quality parameters viz., crude protein, crude fibre and anti-nutritional factors viz., oxalates and nitrates on APBN-1 (Andhra Pradesh Bajra Napier Hybrid -1). The nitrogen levels of 0, 25, 50, 100 and 125 % of the recommended rate i.e., 40 kg ha^{-1} of N as basal dose and after each cut were imposed. Parameters viz., green fodder yields, crude protein, crude fibre anti-nutritional factors viz., oxalates and nitrates were studied after each cut. The study indicated that physical parameters plant height did not vary with growing environment but highest plant height was observed in 100% recommended application of N while most of the treatments were at par. The leaf: stem ratio and no. of tillers/clump was significantly highest when crop was grown under direct sun rather than under shade. Green fodder yield and dry fodder yield was maximum when grown in sun while highest GFY was recorded when N is applied at 125% of recommendation (36.7 t ha^{-1} for three cuts). The fodder quality parameters viz., Crude protein (mean of 11.3%) did not vary with growing environment. Highest CF% was registered in 125%N receiving treatment while crop in sun recorded significantly high fibre. Invariably in all cuts the nitrate concentration of fodder was highest in 125% N receiving treatment and crop in shade recorded more nitrate values, however these concentrations were

much below the toxic levels. Oxalates concentration was significantly highest when grown in sun (3.11%) while highest N treatment recorded highest concentration of oxalates. The study indicated the crop grown in shade did not express anti-nutritional factors in unsafe limits.

Keywords: *shade, bajra napier hybrids, quality, yield*

PP4.5.52. Intensive forage production under rainfed silvipastoral system in semi-arid regions of India

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A field experiment was conducted to explore the fodder potential of various crops and intercrops under subabul based rainfed silvipastoral system. Subabul was the main crop and a combination of crops including annuals perennials, cereals and legumes were studied to aim at highest green fodder production in whole year through resource conservation under rain fed conditions. Crops viz., sorghum, bajra along with intercrop of horse gram in 3:1 ratio, while perennial crops viz., *Cenchrus ciliaris* (anjan grass), *Stylo* and *Desmanthes* were grown in solo as well as intercropped with either of the perennial crops. By the end of third year of study highest green fodder yield of 841.52 q ha⁻¹ was harvested from Subabul- *Cenchrus ciliaris* + *Desmanthes* (3:1) followed by that of Subabul- *Cenchrus ciliaris* + *Stylo* (780.7 and Subabul-*Cenchrus* (719.7 q ha⁻¹) which were all on par but found significantly superior to other combinations. However, during early years of establishment Subabul-pearl millet + sorghum (3:1 ratio) produced highest green fodder yields. The increase in crop canopy with age of perennial crops could be reason for establishment of *C. ciliaris* and *Stylo*. The crude protein yield was also highest in Subabul - *Cenchrus ciliaris* + *Desmanthes* (23.21 q ha⁻¹), while Subabul - *Desmanthes* system has put up 21.93 q ha⁻¹ of CPY. The gross returns and net returns followed the trend that was reflected in GFY. Rs.1,33,213 ha⁻¹ yr⁻¹. The benefit : cost ratio of 5.16 was observed with the best system. Thus under rainfed conditions an intercrop of *Cenchrus ciliaris* and *Desmanthes* in ratio of 3:1 under Subabul is most promising with appreciable green fodder and crude protein yields besides being remunerative.

Keywords: *intensive forage production, silvipastoral system, rainfed*

PP4.5.53. Bio-amelioration of alkali soils through agroforestry systems in central Indo-Gangetic plains of India

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A long term field study was initiated during 1995 at Central Soil Salinity Research Institute, Regional Research station, Lucknow (26° 47' 58'' N and 80° 46' 24'' E) to analyze the effect of different agroforestry systems on amelioration of alkali soils. Three different agroforestry systems (pastoral, silvipastoral and silvicultural) were compared with the control where no agroforestry system was introduced. Tree based silvicultural and silvipastoral systems were characterized by tree species of *Prosopis juliflora* and *Acacia nilotica* along with grass species of *Leptochloa fusca*, *Panicum maximum*, *Trifolium alexandrinum* and *Chloris gayana*. Tree growth of ten years old *Prosopis juliflora* and *Acacia nilotica* planted in combination with grasses was significantly higher over the silviculture system with

the same species. Tree biomass yields of *P. juliflora* (77.20 Mg ha⁻¹) and *A. nilotica* (63.20 Mg ha⁻¹) planted under silvipastoral system were significantly higher than the sole plantation of (64.50 Mg ha⁻¹ and 52.75 Mg ha⁻¹). Fodder yield under pastoral system was significantly higher than the silvipastoral system during initial years but it was at par with that of silvipastoral systems after eight years of plantation. The microbial biomass carbon in the soils of silvipastoral systems was significantly higher over the soils under silviculture and control systems. *Prosopis* based silvipastoral system proved more effective in reducing soil pH, displacing Na⁺ from the exchange complex, increasing organic carbon and available N, P and K. Improvement in soil physical properties like bulk density, porosity, soil moisture and infiltration rate was higher in *Prosopis* based silvipastoral system than the silviculture and control. On the basis of biomass production and improvement in soil health due to tree+ grass systems, silvipastoral agroforestry system could be adopted for sustainable reclamation of highly alkaline soils.

Keywords: *agroforestry systems, alkali soils, biomass yield, soil microbial biomass, soil amelioration*

PP4.5.54. Fruit tree based agri-silvi-horti cultural system for semi-arid regions

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Crop production in drylands in general and marginal lands in particular results in low and unstable yields because of aberrant monsoon behaviour. These marginal lands are not able to sustain arable crops particularly during drought years. Tree component in dryland increases production and income, besides imparting stability to the farming system. Among the alternate land use systems developed, dryland horticulture systems are picked up by the farmers due to cash benefits derived from these systems.

Tamarind (PKM-1) based Agri-Silvi horti system tested for 6 years (2004-2010) at AICRP on Agroforestry, Rajendranagar has shown that higher pod yield (1.4 to 2.1 t ha⁻¹) and pulp yield (0.38 to 0.52 t ha⁻¹) was realised in the system. In the same system, filler trees of custard apple recorded fruit yield of 0.44 to 0.83 t ha⁻¹. Intercropping in early stages with Redgram was more beneficial because of higher yield (1.75 t ha⁻¹) and good market price. Similarly, Tamarind trees produced higher pod yield (1.5 to 2.2 t ha⁻¹) and pulp yield (0.4 to 0.5 t ha⁻¹) with additional yield of Curry leaf (1.0 to 1.4 t ha⁻¹). In the early stages, intercropping with Redgram was more beneficial because of higher yield (1.6 t ha⁻¹) and good market price.

The economics worked out were higher with Tamarind + Curry leaf (filler) + Redgram which produced net returns of Rs. 33,365 ha⁻¹ than with combination of Tamarind + Custard apple + Redgram (Rs. 26,815 ha⁻¹), probably due to slightly long gestation period of curryleaf than custard apple. The system is helpful in generating more employment potential especially during off season, when the regular crops are not cultivated.

Keywords: *agri-silvi-horti system, semi-arid, tamarind, intercrops and employment potential*

PP4.5.55. Soil restoration through agroforestry in the Sudano-Sahelian area of Cameroon

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In the Sudano-sahelian area (SSA) of Cameroon, strengthening of drought and declining soil fertility are the main constraints to agriculture in the area. This situation has led to a decrease in yield and available land. These problems of productivity and sustainability of the system led the Cotton Company, CIRAD and IRAD to work together within the framework of Water-Soil-Tree (ESA) project since 2003 to develop techniques for rehabilitating degraded soils and increase crop yields. Agroforestry is part of the systems of Conservation Agriculture (CA) in SSA, characterized by linear timber plantations such as hedgerows, woodland strips, windbreaks, to fight against the erosion of fields or adjust the crop area to allow the land to be stable and to avoid conflicts between breeders and farmers.

The objective of this study is to obtain consistent estimates of population adoption rates of agrosystems and their determinants in SSA. A survey was conducted in the ESA project between 2008 and 2009 with farmers and the paper applies the average treatment effects (ATE) framework on data from a random cross-section sample of 303 farmers in Cameroon to account for selection bias and extend it by explicitly differentiating between with and without exposure to a technology. Results indicate that parameters differ considerably when accounting for heterogeneous exposure. We further find that the awareness of improved technology is mainly influenced by information access variables, while adoption is largely influenced by economic constraints. These results are also important for other technologies that are knowledge-intensive and require considerable adjustments in traditional practices.

Keywords: *agroforestry systems, average treatment effect, farmers, Soudano-Sahelian area of Cameroon*

PP4.5.56. ‘Honey Forests’ as an example agroforestry practice and convenient woody species in Turkey

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Turkey has 21.7 million ha forest areas meaning that forest land covers approximately 27% of the country. However, approximately 50% of this forest land is degraded and unproductive and hence it has become commonly accepted by FAO that only 13% of Turkey is covered by forests. Anatolia's geographical location, its land formation, climate types and plant species and also people have brought a natural synthesis generating different agroforestry systems and several plant combinations.

In Turkey, forest villagers are some of the poorest group of people. About 7 million people live in the rural areas making agroforestry a very strategic tool for supporting these people. In the recent years, Forest General Directorate in Turkey has given great importance to the establishment of ‘*Honey Forests*’.

This study aimed to present information on the convenient species for establishing “*Honey Forests*” in different regions and special honey production in the natural *Pinus brutia* forests in the Mediterranean forests of Turkey. Moreover, one out of every five kg of honey produced in Turkey is directly from pines honey especially Muğla Forestry Regional Directorate. Despite having 5 million beehives and producing 82 000 ton of honey, the average production in Turkey (17kg/beehive) is still lower than world average (22 kg/beehive).

From the results, it can be concluded that all the agroforestry systems need scientific support and institutional financing to stimulate the increase in honey production in Turkey. Promotion of agroforestry in Turkey will help the country address various problems such as environmental degradation, lack of food security, and deforestation.

Keywords: Turkey, honey, trees, agrosilvopastoral, plant diversity, villagers, beekeeping

PP4.5.57. Economic Viability of soybean (*Glycine max*) – *Melia azadirach* based agroforestry system of Karnataka

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Melia azadirach L also known as chinaberry or Persian lilac is a deciduous tree native to India and which has long been recognized for its medicinal and insecticidal properties. *Melia* is considered as multipurpose tree because of its multi – directional and wide uses in agriculture. It is commonly planted along the bund / canal in irrigated area and its foliage is used for goat feed.

An experiment was conducted from 2002 – 2010 to know the economic viability of soybean (*Glycine max*) - *Melia azadirach* based agroforestry systems at Main Agricultural Research Station, UAS, Dharwad on medium black clay soil under rainfed conditions. The experiment consisted of four densities viz, 5 x 1m, 5 x 2 m, 5 x 3 m and 5 x 4 m. Soybean (JS - 335) crop was grown in the interspace of melia rows and also sole crop during Kharif every year. Recommended package of practices were followed for soybean. All the silvicultural practices were followed for better development of *Melia azadirach*. After the 5th year, the soybean yields significantly decreased in 5 x 1m and 5 x 2m spacing of *Melia* as compared to 5 x 4 m spacing. Plant height, leaf area and total dry matter production of soybean were significantly lower in 5 x 1m melia alleys as compared to sole crop. The diameter at breast height was significantly higher in wider row spacing, 5 x 4m as compared to 5 x 1m spacing. The net returns and B: C ratio were significantly higher in melia at 5 x 4m soybean followed by at 5 x 3m + soybean as compared to the other treatments. Hence, it can be recommended that 5 x 4m is suitable under rainfed conditions. It can be recommended for planting on bunds / canal / nala etc.

Keywords: densities, B: C ratio, internal rate of return, agroforestry

PP4.5.58. Nutritive value, associative effects and ruminal dry matter degradability kinetics of whole fruit meals in five tropical

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The objective of this study was to evaluate the associative effect and ruminal kinetics of the dry matter degradability of whole fruit flour from “tepame” *Acacia pennatula* (Ap), “cascalote” *Caesalpinia coriaria* (Cc), “guacima” *Guazuma ulmifolia* (Gu), “vainillo” *Senna atomaria* (Sa) and “asmol” *Zizyphus mexicana* (Zm), collected in the State of Colima, Mexico. At the same time the study assessed the nutritive quality and fractions of fiber: neutral detergent fiber (NDF), acid detergent fiber (ADF), cellulose, hemicellulose and lignin of the tropical native trees. The kinetics test was performed for each of the diets of the five arboreal species, introducing in the rumen for each one of the 5 g of flour of the fruits of the tree species evaluated. The periods of incubation were: 4, 8, 12, 24, 36, 48 and 72 hours. The experimental design was completely randomized; with a split plot arrangement where the different

flours of the tree species were evaluated. The mean comparison was conducted with the Tukey's test ($P < 0.05$). Chemically fruits ranged from 85.2 to 89.9% of dry matter (DM), 6.0 to 12.0% crude protein (CP), 46.8 to 54.9% of neutral detergent fibre (NDF), and from 11.0 to 33.2% of acid detergent fibre (ADF). The highest potential DM degradability (a+b) was observed for Cc of 95.8% when in the diet was the flour fruit of Cc, increasing a little when in the diet was included Ap of 96.96%. The degradability of Gu was the lowest of 40.1%, however, when the diet was with the others species had a little increase in its degradability. The rate of degradation of DM ranged from 0.152 h^{-1} for Gu to 0.03 h^{-1} for Cc. Associative effects were detected for the kinetics of ruminal degradability of DM between the meal present in the ration and the meals incubated *in situ*

Keywords: *dry matter, fruits, native tropical species, protein crude*

4.6 Building development abilities through education and capacity development

PP4.6.1. Capacity building for natural resources and agroforestry in agricultural education

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Recognising the need to realise the value of its resources in sustainable ways, the Government of Zimbabwe embarked on an initiative to develop a comprehensive and state-of-the-art national system of natural resources and agroforestry development. Performance of capacity development projects require flexibility, good understanding of local realities, special skills and high levels of participation.

Building the capacity of organisations requires attention including: **World view:** a coherent frame of reference that the organisation uses to interpret natural resources and agroforestry issues; **culture:** a way of doing things that enables the organisation to achieve its objectives, and that it can be effective and have an impact; **structure:** a clear definition of roles, functions, lines of communication, and mechanisms for accountability; **adaptive strategies:** practices and policies that enable an organisation to adapt and respond to changes in its operating environment; **skills:** knowledge, abilities, and competencies; **material resources:** technology, finance, and equipment; and **linkages:** an ability to develop and manage relationships with locals and organisations in pursuit of overall goals of resources and agroforest development. The government of Zimbabwe developed the Indigenisation programme and the National Development Plan guide policy within agricultural colleges and universities. The key contribution of colleges and universities are as follows, research and information, agricultural extension service, research innovation and training, natural resources and agroforestry needs.

Natural resources contribute to growth, employment and fiscal revenues; but they need to be managed well. Governance of natural resources is especially crucial in the context of:

- Divided societies or where there is ethnic conflict; poor or highly unequal societies;
- Failure to govern well renders natural resources a "curse", so it is vital to examine the status of Natural Resources Management (NRM) and the capacity challenges.

The state has also adopted policies providing much stronger support for decentralized resources management and resource protection.

Keywords: *capacity building, natural resources, agriculture education*

PP4.6.2. Adoption of agroforestry practices by limited resource farmers in North Carolina, USA

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The purpose of this study was to assess the adoption of agroforestry practices by limited resource farmers in North Carolina. Respondents were knowledgeable about the benefits of agroforestry and highlighted the following benefits: increasing of income, improving of wildlife habitat, soil protection, improving water quality, increasing biodiversity, and increasing shelter for livestock and product diversification. A questionnaire was developed to gather respondents' knowledge about agroforestry practices. A seventy percent response rate was received. The study found that most respondents lacked adequate information on agroforestry practices. Respondents reported that the barriers for adopting agroforestry practices were: no market for products, expenses of additional resources, lack of technical assistance, lack of information about agroforestry, lack of demonstration sites, and insufficient land. However, it was found that respondents were willing to adopt agroforestry practices such as alley cropping silvopasture, riparian forest buffer, forest farming and wind breaks. Based on the findings, there is a need for incentives that will encourage farmers to adopt agroforestry as an income-generating venture. Limited resource farmers should be assisted to join cost share programs provided by state and federal agencies. These cost-share programs may be used to prevent these barriers of adopting agroforestry practices in the form of equipment and other agricultural inputs. More importantly, agricultural policies need to be enacted to address farmers' needs and ensure agroforestry is part of the agriculture agenda for improving land productivity.

Keywords: agroforestry, USA, policies, farmers

PP4.6.3. Transformation of fruit tree orchard into multi-storied agroforestry system: a way for higher production and income

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Fruit tree based agroforestry systems have been expanding to farmland ecosystems as crop farming is becoming risky and loosing concern. Jackfruit orchards having sporadic understoried crops predominantly found in upland of terrace ecosystem were transformed into multi-storied agroforestry system for maximizing production through utilizing resources. Jackfruit tree was kept as upper-storied crop; while papaya and lemon were established as middle-storied; and brinjal as lower-storied crops. The system was managed scientifically to ensure maximum resource utilization. Light availability, land equivalent ratio (LER) and benefit cost ratio (BCR) were determined to justify the advantages of this system. Light availability at middle- and lower-storied crops was reduced by 26.56 and 32.34%, respectively. Middle-storied crop did not cut much light due to pruning of lemon tree and nature of papaya plant. The yield of Jackfruit was increased by 33.66%, while yields of papaya and brinjal were decreased by 17.86 and 24.73%, respectively. Yield advantage in Jackfruit might be due to judicious use

of water and nutrients for middle- and lower-storied crops. Yields of middle- and lower-storied crops were reduced due to competition for resources. LER was appreciably higher in multi-storied agroforestry system (3.11) because of increased production. BCR was good in multi-storied agroforestry system and income from this system was 182% higher compared to sole Jackfruit system. Micro-climate seemed to be improved as the new system kept the farm greenish all the times. These are the results of two years study while benefit would be much higher when yield of lemon tree would be received.

Keywords: *higher income, higher production, multi-storeyed agroforestry system*

PP4.6.4. Decentralised capacity building of rural communities in agroforestry: an efficient means of reforestation and the fight against climate change

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Within the framework of integration and the safeguard of biodiversity ethics in development projects in rural areas, a plan for a decentralised capacity building was designed for the period of 2007 to 2013. Villages surrounding the National Park of Togodo-South (PNT-S) in the District of Yoto, in Togo (West Africa) were the target of this project. Professors and graduate students in agronomy, environment, botany, geography and sociology from the University of Lomé were invited for a three day training on the “Integration of biodiversity ethics in the development projects in the rural areas”. The trained students were deployed in the villages for a ten day stay in order to familiarise themselves with the realities and the needs of the population in terms of the protection of biological diversity, agro-forestry, and the fight against climate change as appropriate means to reduce poverty in the rural areas. Semi-structured questionnaires, focal group discussion and participation of the students in some farming activities were used as means of identifying the opinion leaders as well as the needs in terms of capacity building of resource persons in agro-forestry. The trained leaders were later organised into groups for a transfer of knowledge to their local communities. This was done with the view of helping them form a lasting opinion in order to develop a commitment of the rural populations to: (i) get involved in agro-forestry and reforestation activities and (ii) fight against the waste of traditional domestic energy derived from firewood. Sensitisation campaigns in favour of reforestation and the economy of domestic energy were identified as the actions to support a decentralised capacity building system which was perpetuated up to 2013.

The three university professors involved in the project trained 10 students who contributed the capacity building of 32 rural groups of 9 members each, which gave a total of 228 persons from 8 villages surrounding the National Park of Togodo-South (PNT-S). From 2008 to 2013 181.18 of the initial 85 acres were effectively planted with 130,000 plants, which indicate 1600 teaks per acre. The 75 women who were members of the groups applied on daily basis the economic measures in favour of domestic energy to fight against deforestation. Plans are under way to look at the carbon credit system as a sufficient and efficient means of covering the potential for reforestation and systematizing the sensitization of the entire population in the 8 villages to adopt a positive attitude towards an energy efficient economy.

Keywords: *capacity building, agro-forestry, rural areas, climate change, poverty reduction, Togo.*

5.0 Applying science to the future of agroforestry: breakthroughs and innovations

5.1 Humid multistrata systems

PP5.1.1. Farmers' local ecological knowledge of trees in coffee agroforestry systems in Nicaragua and Guatemala

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Coffee agroforestry systems in Central America provide valuable ecosystem services, conserve biodiversity and contribute to poverty reduction. Remarkably, very little information exists on specific tree-crop interactions. This study contributes to filling this gap by gathering local ecological knowledge in two coffee-growing regions bordering natural protected areas in Nicaragua and Guatemala. Over 90 coffee farmers from each site were interviewed, their knowledge elicited and analysed using knowledge-based systems methods; and ranking exercises comparing trees for six selected attributes for each site were performed.

Knowledge of more than 43 trees and comparison of 32 ranked species, some of them common to both sites, was found to be detailed and explanatory and provided valuable insights into the different attributes and roles of trees in coffee agroforestry systems from a farmer's perspective. Tree compatibility with coffee was explained through a local functional classification which identified "caliente" (hot) or "fresco" (fresh/cool) trees, with varying degrees of consistency between farmers. "Caliente" trees were often highly valued for their timber or fruit products but had negative effects on coffee growth and productivity. Statements related to management and above-ground tree characteristics were very abundant, and farmers were particularly detailed in tree species that affected soil moisture and/or fertility as well as attributes related to leaf litter. Trees with soft-textured leaves were likewise ranked as fast growing and these were usually considered as the most suitable shade trees. Overall, knowledge was influenced by the environmental context specific to each site. On the whole, farmers selected trees that provided ecological benefits to their main crop and/or contributed products to their livelihoods and additionally managing them to reduce any known negative effects on coffee plants. Local knowledge has refined our understanding of farmer decision-making regarding shade trees thus enabling to more effectively communicate with farmers when designing appropriate interventions.

Keywords: *coffee agroforestry, Guatemala, local ecological knowledge, Nicaragua*

PP5.1.2. Intraspecific trait plasticity in coffee agroforestry systems of Costa Rica

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While it has been shown that coffee-shade agroforestry systems require fewer inputs and achieve greater coffee yield stability, little work has focused on the shade tree and environmental processes that

control intraspecific leaf trait variation of coffee crops. It has been observed in natural plant communities that functional leaf traits are modified along environmental gradients. Accordingly, we would expect plasticity in coffee leaf traits along a: i) local scale gradient (light and nutrients) induced by shade tree diversity and ii) large scale gradient (climato-edaphic) induced by altitude. The objective of this study was to examine the effect of such environmental gradients on coffee plant response in multiple on-farm research sites of variable shade tree diversity and altitude in the Cartago and San Jose regions of Costa Rica. We analysed coffee under full sun and shade for leaf-level photosynthetic rates (infrared gas analysis), leaf traits (morphological/nutritional) and light transmittance (hemispherical photographs) above coffee strata. Our results show large variability of coffee leaf traits, coffee photosynthetic rates, specific leaf area (SLA) and leaf dry mass deviated with shade tree richness and climato-edaphic conditions. Mean leaf mass and SLA tended to increase with increasing shade tree diversity, with maximal net photosynthesis at 60% total light transmittance under shade canopies. This positive shade tree effect was minimized with increasing altitude where full sun coffee photosynthesized at higher rates than shaded coffee at high altitudes. Concurrently, other coffee leaf traits strongly differentiated between full sun and shaded agroforestry with increasing altitude. Results suggest greater plasticity toward leaf-level resource acquiring traits as shade tree diversity increases, but only in nutrient and climate-limiting environments. These findings help predict coffee performance across environments, whether induced by natural (climato-edaphic) or managed (shade tree presence) phenomenon, contributing to the growing literature on trait variability to environmental change in agroforestry systems.

Keywords: *biogeography, coffee agroforestry, leaf traits, shade tree interactions*

PP5.1.3. Studies on the nutrient application and their effect on the health and the nutrient uptake in *Albizia chinensis*: A mu

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Albizia chinensis is nitrogen fixing gentle, shade tree species and beneficial to tea, cocoa and coffee crops. It can also be interspersed with bananas where it probably acts as a partial wind break and increases humidity. The stock quality of the species is poor apart from this there is no recommendation for raising the planting stock with integrated use of fertilizers all this affect its prospects in the field. The study was conducted to standardize the integrated dose of organic manure and inorganic fertilizers for getting the quality planting stock of the species. The eleven treatments by integrating farm yard manure, nitrogen and phosphorus were applied in the polybags raised stock. The experiment was conducted in the Completely randomized block design Effect of combined doses of FYM, nitrogen and phosphorus at the rate of 10 t/ha x 60 kg/ha x 50 kg/ha produced the highest germination (56.30%) and seedlings shoot (30.75 cm) and root length (36.43 cm), number of leaves (8.22), leaf area (105.50 cm²), shoot (3.17 g) and root weight (3.82 g) and stock quality index (0.81). FYM x nitrogen x phosphorus interaction resulted in significant change in NPK contents and their uptake. F3N3P2 and F3N3P3 interaction combination produced the seedlings with the highest nitrogen (2.82%) and phosphorus contents (0.124%). Whereas, F3N3P3 interaction registered the maximum potassium (1.28%) and NPK uptake (N:131.50; P:8.01 and K:70.27 mg/plant) in *A. chinensis* seedlings in the nursery.

Keywords: *none*

PP5.1.4. Coffee and tree root systems in sub-optimal soil and climatic conditions in unshaded and shaded coffee compared

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Whereas under optimal environmental conditions complementarity in resource use by coffee and shade trees has been demonstrated, in suboptimal dry conditions there can be competition for water, severity of which depends on tree species and soil conditions. Channels created by dead tree roots through the pan may benefit subsequent coffee root growth. This study compares rooting behaviour in Arabica coffee both unshaded and shaded by two previously untested tropical timber species (deciduous *Tabebuia rosea* Bertol. and evergreen *Simarouba glauca* DC.) in andisol soils with a shallow compacted soil layer (*talpetate*) in sub-optimal environment conditions (455m altitude, 26-27°C, 1200-1400mm rain/year, six months dry season) in Nicaragua. The *talpetate* varied greatly in terms of depth, thickness and physical structure. 12 trenches 200cm deep were dug in shade both near and far from tree stems, and six trenches in non-shaded plots. Roots were counted per unit area on two perpendicular soil faces. Most coffee fine roots were concentrated in the top 30cm and were less dense under shade than when unshaded. There were more numerous tree roots per unit area in *Simarouba glauca* than *Tabebuia rosea*, but nevertheless coffee roots in the profiles located close to *Simarouba glauca* trees were denser than in *Tabebuia rosea* plots. A linear model showed the effect of *talpetate* on diminishing coffee root density in both the full sun and the shade plots. The root system of *Simarouba glauca* was denser in deep layers than that of *Tabebuia rosea*. *S. glauca* seems better suited as a coffee shade tree than *Tabebuia rosea* in such environmental conditions. More studies are underway, both to confirm these observations on root system of coffee and shade trees (to be presented during the congress) and to understand the consequences of these differences of tree root density on competition between timber trees and coffee.

Keywords: compact soil layer, competition for water, *Simarouba glauca*, *Tabebuia rosea*

PP5.1.5. Agro biodiversity for livelihood security: A case study of coffee based agroforestry systems in Mexico

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This study examines the livelihood benefits resulting from agrobiodiversity practised by innovative farmers in their coffee plantations in the Huatusco region of the state of Veracruz, Mexico. Coffee cultivation is the main economic activity in the region's agricultural sector. Most farmers grow coffee in mono-crop systems and are thus vulnerable to price fluctuations resulting from simultaneous harvest and over-supply of a single commodity. Some farmers have associated multiple crops in Coffee plantations (agroforestry techniques) as a strategy to improve their livelihoods. Innovative farmers who increased agrobiodiversity in their farms have significantly improved their livelihoods compared to mono-crop plantation owners. This research shows that increased agro-biodiversity can be a strategy to improve the livelihoods of coffee producers in the state of Veracruz, with significant economic benefits depending on the crop combination: Coffee-*Inga spuria* is the least economically profitable combination, with an internal rate of return (IRR) of 7; by contrast, Coffee-Pink Cedar yields an IRR of 25 with a benefit-cost ratio (B/CR) of 1.76. The Coffee-Fish combination has the highest IRR (124) with a benefit-cost ratio of 1.6 and net present value (NPV) of Mex\$ 229,055. The choice of crop ultimately depends on the farmer's priorities. The associated benefits can be classified in three ways

which correspond to the three-pronged goal of sustainable development: (i) ecological sustainability (through increased ecosystem resilience), (ii) economic stability (through diversified, less risk-prone sources of income), and (iii) social well-being (through lower emigration).

Keywords: *coffee plantations, ecological sustainability, economic profits, social well-being, Mexico*

PP5.1.6. Productivity of Conilon coffee in agroforestry system and monocrop in the Brazilian Amazon

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Due to the economic, social and environmental advantages of agroforestry systems, its adoption in the Amazon can be one of the alternatives of promoting the sustainability of agricultural production in this region. The objective of this work was to evaluate the effect of two coffee crop systems (monocrop and agroforestry system) on the productivity of different cultivars of conilon coffee (*Coffea canephora*). The research was conducted at Embrapa Acre, in Rio Branco-Acre, Brazil (10°1'30"S, 67°42'18"W, 160 m of altitude). A randomized complete block design was used in split plot, with six treatments and six replications. Plots were represented by coffee crop systems and subplots by conilon coffee cultivars (BRS-Ouro Preto, Robusta Tropical and Espirito Santo), with 14 coffee plants per subplot. The agroforestry system was composed of coffee, açai (*Euterpe oleraceae*), andiroba (*Carapa guianensis*) and banana (*Musa* sp). Production coffee data was related to the first harvest. They were subjected to variance analysis in the SISVAR software and means were compared by Tukey test at 5% probability. There was no interaction between the factors studied. The cropping systems had no influence on the processed coffee productivity. However, there were significant differences in productivity among the studied coffee cultivars. Cultivars BRS-Ouro Preto and Robusta Tropical were the most productive and did not differ among themselves, with an average productivity of 0.59 and 0.52 kg of processed coffee per plant respectively; while the cultivar Espirito Santo differed from the others with productivity almost 50% lower than the others (0.28 kg of processed coffee per plant). It is assumed that the absence of effect of cropping systems on the coffee productivity was due to the spacing adopted and age of the forest species in the SAF, which had not yet grown enough to promote positive or negative interactions, to influence the coffee productivity.

Keywords: *Amazon, coffee, multi-strata, native tropical species*

PP5.1.7. Uniformity of fruit ripening of Conilon coffee in agroforestry system and monocrop system

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The objective of this work was to evaluate the effect of two coffee cropping systems (monocrop and agroforestry system) on the uniformity of fruit ripening of different cultivars of conilon coffee (*Coffea canephora*). The research was conducted at Embrapa Acre, in Rio Branco-Acre, Brazil (10°1'30"S, 67°42'18"W). A randomized complete block design was used in split plot, with six treatments and six replications. Plots were represented by coffee crop systems and subplots by conilon coffee cultivars (BRS-Ouro Preto, Robusta Tropical and Espirito Santo). The agroforestry system was composed by coffee, açai (*Euterpe oleraceae*), andiroba (*Carapa guianensis*) and banana (*Musa* sp). Data of coffee

ripening were collected in the first harvest. At the first harvest of coffee, sample of 200g of coffee fruits were removed each plot and quantified by counting of the unripe, ripe (cherry) and dry fruit. Subsequently was calculated the proportion of coffee fruits at each maturation stage. The ripening stage of coffee fruits was different in the two cropping systems. There was a slight improvement in uniformity of fruit ripening from the agroforestry system. Fruits of coffee plants in monocrop, in other words under full solar radiation, showed maturity stage advanced than the fruits from agroforestry system, which were shaded. In the monocrop there was a higher percentage of dry fruits (40%) and a smaller fraction of green fruits (19%), while the opposite occurred in the agroforestry system, where only 20% of the fruits were dried and 29% green. The percentage of mature fruits was 41 and 51% in monoculture and agroforestry systems, respectively. The coffee cultivars showed similar behavior. All cultivars had 37% of dry fruits. Vitoria and Espírito Santo cultivars showed 24% of green fruits and BRS Ouro Preto 25%. The percentage of ripe fruit was 31% in BRS-Ouro Preto and 37% in other.

Keywords: Amazonian Region, *Coffea canephora*, multi-strata

PP5.1.8. The efficiency of cocoa pollination in agroforestry systems under bio-fertilizer application

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In the humid tropics, a significant amount of the agricultural landscape where cocoa (*Theobroma cacao*) is grown is managed as agroforestry systems and pressures to intensify cocoa production are likely to increase. The current trend for agricultural intensification in cocoa cultivation worldwide aims at significant reductions or total elimination of the shade canopy. However, losing the shade canopy implies losing the potential to produce valuable ecosystem services and particularly cocoa pollination. Pollination is a limiting factor of cocoa production that has been investigated in the 70's and 80's essentially by trapping methods. The genus *Forcypomia* sp. is acknowledged to be the main insect responsible for cocoa pollination, when other insects such as ants and *Trips* sp. would play a secondary role, essentially for self-compatible varieties of cocoa. However, these species were trapped in the immediate surrounding of the tiny cocoa flowers and no study has succeeded so far in observing and describing the insects actually visiting the inside of the cocoa flowers. We used a digital video recording system that allowed us to monitor and record all insects visiting cocoa flowers of three self-incompatible clones CATIE-R4, CATIE-R6 and PCMT-58 from 6:30 am to 11:30 am. The cocoa trees were monitored in low-flowering season and in high-flowering season in Turrialba, Costa Rica. The leaf litter was collected around the cocoa trees to investigate the presence of eggs of pollinators or predators. The cocoa trees were planted at 1111 trees per ha, associated with *Cordia alliodora*, *Cedrela odorata*, *Erythrina poeppigiana* and *Musa* sp. They were compared with and without bio-fertilizer application. Our results show that the diversity and the frequency of insects visiting cocoa flowers are influenced by the flowering period and do not rely specifically on the *Forcypomia* genus. Video recording and further histological cuttings made on visited flowers demonstrated the important role played by a number of species in cocoa pollination and fecundation. These results open good perspectives for the ecological intensification of cocoa production in Agroforestry Systems.

Keywords: fecundation rate, insect diversity, pollination services, video recording

5.2 New tools and paradigms

PP5.2.1. Biomass quantification in trees on farms: challenges and promising directions

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Trees are ubiquitous features of farms and landscapes in tropical developing countries and deliver a variety of ecosystem services including climate regulation through carbon accumulation and storage in biomass. Yet, approaches to quantify biomass of trees on farms can best be described as nascent when compared to forest biomass. In this paper, we argue that trees on farmland deserve concerted attention because of their widespread distribution and the unique challenges they present. For example, trees on farms typically exhibit irregular geometries and phenotypic plasticity induced by tree management and variable growing conditions resulting in significant deviations from theoretical allometric relationships. We will illustrate that such knowledge gaps propagate uncertainty and bias when estimating biomass of trees on farm at various spatial scales. We will then discuss statistical and technical advancements in building of allometric equations, dendrochronology, and remote sensing that may help deliver more precise biomass estimates in the near future. Though promising, the new methods alone will be inadequate to better understand and greater utilize trees on farm for climate change mitigation. That goal will require efforts to integrate and package data and information into robust and useable formats for end users.

Keywords: *agroforestry, allometric models, biomass carbon, trees on farm*

PP5.2.2. Advances in tropical dendrochronology and its application in climate change and agroforestry research

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Agroforestry is confronted with new challenges as agroforestry species with the ability to acclimate to changing climate conditions have to be identified. Recently, the science of tropical dendrochronology, to understand the long-term impacts of climate variations at the species, community and landscape levels, is evolving. This presentation will highlight the on-going application of dendrochronology in the tropics. It examines responses of tropical tree species to climate variability, and discusses the potential use of tree rings for understanding the drivers and impacts of climate change in sub-Saharan Africa and their ability to reconstruct past regional climate variability and climatic trends. Our approach considers large-scale climate gradients and different temporal scales (inter-annual and intra-annual variations) and combines multi-parameter measurements (ring width, carbon and oxygen isotopes, whole wood and cellulose measurements). The potential to link tree rings and remote sensing imagery (NDVI) to understand the relationships between cambial dynamics, length of growth period, and climate will also be discussed. Dendrochronology can provide us empirical data to make informed decisions that can help advance agroforestry science.

Keywords: *dendrochronology, stable isotopes, carbon sequestration, climate proxy*

PP5.2.3. Vulnerability of coconut-based agroforestry systems in Sri Lanka to climate change

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Scientific information on response of coconut (*Cocos nucifera* L.) based agroforestry systems to climate change, with respect to pollination and fruit set (FS), is scarce. Since this cropping system has a high environmental, economic and social importance, there is an urgent need to fill this research gap for enhancing its sustainability under climate change effects. This study evaluated the effect of heat stress alone and both heat and water stress (drought) on FS related parameters of coconut and its variation with cultivars under field conditions and response of *in vitro* pollen germination of different cultivars to temperature.

The coconut plantations in the intermediate agroclimatic zone (IZ) of Sri Lanka and dry agroclimatic zone (DZ) under irrigation were used to test the effect of heat and water stress on FS. Seven hybrids cultivated in the DZ and IZ were used to test the cultivar differences of heat and drought stress effects on FS. Pollen of these cultivars was used to determine the cardinal temperatures for *in vitro* pollen germination (PG).

The critical temperature for FS under both heat and water stress was 33°C and the most sensitive period was the first three months after inflorescence opening. In the absence of water stress, the critical temperature and VPD for FS were 35°C and 2.5 kPa, respectively. Female flower production and quality of pollen were less sensitive to heat stress in the absence of water stress. Cultivar differences were observed for FS under field conditions and *in vitro* PG. When inflorescences exposed to drought stress during the first three months, FS in all the cultivars was reduced and TT showed the lowest fruit set in the IZ whilst there was no FS in any cultivar in the DZ. When inflorescences exposed to drought stress during the 5th to 6th months of development, DGT and Dwarf Green x San Ramon (DGSR) outperformed other crosses in the IZ whilst DGT was the best performer in the DZ. DGT exhibited the highest PG (68%) and the widest temperature range for *in vitro* PG.

Dwarf Brown x Tall showed the highest T_{opt} (30⁰ C) whilst DGT showed the highest T_{max} (41⁰ C) for *in vitro* PG. The climate change impacts on quality of female flowers at receptive stage and pollen, their recovery following a drought, and relationship with other physiological factors of these cultivars were studied.

Keywords: *climate change, coconut based agroforestry, fruit set, pollen*

PP5.2.4. Sustainable production, harvesting and conservation of pesticidal plants

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The goal of most poor farmers in Africa is to achieve food security. One important limiting factor to food production is insect pest management. Pesticidal plants (PPs) have been used for thousands of years by man until the 1940s when synthetic pesticides (SP) were introduced. Unlike SP, PPs are relatively safe to use, low-cost, environmentally benign, difficult to adulterate, and accessible by small-scale farmers who have difficulty in buying SP. However, most of these plants are neglected and underutilized. Many grow naturally even on degraded lands, whilst others are more difficult to

cultivate. Their sustainability through concerted efforts in their propagation, harvesting, conservation and use could contribute to increased agricultural productivity and sustainable livelihoods as well as environmental conservation. Both indigenous and scientific knowledge on PPs were transcribed during a workshop in January 2013 where farmers, technicians and scientists from all over Kenya showed their knowledge on these species. Some examples of these PPs are: *Aloe ferox*, *Dysphania ambrosioides*, *Euphorbia tirucalli*, *Lippia javanica*, *Solanum incanum*, *Strichnos spinosa*, *Tephrosia vogelii*, *Tagetes minuta*, *Vernonia amygdalina*, *Tithonia diversifolia* and *Azadirachta indica*. At present their priority in agricultural policy is minor as their commercial incentives are low. Studies are ongoing on protocols for propagation and harvesting as well as suitable germplasm collection that optimizes growth potential and possible management options for invasive species. Preliminary results on one of the candidate species, *Tagetes minuta*, show that seeds collected from large populations have higher germination and growth potential compared to collections from small clusters of populations. By building capacities of farmers and local institutions in on-farm management strategies of PP and use, agricultural production could be increased.

Keywords: *agroforestry, crop protection, food security, pesticides*

PP5.2.5. Measuring carbon stocks in agroforestry systems: contributing to climate change mitigation and adaptation

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Discrete trees and small groups of trees in non-forest landscapes and agroforestry systems are referred to as trees outside forests (ToF). These systems play an important role in climate change mitigation through carbon sequestration and storage. ToF also protect soil, can improve farm livelihoods, and in some cases serve a role for wildlife habitat and offer an aesthetic value. Despite the significance of ToF, national forest resource inventory programs geo-spatial analyses are challenged to report accurate ToF measurements. For national level GHG inventory reporting (NATCOM) under UNFCCC, there is a need to accurately measure and monitor the ToF carbon stocks and stock changes. Accurate ToF inventory relying solely on ground-based data collection is cost prohibitive. Visual mapping of all trees using very high resolution (sub 1 meter) is also costly and time consuming. We explore the potential of using a combination of field-based measurements and automated tree-crown detection with very high resolution data in a sampling method to map ToF areas and estimate carbon and reduce high resource costs. We also report the challenges and possible opportunities to combine these methods with medium resolution satellite remote sensing analyses (e.g. Landsat, ASTERVNIR, etc).

Keywords: *carbon stock assessment, climate change, MRV, remote sensing and GIS*

PP5.2.6. Suber: tool for dynamic cork oak-based agroforestry systems management in Portugal

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An improved version of the Suber growth and yield model was released at the end of 2011. In addition to the enhancement of some routines of the model relevant for growth and production estimates, a large

effort in the development of user-friendly interfaces and dissemination of the tool for decision makers is being carried out.

The Suber model is now included in the sIMfLOR platform, a user-friendly interface that loads different simulators considering different management options and climate scenarios for the Portuguese forest and agroforestry ecosystems. This platform is available for free download in the FcTools website (www.isa.utl.pt/cef/forchange/fctools).

The use of these new interfaces allows facilitating:

- The definition of a set of sequential management operations to be considered in the simulations
- The analysis of the impact of different scenarios using a set of sustainable management indicators such as cork production, carbon sequestration and stand structure
- The visualization of default graphics or building new ones using the outputs from the simulations

Keywords: *Cork oak, knowledge transfer, management tool, Suber*

PP5.2.7. Quantification of forest carbon degradation in Nicaragua using RapidEye remote sensing data: Wiwilí and El Cuá case study

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Forest degradation and deforestation affect ecosystem function and climate regulation services such as carbon storage. Historically, Central America has been a deforestation and forest degradation hotspot. Wiwilí and El Cuá municipalities in northern Nicaragua are no exception, where absence of productive and conservative systems (agroforestry systems), subsistence agriculture and cattle ranch expansion have driven deforestation and degradation.

We estimated carbon stocks across a forest degradation gradient based on common biophysical variables and commercially available (RapidEye) remote sensing data. We measured 80 temporary forest plots (50x20m) for above-ground biomass to sample a gradient of forest degradation. We measured biomass in trees (≥ 10 cm DBH), sapling wood (5-9.9 cm DBH), other growth forms (fern tree, palms and lianas), and large detritus (snags and wood debris). Above-ground carbon stocks were estimated by a range of allometric models. Precipitation, temperature, altitude, slope, canopy cover, and aspect were also used as input variables for C modeling. We tested linear mixed models, generalized additive mixed models and regression tree approaches to explain carbon stocks based on vegetation indexes and biophysical variables. Additionally, we grouped plots into low (17-168 MgC ha⁻¹), medium (168-302 MgC ha⁻¹) and high (302-418 MgC ha⁻¹) carbon stocks (with conglomerate analysis) to test for a categorical classification approach based on discriminant analysis.

Results show a gradient of total above-ground carbon between 17.78 - 379.2 MgC ha⁻¹. Linear mixed models using the MCARI-MTVI2 vegetation index, showed the best performance ($R^2 = 0.62$ ($p < 0.0001$)). Categorical classification showed improved performance with a 17% mean classification

error.

The results showcase the potential of multispectral high-resolution imagery to quantify tropical forest degradation. If the communities have an active role in decisions affecting forests on which they depend and there is a full recognition of their rights, it is possible to mitigate the negative impacts that affect their livelihoods.

Keywords: *allometric models, biomass carbon, forest degradation, RapidEye*

PP5.2.8. Comparison of pixel and sub-pixel classifiers for assessment of agroforestry in Ludhiana district of Punjab, India

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Agroforestry is a land use where trees are deliberately grown with agricultural crops either within the field or on the bunds/ boundary. There are innumerable examples of this traditional land use practices in many parts of the world and there is a long tradition in India too. In India, agroforestry practices prevalent in different agroecological zones occupy sizeable areas. These practices have great potential for climate change mitigation through sequestration of atmospheric CO₂. In the state of Punjab, farmers prefer to grow multipurpose tree species such as *Eucalyptus* and *Populus* on their fields with agricultural crops. Reasons for adopting these species by the farmers are their fast growth and use of wood in paper and plywood industries. These agroforestry systems are not only remunerative to the farmers but also improve soil fertility of agricultural fields.

Multispectral remote sensing data (Resourcesat-2/ LISS III) of Ludhiana district was classified for different land uses/ land covers by applying pixel and sub-pixel classifiers. The area under agroforestry was estimated to be 5.05 and 5.56 percent in the district by unsupervised and supervised methods, respectively. But scattered trees on farmlands and boundary plantations were not classified as agroforestry by these pixel-based methods because entire pixel areas were not covered by trees. Moreover, mature sugarcane crop was also wrongly classified as agroforestry. To overcome these limitations, sub-pixel classifier was applied on agricultural area of the district and improved results were obtained where pixels covering minimum 20 percent to 100 percent tree cover were classified as agroforestry. In sub-pixel classification, scattered trees, boundary plantations as well as block plantations were included in agroforestry class. By this method, the area under agroforestry was estimated to be 14.90% in Ludhiana district. Hence, sub-pixel method was found better than pixel-based methods for assessment of agroforestry.

Keywords: *agroforestry area, land use/ land cover, multispectral remote sensing, pixel and sub-pixel classification*

PP5.2.9. Investigation for the area under agroforestry in Uttarakhand using medium resolution remote sensing data and DEM

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Agroforestry is a traditional and ancient land use practice in India i.e. having the deliberate integration

of trees in crop and livestock production systems. The diagnostic survey and appraisal revealed that there are enumerable agroforestry practices prevalent in different agroecological zones of India occupying sizeable areas. The most, if not all, agroforestry systems have the potential to sequester carbon. With adequate management of trees under agroforestry systems, a significant fraction of the atmospheric CO₂ could be captured and stored in plant biomass and in soils. The geospatial technologies have shown great potential in natural resource management throughout the world, in the fields like forest cover mapping, agricultural planning, watershed management, land use planning, etc. To know the potential of agroforestry in carbon sequestration, accurate assessment of areas under various agroforestry systems is essential. The Centre is working on the development of methodology for estimating the area under agroforestry using geospatial technologies.

In the present investigation, the occurrence of agroforestry systems in the Uttarakhand state of northern India using remote sensing data in conjunction with digital elevation model (DEM) is presented. Land use and land cover classification of Resourcesat-2/ LISS-III (23.5 m resolution) data was done by applying maximum likelihood classifier and the area under agroforestry was delineated and mapped. The agroforestry map was visually examined in association with elevation and slope maps generated from Cartosat DEM. Since agroforestry is mostly practiced by farmers in and around habitation and agricultural lands in the hills, the area on very high altitudes (more than 2000 m) and steep slopes (more than 45 degrees), where human settlements are generally not found, was eliminated in mapping. The area under agroforestry is thus estimated to be 63 543.09 ha (1.21%) in Uttarakhand state. Agroforestry practices are mainly confined to terrace bunds, foothills, forest fringes and plain areas in the state.

Keywords: *agroforestry systems, digital elevation model, geospatial, Uttarakhand*

PP5.2.10. Potential use of lemon-scented Eucalyptus oil as a bioherbicide on rice and associated weed species

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The use of botanicals and allelopathic chemicals could possibly replace environmentally harmful synthetic herbicides and is fast becoming an important means of controlling noxious weeds. Eucalyptus essential oils and their constituents have attracted much attention because of their phytotoxicity and relatively quicker degradation in the environment. This will help in establishment of economically sound eucalyptus-based agrisilvicultural systems.

The present investigation was carried out to assess the inhibitory effect of leaf oil of *E. citriodora* against dominant weed species of rice viz., *Cyperus iria*, *Echinochloa colona* and *Celosia argentea*. In a laboratory bioassay, seed germination of test plants were significantly reduced in response to the concentrations of leaf oil. Maximum inhibition was observed with *C. argentea* followed by *C. iria* and *E. colona*, whereas, the least effect was seen on rice. Dose response curve was generated and least concentration for 50% reduction (LC₅₀) was maximum for *E. colona*, whereas, minimum for *C. argentea*. Further, seedling growth of test plants in the treated seedling was significantly reduced at concentrations from control to 5.0 ppm volatile oil.

Another greenhouse experiment was conducted to establish the herbicidal activity of *E. citriodora* against 4-week-old rice and weed species (*C. iria*, *E. colona* and *C. argentea*) and to explore their

possible mechanism of action. Spray treatment of volatile oil on the plants of weedy species adversely affected the growth in terms of plant height, chlorophyll content and fluorescence, thereby indicating the adverse effect of eucalyptus oil on photosynthetic machinery. The increase in proline and H₂O₂ content in oil treated plants indicating oxidative stress caused cellular damage and electrolytic leakage. Therefore, it may be concluded that volatile oil of *Eucalyptus citriodora* show strong phytotoxicity and possess weed-suppressing ability. Hence, it could be used as a potential bioherbicide for future weed management programs.

Keywords: *essential oil, eucalyptus, phytotoxicity, rice, seedlings growth and weeds*

PP5.2.11. Modelling shade influence on coffee quality and its interaction with other factors using Bayesian Networks

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Coffee quality (CQ) is influenced by several factors such as genotype, altitude, climate, shading, farming system, slope exposure, soil conditions, and postharvest process. It is unclear, however, how the factors interact as most studies include only a few of them, and those with more show contradictory results. Understanding those interactions is a key step to improve the determination of CQ, and coffee production overall at farm, regional and national levels. In this study we therefore want to explore how the CQ-influencing factors interact, and how important each factor is in the explanation of the final CQ, with shading as the starting point.

To answer the question, we developed a Coffee Quality Model (CQD) for *Coffea arabica* L. implemented as a Bayesian Belief Network based on empirical data, and scientific and expert knowledge from Nicaragua. CQD includes the factors altitude, shade, farm management, coffee productivity, farm size, slope exposure, and soil texture as parent or explanatory variables. The children or response variables are physical and organoleptic CQ. The model was tested and validated against additional datasets from Nicaragua and Honduras.

CQD was able to predict both CQ components with an acceptable accuracy (RMSE), and explicitly showed the interactions between shade-altitude, shade-yield, shade-farm management, and combinations thereof which defined the CQ. Our next steps will be to further refine the model and make it applicable to other locations as well. For this we will add other coffee varieties and parent variables, implement continuous variables instead of discrete ones, and increase the number of states of the variables.

Keywords: *Bayesian Networks, Coffee Quality, Modeling Agroforestry Systems, Shade Tree Interactions*

PP5.2.12. Quantification of forest carbon degradation in Nicaragua using RapidEye remote sensing data: Wiwilí and El Cuá case study

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Forest degradation and deforestation affect ecosystem function and climate regulation services such as carbon storage. Historically, Central America has been a deforestation and forest degradation hotspot. Wiwilí and El Cuá municipalities in northern Nicaragua are not exception, where absence of productive and conservative systems (agroforestry systems), subsistence agriculture and cattle ranch expansion have driven deforestation and degradation.

We estimated carbon stocks across a forest degradation gradient based on common biophysical variables and commercially available (RapidEye) remote sensing data. We measured 80 temporary forest plots (50x20m) for aboveground biomass to sample a gradient of forest degradation. We measured biomass in trees (≥ 10 cm DBH), sapling wood (5-9.9 cm DBH), other growth forms (fern tree, palms and lianas), and large detritus (snags and wood debris). Aboveground carbon stocks were estimated by a range of allometric models. Precipitation, temperature, altitude, slope, canopy cover, and aspect were also used as input variables for C modelling.

We tested linear mixed models, generalized additive mixed models and regression tree approaches to explain carbon stocks based on vegetation indexes and biophysical variables. Additionally, we grouped plots into low (17-168 MgC ha⁻¹), medium (168-302 MgC ha⁻¹) and high (302-418 MgC ha⁻¹) carbon stocks (with conglomerate analysis) to test for a categorical classification approach based on discriminant analysis.

Results show a gradient of total aboveground carbon between 17.78 - 379.2 MgC ha⁻¹. Linear mixed models using the MCARI-MTVI2 vegetation index, showed the best performance ($R^2 = 0.62$ ($p < 0.0001$)). Categorical classification showed improved performance with a 17% mean classification error.

Our results show the potential of multi-spectral high-resolution imagery to quantify tropical forest degradation. If the communities have an active role in decisions affecting forests on which they depend and is a full recognition of their rights, is possible to mitigate the negative impacts that affect their livelihoods.

Keywords: *allometric models, biomass carbon, forest degradation, RapidEye*

5.2.13. Use of information, communication technologies for promotion of agroforestry in the Pacific

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The forest sector within Pacific Island Countries and Territories (PICTS) are at the cross road in terms of fighting against the negative impact of climate change, growing demand for ever rising population and high intensity of natural disasters.

Forest also, for generations have been providing for social, cultural and economic needs of Pacific Island Communities and now it is the time for the communities to manage their only resources in sustainable manner for them and future generation to benefit from the good and services that is provided.

A 'Outside the box' approach is needed to protect, conserve and adapt our forest ecosystem from these calamities so that the current and future generation continue to enjoy the goods and services provided by it.

The age old concept of agroforestry is coming to forefront now and various opportunities need to be explored to promote these models for sustainable management of resources. Breakthrough in ICT for development has given us new rays of hope to reach the remotest communities in the Pacific to spread the gospel of adopting agroforestry for sustainable future.

Despite so many conferences, meetings and international negotiations, we continue to face forest degradation and upon a careful look, all this points into just one direction and that is our communication is either inadequate or ineffective.

So through this paper the presenter will explore different opportunities available in ICT field to create awareness on agroforestry as well as other forestry issues. Farmers and tree growers have started to use mobile smart phones and are connecting to other web based tools via internet especially social media (web 2.0 tools). These tools should be explored to create the much needed awareness.

Due to the smallness of the Island countries in Pacific region, Agroforestry is the way forward and use of ICT for knowledge transfer is an ideal platform to create enabling environment to address issues such as food and nutritional security, climate change adaptation, income security and meeting cultural and social needs of the communities that are closely knit to the nature.

It has been always a norm that those in forestry should stay away from advancement in technology but now this is the opportunity to embrace it for better management of our sector (forestry sector). So it's time for foresters to embrace technology and take advantage of it. Let us do smart agroforestry with ICT.

Keywords: *agroforestry models, soil fertility and SFM, biodiversity and conservation, food and nutritional security, media for development – communications*

PP5.2.14. Demand and supply of pulpwood forecast by artificial neural network model

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The future global paper production will be nearly 521 million tonnes in 2021. In India, the present demand of paper and paperboard including newsprint is at 11.15 million tonnes per annum and per capita consumption is nearly 10.5 kg. The growth in the number of paper mills was from 17 units in 1950 to 759 units in 2010 with the production of 10.11 million tonnes per annum. In Tamil Nadu, Tamil Nadu News prints and Papers Limited (TNPL) and Seshasayee Paper and Board Limited (SPB) are the major pulpwood based paper industries. In the past, industries got the raw materials from Tamil Nadu Forest Plantation Corporation (TAFCORN), farmlands and open market. Recently, these industries have amplified their paper production capacity which requires 8 to 9 Lakh tonnes of pulpwood per year whereas the availability of pulpwood is nearly 6.5-7 Lakh tonnes per year. This short supply will affect their performance in the market. This paper assessed the factual demand and supply gap of industrial raw materials during 2001-2011 with different forecasting methods viz., trend analysis, moving average, single exponential smoothing model and Artificial Neural Network (ANN). Based on forecast accuracy, ANN is observed as a reliable method which measures that the demand supply gap of raw materials will be 1,05,406 and 2,41,512 Lakh tonnes in 2015 and 2020 respectively. In order to bridge the gap, industries must additionally produce raw materials by promoting resourceful captive plantation and the farm forestry area of 1000 -1200 hectares per year by an appropriate business model.

Keywords: paper industry, demand supply gap, pulpwood and ANN

PP5.2.15. The empowerment agroforestry in the simulations and the complaints by the social games like EcoCity

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Networks (Facebook, Google Plus) and social games (EcoCity, MegaCity) can increase the participation of all stakeholders in decisions between the environment and productivity. The narratives involving players of Ecocity, for example, can serve as a basis for thinking in narratological principles applied to agroforestry practices, guiding management cooperation cities (virtual) where, for example, at an early economies of these cities would require more energy and generate more ailments and dissatisfaction by focusing its activities in production logistics and distribution obesogenic foods a second time and require less power and generate less disease and dissatisfaction by focusing on the production and distribution of sustainable food. This research focused on the playful and the political narrative of EcoCity (for Facebook) and highlighted some interaction mechanisms that can be designed to simulate paradigms in transition between traditional economic and sustainable. The artificial intelligence that analyzes the evolution of the strategies chosen by the players-managers of their cities can be of service to simulations of agroforestry projects to be implemented effectively. Thus, we observe that cooperation through play can be given not only to raise awareness about reforestation, but can be effective in agroforestry projects in development.

Keywords: city-building social game, electronic government, paradigmatic transition, social solutions

5.3 Biodiversity and agroforested habitats

PP5.3.1. Farm size and distance to markets determine on-farm tree richness and diversity in Machakos county, eastern Kenya

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Trees on farms play a vital role in providing diverse goods and services to those farmers practicing agroforestry in Kenya. Other than the environmental advantages of agroforestry such as carbon sequestration and species conservation, trees provide soil and microclimate enhancement, deliver fruits, medicines, fodder, timber and fuelwood. However, tree species richness and diversity are influenced by numerous socioeconomic and biophysical factors. Promotion of on-farm tree planting activities requires detailed knowledge on these driving forces. The purpose of this study was to assess the effects of different socioeconomic and biophysical factors on tree richness and diversity in smallholder farms in the study area.

On 90 randomly selected farms covering five agroecological zones along an elevation gradient, farm sizes were measured, all trees inventoried and farmers interviewed on basic socioeconomic household data and tree management and uses. Correlations and stepwise multiple regression analysis were used to estimate the influence of the assessed socioeconomic and biophysical variables.

A total of 103 tree species were recorded including 44 exotic and 59 indigenous species. In terms of

abundance, exotic individuals dominated with 67% of all counted individuals. On average, 12.7 tree species (62% of them exotic ones) were cultivated per farm that had a mean size of 1.6 ha. Tree diversity was relatively high with a mean Shannon diversity index of 1.73 and a mean Shannon evenness of 0.70. Tree species richness was positively influenced by farm size and market distance, but negatively by elevation, number of plots within the farm and a male household head. Tree abundance was positively influenced by farm size and number of plots. Farm size, however, had a strong negative effect on Shannon evenness.

Results of this study can contribute to modify agroforestry programmes for implementing future tree planting activities for different target populations in various economic and environmental circumstances.

Keywords: *biophysical factors, Shannon diversity index, Shannon evenness, socioeconomic factors*

PP5.3.2. Agroforestry systems: an important complementary tool for biodiversity conservation in Bangladesh

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Agroforestry is a biodiversity-friendly land use practice. Agroforestry practices may vary, but their essential features are that they produce multiple products and services. Included in this output may be conservation outcomes. Interaction between agriculture and biodiversity conservation needed to be looked into in Bangladesh where the economy and people's lives are dominated by agriculture. Agriculture-land issues are bound to have impact on the future biodiversity conservation policy in Bangladesh. In Bangladesh, agricultural land use always takes place at the cost of natural ecosystem and their biodiversity. At present, due to technological advancement and developed markets for agricultural products, the impacts of traditional agriculture on ecosystems and landscapes in Bangladesh become more dramatic. Under this frightening situation, different agroforestry systems of Bangladesh like homestead agroforestry, farmland agroforestry, forestland agroforestry, char land agroforestry and social forestry can be considered as the ex-situ conservation sites by providing habitat resources for the wide range of plant and animal species. Trees and shrubs planted as the shelterbelts of southern coastal areas of Bangladesh are very functional from the biodiversity conservation point of view.

Keywords: *agroforestry, Bangladesh, biodiversity, conservation*

PP5.3.3. Soundscape and soil bacterial diversity in alley cropping, silvopasture, forest, and conventional agriculture systems

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Sustainable land use systems are critical for maintaining environmental quality, biodiversity, and for reducing the impacts of climate change. Above- and below-ground environment in different land use systems influences the different microbes and organisms in each habitat. At the same time, we can alter such environments through management and other cultural practices. An evaluation of soil bacterial diversity and soundscape diversity can provide a strong indication for the overall sustainability of any land use system. The objective of this study was to evaluate soil bacterial diversity and soundscape

diversity for alley cropping, silvopasture, forest, and conventional agricultural systems and assess the sustainability of each land use type. Replicated soil samples were taken from each land use and soil bulk density, %C, and %N were quantified. Soil bacterial diversity was evaluated through DGGE profiles created from each soil sample. Soundscape diversity was evaluated by collecting all sounds for each land use for a 3-day period. Grid sampling was conducted within each land use type to monitor and record soundscape diversity using low cost USB- Recorders (LCR). To better compare the results, a hitech H4N (Zoom) recorder was used to validate the LCRs. All sounds ranging from 20 Hz to 20 KHz were recorded. Shannon-Weiner diversity indices were calculated for both soil bacterial communities and soundscape data. Preliminary results show that both above-ground and below-ground diversity are influenced by management practices. It was observed that forest, alley cropping and silvopasture systems harbour higher ecosystem diversity compared to conventional agriculture.

Keywords: *bacterial diversity, biodiversity, cropping systems, soundscape*

PP5.3.4. Landscape trends and biodiversity dynamics of coffee agroforestry systems in the Western Ghats (India)

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The district of Kodagu in India produces 2% of the world's coffee in complex agroforestry systems nested between rice fields and forests. The development of coffee was done at the expenses of the predominantly privately or family-owned forest, 30% of which was lost over the last 30 years. However, landscape level dynamics no longer happen at the forest/farm interface as all but the smallest forest fragments or the state-controlled forests have now been converted to coffee. Today, environmental change is happening within the plantations with market incentives and technological alternatives driving farmers to more intensive modes of production. The impact of this intensification on biodiversity is difficult to document with remote sensing alone and requires intensive field data collection. Here, we present an in-depth analysis of the structure and composition of the canopy cover of the coffee agroforestry systems of Kodagu. We sampled 515 blocks randomly distributed over 114 plantations. In each block, we sampled up to 50 canopy trees (30 cm minimum gbh) following a variable area transect method. Our 20 000 trees database highlights two trends in the management of the plantations. Farmers (i) have a wide range of management practices, adjusting tree density and cover to suit their production strategy, and (ii) change the composition of the canopy, replacing the biodiversity rich canopy cover sheltering coffee plants with *Grevillea robusta*, a fast growing timber species. While these trends were suggested by previous interviews with local stakeholders, this is the first time that they are shown and quantified at the landscape level. We demonstrate how individual choices made by farmers at plot level have an impact on the distribution of biodiversity at landscape level, suggesting that interactions across scales need to be taken into account to devise efficient management strategies to mainstream biodiversity conservation in production landscapes.

Keywords: *Grevillea robusta, Kodagu, biodiversity conservation, variable area transect*

PP5.3.5. Exploring agrobiodiversity on the farm land of Sirajganj district of Bangladesh: a case from Ullapara upazila

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In the past, the conservation of biodiversity meant mostly for the management of protected areas and natural forests ignoring possible roles of farm areas and the ways rural communities promoted agrobiodiversity in their farmland. A survey of over 145 households was conducted to explore the agrobiodiversity status in the farmland of Ullapara in Sirajganj district, Bangladesh where natural and plantation forests did not exist adjacent to the study area. Respondents were interviewed on their farmlands and the trees on the farms were inventoried simultaneously. A total of 39 tree species belonging to 22 families including timber, fruits, fuelwood and multipurpose tree species (MPTS) were recorded. The most frequent species was *Eucalyptus camaldulensis* (83%) followed by *Swietenia macrophylla* (60%), *Artocarpus heterophyllus* (59%) and *Cocos nucifera* (55%). Tree density for the whole study area was $87.35 \pm 9.28/\text{ha}$ with the highest density ($151.63/\text{ha}$) on small farms (farm area < 0.66 ha) and lowest density ($51.05/\text{ha}$) on large farms (farm area > 1.32 ha). For the study area as a whole, mean value of Shannon-Wiener Index and evenness of species were 3.33 and 2.09, respectively with larger farms having the greatest tree species diversity (3.68 ± 0.19) and marginal farms having the lowest (2.96 ± 0.19). There was a strong positive correlation (Spearman's $\rho=0.334$, $n=145$, $p \leq 0.01$) between actual farm size and the species diversity. A total of five types of cereal crops and two types of common vegetables were grown in the study area. Mean production of all agricultural crops was the highest (5323.86 ± 321.09 kg/year/household) on large farms. Chicken (average 12/household) and duck (average 8/household) appeared as major livestock components. The mean value of livestock was estimated as 113702 BDT/year in large farms, which was significantly higher than that in the other three categories.

Keywords: *agrobiodiversity, natural forests, farms, tree species*

PP5.3.6. Tree dominated agriculture for environmental services and sustainable livelihoods in Sri Lanka

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With the rapid decline in forest cover in Sri Lanka, the government responded by planting exotic tree monocultures. As an alternative, the NGO, the NeoSynthesis Research Centre, has taken a community-based watershed approach turning degraded home gardens into forest gardens. Multifunctional landscape designs that mimic the structure and function of nearby native forests incorporate both native and exotic species making possible the building of soils and the protection of both water quality and availability. These gardens provide food, medicines, fuelwood, fodder, and timber. Native species are used to restore adjacent riparian areas and provide buffers separating the gardens from native forests. Three demonstrations have been evaluated based upon the preservation of biodiversity, improvements in water quality, and increased farmer incomes.

48 farms under swidden cultivation were converted to forest gardens in the Maragala Oya watershed. A comparison of the presence of bird species between the forest gardens and nearby native forests showed that the former had a greater number of species while forest plots had a higher number of endemics. Farmer income increased with pepper as the dominant crop.

In the Kalpitiya Peninsula, native vegetation was established around a well contaminated with nitrates and nitrites beyond WHO safe levels. Land surrounding the well was converted to organic management. Once a canopy formed above-ground and a dense root mat beneath, water was tested monthly for 5 years and showed a return to water safe for human consumption.

250 home gardens were rehabilitated as tree-dominated agriculture in tsunami impacted Kalmunai. 1001 micro-watersheds surrounding wells were converted to organic management protecting water quality. To protect against future disasters from the sea including raising levels, a three kilometre coastal forest buffer of native species was established. Vegetable production now provides 35% of family income.

Keywords: *restoration, tree dominant, agriculture, biodiversity*

PP5.3.7. Ecosystem processes in coffee agroforestry with multispecies vs. monospecific shade tree canopies in Coorg, south India

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Kodagu, the main coffee growing region in India lays in the Western Ghats – one of the eight hottest biodiversity hotspots worldwide. Kodagu coffee is traditionally grown in highly diverse agroforestry systems. Therefore the region still provides a refuge for many animal and plant species. But the agroforestry system faces transformations: native shade trees are replaced by *Grevillea* spp., a marketable fast-growing exotic timber species. Moreover, nutrient inputs are increased while organic production becomes less attractive due to increasing labour costs. These multifarious changes are expected to lead to a major loss of biodiversity and might also impact the long-term sustainability of coffee production.

We compared multiple ecosystem services (nutrient cycling, resilience to climate change, pollination, coffee production) in coffee agroforestry systems with different shade tree mixtures as well as management systems (organic, conventional). We present first data on different aspects of nutrient dynamics: i) standing litter, ii) soil macro- and micronutrient availabilities; and iii) coffee fruit set. We included 27 farms, of which 10 were organic – multispecies shade tree systems (organic stands), 9 were conventional – multispecies shade tree systems (native stands) and 8 were conventional – *Grevillea* spp. shaded systems (*Grevillea* stands).

First results indicate that standing litter is higher in native and organic than in *Grevillea* stands. Soil pH, organic matter content, and micronutrient availabilities tend to be lowest in *Grevillea* stands; while fruit set did not differ in the three stands. These results highlight the importance of understanding the interactions of shade tree diversity and management systems in coffee agroforestry. Analyses currently in progress will improve our understanding of trade-offs between long-term maintenance of ecosystem services such as nutrient cycling and maximization of coffee production.

Keywords: *biodiversity, coffee agroforestry, nutrient cycling, shade tree management*

PP5.3.8. Small landholder agroforestry: contributions to ecosystem services in M M Hills Wildlife Sanctuary, South India

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We surveyed 90 landowners in 13 villages in the Malai Mahadeshwara Hills Wildlife Sanctuary to better understand the role of agroforestry in traditional south Indian farms in forest landscapes. The average landholding is 2.96 acres and agriculture is dominated by the production of finger millet (*ragi*), beans (*avare*), brown mustard (*sasive*) and maize (*jola*). Small farmers play a significant role in biodiversity preservation by protecting and planting native and economically important tree species on their properties. We found a total of 1514 trees of 137 species on the agroforestry land of these farmers. The number of trees per property ranged from 1 (7 landowners) to 142 (1 landowner) with about half (48%) of the landowners maintaining 9 or more trees on their property. Home or kitchen gardens also play an important role in the incorporation of trees into the landscape, accounting for approximately 10% of the abundance and one-third of the diversity of tree species. Small landholder agroforestry systems also represent a notable contribution to carbon sequestration. We found a mean basal area of 795.0 cm³ wood/farmer or 268.6 cm³/acre preserved through traditional farming methods. Using a general allometric model, we roughly calculate that each farmer preserves an average of 1944 kg of wood biomass, or about 970 kg of sequestered carbon.

Keywords: *biodiversity, carbon sequestration, smallholder farmers, south India*

PP5.3.9. The effects of agroforestry on pest control and soil health: results from a meta-analysis

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A growing number of scientific studies have investigated how agroforestry influences various ecosystem services of importance for on-farm productivity. We are currently conducting a quantitative synthesis of work that has explored the effects of agroforestry on two services of critical importance for smallholder farmers in the humid tropics: pest control and soil health. To synthesize the results from the different studies we use a meta-analytical approach. This enables us to combine effect-sizes reported in individual studies into an estimate of overall strength of the effect. We are investigating the impact of a range of agroforestry practices including shade tree planting, alley cropping and improved fallows and the effects they have on various indicators of the two ecosystem services. For pest control this includes, for example, abundance of arthropod pests, pathogens, weeds and crop damage, and for soil health, e.g. available N and P, soil structure, erosion and infiltration. This paper presents results of the quantitative synthesis, the implications for future research and development and formulation of evidence-based policy for the up-scaling of agroforestry in the humid tropics.

Keywords: *biological control, meta-analysis, quantitative synthesis, soil health*

PP5.3.10. Wild edibles in indigenous agroforestry system: a case of Attappady Valley, southern Western Ghats

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Agroforestry is a system that applies management practices, which combine agricultural crops, tree crops and natural vegetation as well as animals that are compatible with cultural patterns of the local population. Edible wild plants in the mountain agroforestry system are often the source of emergency food and nutrient supplements in the day-to-day life of forest dwellers and indigenous communities. In the Western Ghats hill ranges, agroforestry systems where trees are grown with crops and animals also encompass rich home gardens. Attappady is one of the two extensive east sloping plateaus on the Western Ghats of Kerala. Three different ethnic groups, viz. Kurumbas, Irulas and Mudugas are living in 187 settlements across different altitudinal and rainfall zones of Attappady besides two settler communities. The present study is a preliminary attempt to document the wild edible diversity found in the agroforestry systems of three different tribal communities of Attappady valley. The paper is based on field observation, discussions with key tribal informants and also from relevant literature. A total of 97 species of wild edible plants belonging to 49 families were recorded from homestead gardens, agricultural fences and avenues of tribal hamlets. The dominant families are Dioscoreaceae followed by Amaranthaceae and Solanaceae. Habit-wise trees and herbs are the dominant category among the species. However, factors such as changing land use, government policies and agricultural practices significantly alter the diversity of wild edibles, transfer of traditional knowledge and prevalence of usage among the tribal communities. Thus the paper highlights the diversity and potential benefits of least concerned agroforestry components in the livelihood of indigenous communities as well as global food security.

Keywords: *agroforestry, food security, Western Ghats, wild edibles*

PP5.3.11. Regeneration of important tree species in community forests of the Khasi Hills, Meghalaya: does management matter?

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We assessed the regeneration of locally important tree species in forest patches under different ownerships in the Khasi Hills, Meghalaya. We found that ownership, and therefore management systems, play an important role in sustaining key tree species for local livelihoods. The livelihood of the Khasis, an indigenous tribe living in the Khasi Hills of Meghalaya, depends to a great extent on their forests for a variety of goods such as fuelwood, timber, food, and marketable items. Mawlyngbna, the case study village, is located on the southern slope of the East Khasi Hills in Meghalaya at an altitude of 800m. The village community manages 612 ha of tropical semi-evergreen forest under different traditional management systems: (i) patches under single family household and (ii) patches under the direct control of the village judiciary court. A scoring method was applied in congruence with forest uses to assess the importance of forest patches under different forest management and tree species utilised. The main stand, middlestorey, and regeneration of trees have been assessed with plots for each management system with a nested plot design. We found a significant difference in the composition and structure between management systems. Due to various disturbances, such as fire, grazing, fuelwood and non-timber forest products (NTFP), collection and tree harvesting, the forests under single family household management are more disturbed than the

community reserved forest and showed lower species diversity. We discuss the challenges and options of community-based managed forest in Meghalaya and conclude that sustainable forest management needs to be implemented in order to provide livelihoods for future generations.

Keywords: *community-based forest management, livelihood, NTFPs, tree structure, tree regeneration*

PP5.3.12. Importance of remnant forests and native shade trees in coffee agroforests for coffee pollination and fruit-set

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Conversion of forests to crop lands has resulted in a landscape mosaic of forest fragments interspersed among various types of agricultural lands and human settlements worldwide. Forest fragments in agricultural landscapes are recognised to provide a variety of ecosystem services, several of which benefit neighbouring agricultural land uses. In a landscape mosaic with a high density of remnant forests dispersed within a largely coffee-agroforestry matrix, we explore the role of forest fragments in harbouring pollinators that enhance coffee fruit-set and the landscape attributes that influence the abundance of pollinators.

Pollination by insects improved pollination success and increased fruit-set by 50%. Three social bees, *Apis dorsata*, *Apis cerana* and *Tetragonula iridipennis* accounted for 95% of all insect visitors. *Apis dorsata*, the wild bee which accounted for 58% of the floral visitors, preferred to nest in larger remnant forests. Flowering in coffee is initiated annually by either irrigation or rain. Irrigation, which stimulated flowering of individual agroforests independently of others, resulted in a dramatic increase in pollinator visits, which was also reflected in higher fruit-set. Flowering at a landscape scale following rain led to a dilution of pollinators across the landscape following a lower fruit-set. The size of the adjoining forest fragment and the availability of alternative floral resources influenced pollinator visitation, pollination success and fruit-set, and the extent of flowering within the landscape determined the direction of the effects. This study emphasises the importance of wild pollinators, remnant forests, extent of coffee and non-coffee (native shade trees) flowering in coffee pollination and fruit-set.

Keywords: *coffee agroforestry system, native shade trees, pollination services, remnant forest*

PP5.3.13. Necessity of agroforestry system to sustain the use and conservation of *Mimusops andongensis* Hiern in Benin

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Mimusops andongensis is a multipurpose species which the wood is used for construction, to produce charcoal and as firewood. Its bark, roots and leaves are used for local healthcare needs, fruits and bark for alimentary uses. This use, together with habitat destruction, limits its availability for rural dwellers and its population conservation. We assessed the population viability of the species in Lama Protected Forest (its main habitat) with different human pressure levels using structural characterization, to

highlight the necessity to grow it in agroforestry system. Dendrometric characteristics and diameter size distributions were assessed through forest inventory. Adult trees were found in 92% of plots in non-degraded forest, in 71% in degraded forest and in only 7% in preforest fallow. Tree-density (in stems/ha) in non-degraded dense forest (42.7 ± 35.0) is 2-23 times higher ($p < 0.001$) than in degraded dense forest (23.1 ± 39.02) and preforest fallow (1.8 ± 7.79). Similar trend was obtained according to the regeneration density (106.2 ± 117.3 , 83.5 ± 140.0 and 17.0 ± 74.0 stems/ha respectively). Diameter size distributions were positively asymmetric showing relative dominance of young or small diameters individuals in non-degraded and degraded dense forests while in preforest fallow, it was similarly exponentially declining indicating a population in extinction. The low density of sexually mature trees accompanied with low regeneration in degraded forest and preforest fallow may negatively impact the long-term viability of the species, despite protecting the forest to prevent products harvesting. Thus, vegetative propagation tests will help to grow the species in agroforestry system, to sustain its use by local communities and its conservation.

Keywords: agroforestry importance, anthropogenic pressure, *Mimusops andongensis*, population viability

PP5.3.14. Effect of shade on efficiency of bio-fertilizers in important rainy season pulse crops of Central India

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Factorial experiments were conducted in important rainy season pulse crops of Central India namely, *Glycine max*, *Phaseolus mungo* and *Vigna radiata*, to study the effect of shade (25%) on efficiency of bio-fertilizers, when applied along with recommended dose of chemical fertilizers under net-house conditions. Each experiment consisted of four factors viz., shade, arbuscular mycorrhizal fungi (AMF), rhizobium and phosphate solubilizing bacteria (PSB), each at two levels: shade (0 and 25%) and bio-fertilizers (applied and not applied). Thus, in each experiment, 16 treatments were employed with four replications. Recommended dose of chemical fertilizer (di-ammonium orthophosphate; DAP) was applied in all treatment combinations. Shoot length was significantly increased by shade in all studied pulses. It was significantly higher in all bio-fertilizer based treatment combinations viz., AMF, rhizobium, PSB, AMF+rhizobium, AMF+PSB, PSB+rhizobium and AMF+rhizobium+PSB, in *G. max*, and the values were comparable in *P. mungo* and *V. radiata* in different treatment combinations. Dry weight was significantly reduced by shade and most of the bio-fertilizer based treatment combinations increased it in all pulses, with few exceptions. Flowering and pod formation started earlier in open. Creeping behaviour was recorded in *P. mungo* under shade. Yield was adversely affected by shade and bio-fertilizer based treatment combinations significantly increased it in *P. mungo* and *V. radiata*, but not in *G. max*. Shade significantly increased nodulation and it did not affect root colonization by AMF. In general, efficiency of bio-fertilizers was more in open as compared to shade and their application along with chemical fertilizer (DAP) is likely to increase the growth and yield of studied pulses in open as well as in shade in agroforestry systems.

Keywords: agroforestry, bio-fertilizers, integrated nutrient management, pulses, shade

PP5.3.15. Dry afromontane forest tree species effect on leaf litter production, nutrient status and decomposition rate

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The study investigated litter fall production, nutrient content and rate of decomposition of abscised leaves of *Carissa edulis*, *Juniperus procera*, *Mytenus obscura*, and *Olea europaea*. Abscised leaves were collected using litter trap and evaluated by the litter-bag method. A total of 192 litter bags measuring 10 x 15 cm and 2 mm mesh were installed in a randomized complete block design and collected monthly for 8 months. Carbon (C), Nitrogen (N) and Phosphorus (P) were analysed monthly. Leaf of *Juniperus procera* had significantly higher C ($P<0.05$) but lower N, P and K than the leaf of the other species. N concentration was the highest in *Carissa edulis* and was significantly different ($P<0.05$) compared to the other species. *Carissaa edulis* had higher N, P and K but low C content. The highest leaf mass loss (27%) was observed in *Carissa edulis* followed by *Mytenus obscura* (22%). The mass loss for *Juniperus* species was only 9%. The highest litter fall production was obtained from *Juniperus procera*. The highest initial N, P, K levels was found in *Carrisa edulis* whereas the lowest was found in *Juniperus procera*. The fastest litter decomposition rate was observed in *Carrisa edulis* whereas the lowest was found in *Juniperus procera*. High lignin, lignin: N and C: N was found in *Juniperus procera* followed by *Olea europaea* while they were low in *Carissa edulis*. The rate of decomposition of *Juniperus procera* leaves was slower than the other three species. The slower decomposition rate of *Juniperus procera* leaves could be due to the presence of higher lignin, lignin: N and C: N contents than in the other species. This study suggests that, we can use the litter fall of *Carissa edulis* for chemical fertility maintenance while the leaves of *Juniperus procera* could be used as mulch to prevent erosion.

Keywords: leaf litter, litter decomposition, litterbags, nutrient, *Carissa edulis*, *Juniperus procera*, *Mytanus obscura*, *Olea europaea*

5.4 Agroforestry in dry and degraded lands

PP5.4.1. Factors influencing the adoption of farmer managed natural regeneration in the Sahel Frank Place^{1*}, Joachim Binam², Bayo Mounkoro³, Moussa Boureima⁴, Hamade Sigue⁵, Mouhamadou Diop⁶

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Although evidence from remote sensing images shows that there has been increased tree cover on farms in the Sahel, little is known about why patterns of natural regeneration vary across villages and households. This study draws upon data collected from more than 1000 households in 50 villages across Niger, Burkina Faso, Mali and Senegal in 2011. The data includes a detailed inventory of trees found on farms – by species, stem diameter and number. This enables a set of quantitative and qualitative ‘adoption’ variables to be defined and tested. Explanatory variables are both at village level (e.g. rainfall, access to market, type of parkland) and household level (e.g. land and labour resources, education and access to information, wealth characteristics). Following the different dependent variables, econometric models were used to estimate the effects of the explanatory variables. Coupled with this were a set of 40 focus group surveys conducted in all countries which probed the reasons why farmer-managed natural regeneration varied among villages and among households within villages. Results from regressions on the density of new trees regenerated found that it is often farmers with higher densities of older trees who also regenerate new ones. Interestingly, densities were higher in villages located further from formal markets. Apart from Burkina Faso, many factors were not significant indicating that regeneration of trees is a practice which is equally attractive to all types of

households. Households also identified institutional and policy constraints such as the unreasonable forest codes (mentioned by 44% of households), heavy-handedness on the part of forest officers (38%), uncontrolled cutting of trees (31%) and animal damage (28%).

Keywords: adoption, parklands, regeneration, Sahel

PP5.4.2. Boundary tree planting in maize-based system for improved crop yield and wood supply in Dodoma, Tanzania

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Boundary tree planting is one of the appropriate technologies for on-farm wood production to address land and forest degradation problems in arid and semi-arid areas. However, little is known on the optimum spacing and interactions of boundary trees with nutrient management options to enhance farm productivity. Two split-plot experiments, one for *Acacia polyacantha* and another for *Eucalyptus camaldulensis*, were established to assess the effects of spacing and pruning of boundary trees and nutrient inputs (intercropping of maize with *Tephrosia* and/or pigeon pea, fertilizer, and cattle manure) on yields of wood, maize, and pigeon pea. After 24 months, diameter at breast height (DBH) and crown size of trees did not vary with spacing indicating absence of intra-specific competition. *Eucalyptus camaldulensis* doubled DBH (4.4 cm) and wood yield (4.4 Mg/ha) compared to *A. polyacantha*. Wood yield was the highest at 2x2m (4.4 Mg/ha versus 7.7 Mg/ha). This amount can satisfy the household fuelwood demand for 1.4 to 2.5 years, substantially reducing harvesting pressure on native forests. Pruning branches of *A. polyacantha* increased maize and pigeon pea yields, reflecting reduced competition for above-ground resources. Corresponding yields for *E. amadulensis* were unaffected by pruning, possibly reflecting below-ground competition by tree roots. Maize yield at 1m (0.50 to 1.16 Mg/ha) was significantly lower than yields at 3m and 6m (0.62 to 1.32 Mg/ha) from the boundary. This implies that below-ground competition limited crop growth closer to the tree row. Fertilizer and manure additions enhanced soil nutrients; maize and pigeon pea yields compared to intercropping and control treatments. Root pruning, which may be labour intensive, is not necessary within 3 years after planting since planting crops 3m from border trees may reduce inter-specific competition. This study demonstrates the potential for boundary tree planting and integrated nutrient management approaches in improving crops and wood yields.

Keywords: acacia, pigeonpea, semi-arid, tree-crop interactions

PP5.4.3. Two decades of prescribed burning did not affect soil organic carbon in Sudanian savanna- woodlands of West Africa

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With an increasing threat of climate change in ecosystem functioning, soils are taken as important storages of carbon to mitigate the adverse impacts of climate change. Fire is often considered as having

a negative impact on carbon dynamics in view of emerging climate change mitigation agendas. However, fire has been used as an important management tool in African savanna and grassland systems for both livestock herders and wildlife managers who use it regularly to control bush encroachment and to remove dead and dying vegetation that has low forage quality and is unpalatable to animals. The long-term effect of fire on SOC under free grazing and controlled grazing management systems in the savanna woodlands of West Africa is poorly documented. In this study we examined effects of 19 years (1992-2011) of exclosure and annual prescribed burning on SOC in two sites in Sudanian savanna ecosystems of Burkina Faso. The overall mean (\pm SD) of SOC stocks in the study area were 22.95 ± 7.81 and 23.07 ± 10.81 for top (0-20 cm) and sub-soils (20-50 cm), respectively. Although regular burning has been reported to have consistent long-term negative effect on SOC in grassland soils, we found no significant difference in SOC concentration between burned vs. unburned and closed vs. open plots in both sites. The result can be partly explained by the fact that the study area is dominated by perennial grass species (*Andropogon gayanus* and *Dieteron amplexans*) and that fire burned the above-ground biomass reducing the litter inputs into the soils while it encourages the turnover of root materials. The result suggested that exclosure does not increase and on the other hand burning did not reduce the carbon sequestration potential in savanna ecosystems as expected. Projects targeting at mitigating climate change in dry savanna ecosystems should thus reconsider maintaining the traditionally used prescribed fire as a management tool.

Keywords: exclosure, prescribed-burning, savanna ecosystem, soil organic carbon

PP5.4.4. Indigenous and exotic tree species richness and diversity in homegardens of the Nuba Mountains, Sudan

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Traditional agroforestry homegardens with their high levels of agrobiodiversity could be suitable for *circa situm* conservation of plant genetic resources (PGR). Despite their importance in sub-Saharan Africa, woody plant species richness and diversity of traditional homegardens in semi-arid and arid regions are poorly understood. Furthermore, richness and diversity may be threatened by recent, fast evolving agricultural transformation processes such as commercialisation, which may also occur in the traditional ‘jubraka’ homegardens of Sudan.

61 homegardens in four villages of the Nuba Mountains, South-Kordofan, Sudan, were randomly selected, useful woody plant species identified, individuals counted and diversity indicators calculated. Socioeconomic household data were assessed by interviews and homegardens grouped in subsistence (no sale of products) and commercial homegardens. Statistical analyses included non- parametric tests, and cluster and discriminant analyses.

A total of 53 useful woody species were grown in the homegardens plus 27 woody ornamental species. 18 species were predominantly used as fruit trees, including 12 indigenous and six exotic species. Mean richness of woody species (excluding ornamentals) per homegarden was 6 (range 1-17), of which 26% were exotic species (range per village 15-42%). Mean diversity and evenness indices were 1.32 (range 0 (only one woody species)-2.45) and 0.80 (range 0-1), respectively. Commercial homegardens had similar species richness and diversity indices as well as similar shares of exotic

individuals than subsistence homegardens. Cluster analysis based on plant composition revealed two garden types; 13 species were mainly responsible for cluster formation. One cluster including almost all gardens of the most remote village were characterised by slightly lower species richness, including indigenous fruit trees, and higher proportions of indigenous species ($P < 0.05$).

The assumed negative effects of commercialisation on woody species richness and diversity were not confirmed. The role of homegardens for *circa situm* conservation of PGR should be strengthened by promoting cultivation of indigenous species.

Keywords: *circa situm* conservation, commercialisation, genetic resources, indigenous fruit trees

PP5.4.5. Productivity and nutrient cycling in Acacia lenticularis (L.) Willd based agrisilvicultural systems in eastern India

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Acacia lenticularis (L.) Willd, popularly known as ‘chah’ is a leguminous multipurpose fast growing tree species primarily grown in the northwest alluvial plain of Bihar for fuelwood, fodder and timber with a rotational period of 15 to 20 years. The study was carried out in 15-year-old *A. lenticularis* plantations of density 626 trees/ha at spacing of 2x8m and 1000 trees/ha at spacing of 2x5m established at the Research Farm, Rajendra Agricultural University, Pusa, Samastipur, Bihar. The plantations were intercropped with turmeric (*Curcuma domestica* VAL.) local cv. ‘Rajendra Sonia’. The standing biomass of 15-year-old trees in high density plantation was higher (61.2 Mg ha⁻¹) than that of lower density (44.5 Mg ha⁻¹) plantation. Total vegetation biomass including turmeric was also higher in high density plantation (74.4Mg ha⁻¹) than that of low density plantation (58.9Mg ha⁻¹). Irrespective of the density of the plantation, the biomass of different components was in the following order: stem wood > roots > branches > foliage. Relative contribution to total nutrient content in the different tree components was in the order: bole > branch > root > foliage. The high density plantation-based agroforestry system showed greater nutrient extraction efficiency from soil. The amount of nutrients that returned through litterfall to the soil were distinctly greater in the high density plantation. Of the annual nutrient uptake, 67% N, 48% P and 55% K returned to the ground through the leaves, twigs, roots and crop residues by the high density agroforestry system, whereas, 57% N, 40% P and 41% K returned to the ground by the low density agroforestry system. The turnover rates of nutrients (N, P, and K) on the plantation floor were 0.86 (high density) and 0.90 year⁻¹ (low density). Total nutrients release through litter and roots were 60% N, 42% P and 44% K of the total uptake by the high density agroforestry system, while 52% N, 35% P and 36% K of the total uptake by the low density agroforestry system. About 32-41% N, 46-57% P and 53-58% K of the total nutrient uptake were lost from the system in the harvest of turmeric. This study showed that the nutrient return through litterfall and fine roots under both the low and high density plantations almost balanced the removal of nutrients in turmeric harvest. Hence, the *Acacia lenticularis* based agrisilvicultural systems are sustainable in terms of maintenance of nutrients status in soil.

Keywords: *Acacia lenticularis*, biomass, nutrient cycling, turmeric

PP5.4.6. Converting threat to opportunity: the utilization of pods of Prosopis juliflora, an invasive species as a replacement of concentrated feed

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This study was conducted to determine the level of replacement of concentrate feed (maize, cotton seed cake and wheat bran) by dried ground *Prosopis juliflora* (PJP) on feed intake, live weight gain and carcass parameters of local goats. 20 male weaner goats of similar age (6 - 12 months), and weight (11-15 Kg) were used in randomized complete block design experiment with five dietary treatments. The treatment groups were from no PJP+100% concentrate mix to 40% PJP+60% concentrate mix. Data on feed intake and live weight gain were recorded daily and weekly, respectively, for 90 days. At the end of the experiment, three sample goats from each treatment were slaughtered and different carcass components were weighed. The chemical composition of PJP: 88.30% dry matter (DM), 12.58% crude protein (CP), 19.51% crude fiber (CF), 1.91% ether extracts (EE) and 1.92% ash. The total DMI, CPI, EEI and CFI of T1 and T2 were significantly different among the treatment. No significant difference was observed in BWG and FCE between PJP supplemented and non-supplemented treatment groups. No differences were observed among treatment groups with respect to fasting live weight, carcass and non-carcass components, hot carcass weights, dressing percentages, and commercial meat cuts, edible and non-edible offals ($P > 0.05$). There was also no difference on carcass composition with the same feeding regime ($P < 0.05$). The present study indicated that the possibility of replacing PJP for concentrate feeds up to 40% in goat diets without effect on growth performance and carcass characteristics and measurements. Besides, replacement of concentrate feed by GPJP up to 10% seems economically feasible. Owing to its positive effect on goat productivity, farm profitability and positive role in controlling the invasion of *P. juliflora*, the use of pods from this species should be considered in further research and development.

Keywords: goats, *Prosopis juliflora* pods, body weight gain, feed intake, carcass parameter

PP5.4.7. Short-term improved fallow using forest and multipurpose tree species as a solution for soil degradation in coconut plantations

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This study was designed to investigate the possibility of improving degraded soils due to long-term cultivation of coconut (though short/medium term improved fallow) and to screen out the effective perennial species in revitalizing soil properties. The experiment was conducted in Rathmalagara estate, Madampe belongs to Andigama soil series in low country intermediate zone (IL1 agro-ecological region) including eight forest tree species namely *Acacia auriculiformis* (Acasia), *Calophyllum elatum* (Domba), *Macaranga paltata* (Khanda), *Acacia mangium* (Acasia), *Gliricidia sepium* (Gliricidia), *Swietenia macrohylla* (Mahogany), *Bridelia moonii* (Ketakala), *Tectonia grandis* (Teak). Soil physical, chemical and microbiological properties were determined in surface and sub-surface soil to compare the effectiveness of eight tree species. Results showed the potential of perennial tree species on soil organic matter (SOM) accumulation, indicated by the significantly ($p < 0.05$) higher mean differences (1.12%) of SOM compared to control (0.22%). Highest SOM content (1.86 %) was observed in *G. sepium* planted plots. Soil total nitrogen (TN) content was higher in plots with legume trees compared to non-legume trees, while highest TN (1.48 g.kg⁻¹) was in *A. auriculiformis* plots. Exchangeable potassium was significantly low in plots with perennial trees

compared to control. Significantly high microbiological activities confirmed the symbiotic association of tree species and soil microbes and highest activity ($128.5\text{CO}_2 \mu\text{g}^{-1}$) was observed in *A. auriculiformis* plots. These findings may be the first that provide preliminary evidence for Andigama soil series that confirms the effectiveness of *A. auriculiformis* and *G. sepium* in revitalizing the soil properties of degraded coconut lands using improved fallows.

Keywords: coconut, soil degradation, forest plant species, improved fallows, *G. sepium*, *A. auriculiformis*

PP5.4.8. Productivity improvement in guava based agrihorticultural models through canopy management and mulching under rainfed bouldery riverbed lands

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The study on “Productivity improvement in guava based AHM through canopy management and mulching under rainfed bouldery riverbed lands” was started in 2008 at CSWCRTI, Research Farm, Selakui, Dehradun. There were four levels of canopy management, three levels of mulch as well as four levels of plant density with crop rotations. These were laid out in SPD replicated thrice. After four years of experimentation, maximum canopy spread (3.48 m) was observed in normal plant density (277 plants ha⁻¹) of guava bush managed with 8, 6, 4 and 2 numbers of shoots plant⁻¹ under sunhemp mulch in sunhemp-toria crop rotation as compared to high density plantation (555 plants ha⁻¹). Moisture conservation was 15.6% more in high density plantation of guava managed with 8 shoots plant⁻¹ under sun hemp mulch and green manuring treatment as compared to normal plant density or low density plantation (277 plants ha⁻¹) with 2 shoots plant⁻¹, unmulched and fallow- toria crop rotation, respectively. The average yield of guava 10.0 kg tree⁻¹ (5.6 t ha⁻¹) was recorded under high density plantation with sun hemp mulch at 24.5% higher than normal plant density (277 plants ha⁻¹) during 2011 – 2013. Though maximum marketable yield of guava was harvested (12.5 kg tree⁻¹) with 4 shoots plant⁻¹ with 60 cm shoot length under sun hemp mulched trees in normal density than the high density. The optimum marketable fruit size (70.0 g) was harvested from guava plants trained with 4 and 6 shoots plant⁻¹ under both plant densities. Sunhemp mulch improved fruit yield of guava by 10.4% and 19.2% as compared to weed mulch and control treatment, respectively. Maximum grain and stover yield of toria (510 and 870 kg ha⁻¹) and green biomass of sunhemp (1500 kg ha⁻¹) has been recorded in normal plant density with green manuring treatment as compared to 430 and 550 kg ha⁻¹ grain yield and biomass, respectively under fallow – Toria crop rotation. The sunhemp green manuring increased grain yield by 18.5% over fallow treatment.

Keywords: agrihorticultural models, degraded riverbed lands, in-situ moisture conservation, rainfed production system

PP5.4.9. Tree-crop interaction in rejuvenated Ziziphus mauritiana based agri-horti system: component yield and system productivity

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The *ber* is a multipurpose species of arid landscape supplying fruits, fodder, fuelwood and fencing and

could find place in every farming system of the region as an agroforestry component without any constraints. However, over time, productivity of trees started declining because of aging, poor orchard management, biotic stress, old seedling plantation etc. An attempt has been made at CAZRI Jodhpur, Rajasthan, India to rejuvenate a 33-year-old *ber* orchard. Trees were headed back from ground level in June 2011. Numerous shoots emerged after 12-15 days. 1-2 shoots were budded with early, mid and late season's cultivar Gola, Seb and Umran, respectively. In the next year, intercropping was carried out in the *ber* alleys. The treatments consisted of two intercrops with *ber* viz. greengram and pearl millet, two alleys spacing i.e. 6 m and 12 m (plant to plant spacing in both the alleys was 6 m) tested over three *ber* varieties viz. Gola, Seb and Umran.

During the second year, average fruit yield of rejuvenated *ber* under 6m x 6m spacing + greengram was 47.6% higher over 12x6 m spacing of *ber* + greengram while under pearl millet the yield increment for *ber* was 46.5% with respective yield of 11.4 and 9.5 kg tree⁻¹. Contrarily, the yield of intercrops of greengram (31.1%) and pearl millet (11.0%) was higher under 12m x 6 m spacing with respective yields of 666 kg and 556 kg ha⁻¹ under 6m x 6m spacing. Total system productivity was recorded highest (63.84 qha⁻¹) in *Ber*+ greengram under 6m x 6m and lowest in *Ber*+ pearl millet under 6m x 12m spacing. Overall, system productivity in terms of *ber* equivalent yield was higher under 6m x 6m spacing than 6m x 12m. Amongst the varieties Gola registered higher yield (21.3kg/tree) and total system productivity (86.76 q ha⁻¹) irrespective of spacing and intercrops. A negative effect of *ber* on intercrops yield was seen up to two metres radial distance from the bole of trees.

Keywords: *rejuvenation, Ziziphus mauritiana, total system productivity, agrihorti systems*

PP5.4.10. From Sahara to Congo River, combining assisted natural regeneration and land tenure security to improve slash-and-burn

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Slash-and-burn agriculture (S&B) is the leading factor behind the degradation of tropical forests and represents an ecological and economic dead end. Many authors have noted that this system is very difficult to improve without the support of public policy. In dryland Africa, especially in Niger and northern Cameroon, grants funded by projects and through levies on profits from bundled cotton sales have made it possible to support the conservation of young trees on fields when fallows are cleared and during weeding. This Assisted Natural Regeneration (ANR) support policy was promoted by the state corporation responsible for the development of cotton crops and was accompanied by a delimitation and demarcation of fields. From 1990 to the present, this policy has resulted in the conservation of over one million *Faidherbia albida*, and, in so doing, the expansion and densification of agroforestry parklands.

In the equatorial wetland, of D R Congo, the experience is much more recent. Simple Management Plans of village territories were put in place since 2010 to secure rural land tenure. ANR methods have also been promoted to conserve young trees growing spontaneously in cultivated fields, after S&B, when fallows are cleared and during weeding. In areas where environment was too degraded, leguminous trees have been planted using taungya method. Trees conserved or planted improve fallow

productivity in terms of firewood and other forest products, accelerate the restoration of soil fertility and block the invasion of savanna pyrophytic vegetation, before a new 'slash-and- charcoal' cycle. Over 150 farmers have used ANR and 1700 ha of *Acacia auriculiformis* have been planted.

The use of simple techniques requiring little labour or inputs, associated with land tenure security policies, allows a gradual transition from S&B to more productive and sustainable agroforestry systems (parklands in the Sahel and improved fallow in forest areas).

Keywords: *assisted natural regeneration, improved fallow, land tenure, parklands*

PP5.4.11. Performance of high yielding provenances of bhimal (*Grewia optiva*) along with field crops in North West Himalayas

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Grewia optiva Drummond (bhimal) is one of the most important fodder trees of north western and central Himalayas up to an altitude of 1800m, grown on terrace risers with field crops. It is a medium size tree and provides nutritious leaf fodder during lean winter months when no other fodder is available. Based on a composite index of growth and productivity parameters, three most vigorous provenances of bhimal viz. I.C. Bhaintan, I.C. Chamba and I.C. Malas were identified in studies during 1995-2005 at Dehradun. The study was extended from 2006-2012 with the objectives to: (1) monitor the performance of high yielding provenances of bhimal with respect to green fodder and dry fuelwood production on farmers' fields at different locations (middle hill elevations and valley zones); and (2) monitor the productivity of various field crops in the under storey of bhimal trees at different locations. Marked differences in growth parameters in respect of mean annual increments and current annual increments were observed at valley locations (500m) and middle elevations (1300-1700 m asl). After six years of planting, average plant height at valley locations was 359.8 cm while it was 327.6 cm at middle elevations and collar diameter at middle elevations was 4.77 in comparison to 5.71 cm at valley locations. The average fresh fodder and dry fuelwood productivity was 0.189 and 0.235 Kg plant⁻¹ at middle elevations after six years while it was 0.522 and 0.407 Kg plant⁻¹ respectively at valley locations. In valley locations IC Bhaintan recorded the highest fodder yield of 0.602 Kg plant⁻¹ followed by IC Chamba at 0.503 Kg plant⁻¹. At middle elevations IC Chamba recorded the highest fodder yield at 0.222 Kg plant⁻¹ followed by IC Malas at 0.187 Kg plant⁻¹. The reduction in maize grain equivalent yield at valley locations ranged from 17.7 to 44.0% upto 4m from the tree line while this reduction was 6.2 to 27.3 in middle higher elevations after six years of planting.

Keywords: *bhimal, agroforestry, green fodder, field crops, multilocations*

PP5.4.12. Changes in soil and herbaceous plant community properties after establishment of shrubs in a hot arid region of India

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Desertification is one of the major threats to the sustainability of agriculture and economic development; and vegetation restoration is one of the most effective ways to combat desertification. *Haloxylon salicornicum* and *Calligonum polygonoides* are native shrub species in a hot region

of India, and provide fodder and fuelwood. We assessed effects of establishment of these species on soil and herbaceous plant community properties after 7 years of planting. Soil samples were taken at two depths (0 – 5 cm and 5 – 20 cm) from three sub-habitats, i.e. under the shrub canopy (UC), alleys between shrub (SA) and open area (OA) in 2012. The establishment of shrubs improved soil texture, enhanced water holding capacity, soil organic carbon (SOC), available N (AN), and available P (AP), and decreased bulk density. Compared to open area, the surface soil (0 – 5 cm) beneath shrub canopies had 0.36 to 0.53 mg g⁻¹ higher SOC, 11.5 to 17.2 mg kg⁻¹ higher AN, and 1.4 to 1.8 mg kg⁻¹ higher AP. The improvement in soil properties was larger under UC than SA, at the surface (0 – 5 cm) than at deeper layer (5 – 20 cm), and under the *H. salicornicum* than under *C. polygonoides*. The establishment of shrubs increased density (plant m⁻²), and biomass productivity (g m⁻²) of herbaceous plants. Compared to open area, the density and biomass productivity of herbaceous plants in alleys of shrubs were 13 – 21 % and 42 – 56 % higher, respectively. The density and biomass productivity of herbaceous plants were higher under *H. salicornicum* than under *C. polygonoides*. The results of the experiment suggest that establishment of these species improves soil properties and facilitates development of the herbaceous plant community. The establishment of these shrubs thus could restore desertified land, and augment supply of fodder and fuelwood in hot arid areas of India.

Keywords: arid region, shrub effects, soil properties, herbaceous plant

PP5.4.13. Utilization of riverbed lands through tree canopy management in silvipastoral system of western Himalayas, India

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The area reported to be degraded in various forms in India is 114.01 mha. It is estimated that the demand for green and dry fodder will be twice the present availability in the next two decades. In the foothills of the Himalayas, a large area (2.73mha) categorized as bouldery wastelands formed due to the deposition of coarse soil-forming material. An attempt has been made to establish silvipastoral systems on these degraded lands.

A study (1996-2010) involving *G. optiva* with *Panicum maximum* and *Chrysopogon fulvus* was carried out at the Institute's research farm, Dehradun. Soil profile is predominantly dominated by gravels and consists of 74% boulders. The climate of the experimental area is sub-tropical with an average rainfall of 1600 mm. Year-old tree seedlings were planted in pits (45cm³) at 4m x 4m spacing while grass slips were planted at 0.75m x 0.75m spacing. Tree canopy was managed (lopping, pollarding and coppicing) after 5 years of establishment.

Results indicated that maximum green leaf biomass (2.1t/ha) and firewood (4.9t/ha) was obtained from pollarded trees with grass and this combination yielded the highest biomass (20.5t/ha) among all combinations and was followed by lopped *G. optiva* with *P. maximum* (16.8t/ha).

A dynamic approach to tackle the problem of fodder and feed scarcity must consider how best to utilize the given area which suffers from poor soil fertility and moisture deficit. In such situations, when forage production is of prime concern, a composition of forage plant types which are complementary and not competitive to each other in growth behaviour and yield potentials along with an ability to fulfill nutritional deficiencies in livestock is required to be widely popularized along with technological demonstration and back stopping by line departments. These low cost land use combinations can significantly contribute to the rehabilitation and utilization of degraded lands in

the fragile west Himalayan zone.

Keywords: fodder grasses, *Grewia optiva*, riverbed lands, silvipastoral system

PP5.4.14. Effect of in-situ rainwater conservation practices on resource conservation and growth of aonla (*Emblica officinalis*)

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The Bundelkhand region with a geographical area of 7.07 M ha in central India is characterized with undulating terrain, scarce vegetation cover, hostile climate, lack of irrigation facilities and unfavourable edaphic conditions. Nearly 70% of the total area in the region is subjected to varying degrees of erosion hazards. A field study was conducted during 2011-2012 to 2012-2013 at CSWCRTI, Research Centre, Datia, Madhya Pradesh, India to evolve a suitable in-situ rainwater harvesting practice for resource conservation and augmenting the growth of aonla (*Emblica officinalis*) in agroforestry system on reclaimed degraded lands in red soils of Bundelkhand region in central India.

The treatments (farmer's practice of aonla planting with 0.027 m³ pit (control), pit filled up to 0.75 m with 1 m³ pit, crescent shaped micro-catchment with 1 m³ pit and V-shaped micro-catchment with 1m³ pit) were laid out in Randomized Block design in 4 replications in runoff plots of 21x14 m at 2% slope. Six aonla plants/plot were accommodated at a spacing of 7x7 m. In inter spaces, black gram was grown as rainfed crop during the rainy season and Indian mustard in winter season under limited irrigation adopting recommended package of practices. Results indicated that different rainwater conservation practices were effective in conserving higher rainwater, reducing soil and nutrient losses, further increasing the growth of aonla and yield of inter crops over control. Mean results of 2 years showed that highest runoff (38.9%), soil loss (3.79 t ha⁻¹) and nutrient loss (organic carbon 16.9, N 6.2, P 2.7 and K 7.7 kg ha⁻¹), lower grain yield of black gram (221 kg ha⁻¹) and Indian mustard (1082 kg ha⁻¹) and low growth of aonla (plant height 1.83 m and girth 1.3 cm) were recorded under farmers' practice. However, the lowest runoff (23.3%), soil loss (1.97 t ha⁻¹) and nutrient loss (organic carbon 9.1, nitrogen 4.1, phosphorus 1.6 and potassium 4.8 kg ha⁻¹), higher grain yield of black gram (334 kg ha⁻¹) and Indian mustard (1580 kg ha⁻¹) and higher growth of aonla (plant height 2.21 m and girth 1.5 cm) were obtained under V-shaped micro-catchment over farmers' practice. The study revealed that among different *in-situ* rainwater conservation practices, V-shaped micro-catchment was found the best for resource conservation and enhancing the yield of intercrops and growth of aonla under aonla-based agroforestry system on sloping reclaimed degraded lands in red soils of Bundelkhand region in Central India.

Keywords: aonla, agroforestry, Bundelkhand, blackgram, rainwater conservation, Indian mustard, red soils

PP5.4.15. Performance of *Ziziphus mauritiana* and *Cordia gharf* with different modes of grass sowing in silipastoral system degradation

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The role of fodder trees and shrubs is of great importance in providing leaf fodder to livestock, especially during the crucial lean period. Two trials, with *Cenchrus ciliaris* and *C. setigerus* as grass

species in combination with *Cordia gharaf*, and *Ziziphus mauritiana* were laid in RBD at Mochirai forest range, Bhuj at a spacing of 6 x 4 m. The area was undulating with loamy sand soils. Grass sowing was done in two manners as *C. ciliaris*- low seed rate (1.0 m strip at a distance of 4 m) in shallow 25-40 cm soil and *C. setigerus*- high seed rate (very dense) 8-10 kg /ha, medium 40-75cm soil.

In *C. setigerus* trial, *C. gharaf* recorded more than 90% survival compared to 88.9% for *Z. mauritiana* at 64 months. Survival was also higher for control plants. Dense grass sowing adversely influenced the growth and biomass with control plants recording significantly higher growth. *C. gharaf* recorded significantly higher growth than *Z. mauritiana*. Control trees (5.76 kg tree⁻¹) recorded significantly higher mean biomass (p=0.00) as compared to grass trees (3.33 kg tree⁻¹). Mean biomass was 1.6 fold high for *C. gharaf* (7.5 kg in control to 4.8 kg in with grass treatments) while for *Z. mauritiana* the yield was 2.5 fold high (4.0 kg to 1.9 kg). Strip grass sowing enhanced the survival with grass plants recording 97.5% compared to 87.6% survival rate for control plants. Grass plants recorded also higher growth, maximum for *C. gharaf* and had 10.7% more mean green biomass (6.96 kg tree⁻¹) as compared to control plants (6.29 kg tree⁻¹). The yield was 5.3 to 4.5 kg tree⁻¹ for *Z. mauritiana* and 8.6 to 8.0 kg tree⁻¹ for *C. gharaf* with grass and control treatments respectively, suggesting that at low seed rate grass sowing promotes tree growth.

Keywords: fodder yield, plant growth, silvipastoral system, strip sowing

PP5.4.16. Establishment of *Jatropha curcas* in alkali land with bio-inoculants and various fertilizers doses

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India has about 17.69 million hectares of degraded land due to salinity, alkalinity or other regions. The reclamation of degraded land is useful for the production of fuel, fodder and food with increase in the demand. The four mycorrhizal species used in the experiment were isolated from the alkali land. The AM fungi and other fertilizer doses were used for reclamation of alkali wasteland with *Jatropha curcas*. The AM fungi played important role in plant establishment, growth, branch formation and collar diameter when inoculated with Urea, SSP, FYM and vermicompost. The *Acaulospora laevis* inoculated with Urea + SSP + Vermicompost to *Jatropha* plants showed maximum plant height. The minimum plant height of *Jatropha* plants was recorded in *Gigaspora margarita* inoculated plants with dung. The AM fungi, *Glomus constrictum* inoculated *Jatropha* plants showed maximum number of branching when supplemented with urea + SSP and vermicompost while the minimum number of branching per plant was recorded in *Jatropha* plants inoculated with *Glomus fasciculatum* and dung. The maximum number of collar diameter was recorded in *Jatropha* plants inoculated with *Glomus constrictum* + urea + SSP + FYM + vermicompost and minimum number of collar diameter was recorded in *Acaulospora laevis* and dung inoculated plants. Vermicompost increased soil porosity, organic matter and beneficial microorganisms in the plant root environment, urea provides nitrogen and SSP provides phosphorus which was made available to plants through AM fungi. The soil pH were reduced considerably after eighteen months and nutrition level of soil also increased and become suitable for cultivation of low salt tolerant crops. The data were recorded quarterly from experimental field and found highly significant statistically.

Keywords: *Jatropha curcas*, *AM fungi*, *alkali land reclamation*, *bio-inoculants*, *fertilizers*

PP5.4.17. Socio-economic impacts of farmer managed natural regeneration on rural communities in Senegal

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Farmer Managed Natural Regeneration (FMNR) is an environmental rehabilitation strategy for degraded lands promoted in most areas in Senegal. It provides important goods and services (e.g. food and nutrition, firewood, fodder, medicine etc; and shelter, soil fertility, soil erosion control, etc.) to the local communities. The study is assessing the socio-economic impact of this practice in the eco-zones of Senegal (Central-Northern Peanut and Central-Southern Peanut zones). The methodology consisted of conducting socio-economic surveys amongst 72 continuous practitioners (adopters) and 48 old practitioners/ (non adopters). The results show that the adopters are more resilient than the non-adopters. Adopters produce more livestock manure and use less fertilizer, and obtain higher crop yields than non-adopters. In the Central-Northern Peanut zone, the annual average yield of millet and peanut are respectively 0.53 T/Ha and 0.57 T/Ha for the adopters against 0.40 T/Ha and 0.39 T/Ha for the other group. In the Southern Peanut zone, they are respectively 0.42 T/Ha and 0.40 T/Ha for those adopters as compared to the 0.34 T/Ha and 0.28 T/Ha average yields from non-adopters. In this last zone it appears that non-adopters of FMNR are more exposed to food insecurity than the adopters if we take into consideration the length of time of the annual agricultural product consumption (14% against 3%). Moreover, by taking into account the value of non-timber forest products, households adopting FMNR in the Southern Peanut zone earn on average more income by selling non-timber forest products than the other group (88.5 US\$ against FCFA 35.4 US\$ per farming season). The major constraints to the dissemination of this practice mentioned by communities include: the destruction of young plants during ploughing, wandering animals, illegal logging of trees, low rainfall and the lack of local conventions regulating the management of this practice

Keywords: *agroforestry adoption*, *farmer managed natural regeneration*, *resilience*, *scaling-up*

PP5.4.18. Tree fodders as potential feeds for sheep husbandry in Mali

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The contribution of tree fodder species to sheep production was studied in Mali. First, a survey was conducted in 11 villages of the commune of Zan Coulibaly in order to assess the local tree species used as browse offering the greatest potential for sheep feeding. Results showed that several woody forage resources are used during the dry season. According to farmers' perception, five species, *Pterocarpus erinaceus*, *Ficus gnaphalocarpa*, *Pterocarpus lucens*, *Khaya senegalensis*, and *Terminalia macroptera* would offer the greatest potential. The second activity aimed at assessing the palatability of the five species for sheep. The palatability test was conducted in four villages using 20 sheep. The chemical composition and energy content of the forages showed no difference between villages, but varied depending on the species. The average DM intake, of 643.5 g/d/animal, varied depending on the species. *Ficus gnaphalocarpa* was the most ingested species, followed by *Pterocarpus erinaceus* and

then *Pterocarpus lucens*. The third activity aimed at evaluating the contribution of tree fodder to sheep fattening. Three tree fodder species replacing partially or totally the peanut haulm in a standard sheep fattening ration containing 50% of cottonseed meal and 50% of peanut haulm, were assessed. Forty-nine Djallonké rams were wormed, vaccinated and divided into 7 groups of similar body weight. A ration was assigned randomly to each group. The animals were individually fed for 75 days. They were weighed at the beginning of the trial, every 2 weeks, and at the end of the trial. Weight gains and the economic performance of the rations were determined. The best-performing rations are the ones containing 50% cottonseed plus 50% of either one of the tree forage species *Pterocarpus lucens*, *Ficus gnaphalocarpa* or *Pterocarpus erinaceus*, respectively. In conclusion, sheep production using tree fodder species growing in Mali sounds efficient and beneficial.

Keywords: *farmers' perception, palatability, sheep fattening, tree fodder*

PP5.4.19. Factor analysis to assess impact of silvipasture and grassland ecosystem under arid conditions

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Trees are the inherent component of traditional grassland production systems. The systematic introduction of multipurpose trees in existing or in new grassland development system leads to increased stability of system. In agroforestry systems, the impacts may be visible after a considerable period, especially in terms of soil ecosystem.

The sustainability of soil can be reflected by measured soil physical, chemical and biological properties. The soil biota is vital component in maintenance of soil ecosystem sustainability and health as they play important role in decomposition and mineralization and are quick to respond to changes in soil ecosystem.

In order to quantify the importance of soil biota as an indicator to soil quality, an attempt is made in this paper to use factor analysis to evaluate soil quality parameters in relation to grassland management practices. Four management practices were selected namely Mopane based silvipasture (SP), high input intensively managed grassland (MG), no input grassland (GL) and grasslands converted to agriculture land use (AL). 192 samples from two soil depths (0-15 and 15-30cms) were collected at 2 months intervals. Six soils attributes (CMI, NH₄-N, NO₃-N, MBC, FDA and DHA), three soil biota (Collembola, Acari and others) and three growth parameters (Length, density/m² and IVI) were observed.

The factor analysis result showed that factors 1, 2 and 3 are more significant in explaining system variance, cumulatively explaining 73.58% variability. Factor 1 has positive loading for grass parameters and factor 2 has positive loading for DHA, CMI and soil fauna. Factor 3 had positive loading for FDA. The grass parameters explained the greater part of variability for factor 1, hence named as “vegetation”. Factor 2 has greater loading for soil biota and biochemical parameters named as “biology”. Mean score for factor 1 and 2 was significantly highest and positive in SP followed by the results suggests that soil biota may be rapid indicator of land use assessment of perennial systems like grassland and silvipastoral systems in arid regions.

Keywords: *arid western plain, factor analysis, silvipasture, soil biota*

5.5 Temperate agroforestry

PP5.5.1. Effects of biophysical interactions in the Manitoba maple alley cropping system on yield and nutrition forage crops

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Competition between trees and crops in alley cropping systems for soil moisture, light and nutrients, especially N can lead to decreased productivity of the associated crop. The objective of this study was to evaluate the biophysical interactions of soil moisture and light between Manitoba maple and oat on the yield and nutrition of the oat crop. Oat was seeded within a 9-year-old established Manitoba maple alley cropping site at the nursery site of the Agroforestry Development Centre-Agriculture and Agri-Food Canada, Indian Head, SK, Canada in the 2012 growing season. Tree rows were arranged in the east/west direction and the oat plots were established on the north and south sides of the Manitoba maple rows to evaluate orientation. Gravimetric soil moisture content (SMC) and photosynthetically active radiation (PAR) were collected to evaluate the effects of trees on both parameters with reference to the tree line. Overall SMC increased with distance from the tree row and it was comparatively higher in the north orientation (19.5%) compared to south orientation (17.9%). In contracts PAR values at noon were the highest in the south orientation (1552 $\mu\text{mol m}^{-2}\text{s}^{-1}$). Also crude protein and total nitrogen were significantly higher in the south orientation. Dry matter content (DM), acid detergent fibre, and neutral detergent fibre were not significantly affected by the distance or orientation from the tree row, nor their interactions. However, oat grown in the northern orientated plots had generally higher values in all the forage related parameters compared to the southern orientation, which largely corresponded to the trend in soil moisture content. It can therefore be concluded that SMC played a major role in determining the DM content and nutrition in oat compared to PAR.

Keywords: *competition, photosynthetically active radiation, Saskatchewan, soil moisture*

PP5.5.2. Constraints and mitigation of large cardamom cultivation under traditional Alder based agroforestry system in Sikkim Him

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Large cardamom (*Amomum subulatum*) based agroforestry mainly with N₂-fixing *Alnus nepalensis* and some other tree species is a traditional land use system in the slopes of the Sikkim Himalayas. It has been a potential livelihood support to smallholders, a means to biodiversity conservation, environmental services, ecological health and socioeconomic well being of the people. The plantation area declined by 30% while productivity decreased by 30-40% in recent years due to natural calamities and widespread occurrence of fungal and viral infestations. Most of the plantations are very old with economically non-viable productivity as yields decline after the 20th year of planting. Considering the importance of large cardamom towards the socioeconomic wellbeing of local communities in Sikkim, 100 growers of Dzongu area were interviewed based on a questionnaire to document and analyze their perspective on its production constraint and mitigation. The major constraints based on the priority of the respondents were non-availability of inputs like quality planting materials (resistant to infestations),

irrigation facilities or proper infrastructures, trained labour during harvesting and biopesticides for disease infestation (state is declared organic); technical knowledge, economic/financial support, extension and marketing services. The suggestions of the respondents based on their priority for mitigation of production constraints are regular training and demonstration of production technologies by appropriate extension agencies for proper adoption of improved cultivation practices, timely adequate supply of inputs, availability of post harvest facilities and timely financial support/proper credit facility (incentives for replantation and gap filling of older plantation by disease resistant/tolerant varieties) from financial institutions. This warrants the cardamom growing communities and the agroforestry system to be supported with appropriate policies and institutional support to overcome threats and challenges.

Keywords: *large cardamom, alder-based agroforestry, production constraint, Sikkim*

PP5.5.3. Traditional agroforestry systems in eastern Himalayan region, Sikkim, India

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Sikkim, a state of India located in the Eastern Himalayas region, is an area of 7096 sq.km. The elevation ranged from 270 m (lower hills) to 8598 m (snow bound lands) and annual rainfall ranging from 1300 mm to over 4000 mm. About 80% of the population depends on agricultural land for their livelihood. This paper focuses on different agroforestry systems that exist in south and west Sikkim, and the perception of farmers regarding functions of different agroforestry components and their role in conservation of natural resource and livelihood of the local people in Sikkim Himalayas. The study reveals that agroforestry is an age-old practice in Sikkim and has been a way of life and livelihood for centuries. Ten different agroforestry systems were recognized on farmers' land in south and west Sikkim, which are rich in tree-crop diversity. In total 96 different plant species were recorded in agroforestry systems of Sikkim Himalayas which includes 13 food crops, 32 multipurpose tree species, 11 fruit trees, 6 wild fruit trees, 30 different types of vegetables and 4 fodder grasses of which 85 percent plant species are native. Out of ten agroforestry systems; agrisilvipasture, agrihorticulture, agrihortipasture, livestock based mixed farming systems, apiculture and kitchen garden are the most beneficial and preferred by farmers. The study shows that farmers have considerable knowledge about farming and its contribution to natural resources conservation. Agroforestry systems play both a productive and protective role to farmers. As per the perception of farmers, the functional unit like agricultural crops, vegetable, and fodder crops play a productive role whereas large cardamom, multipurpose tree species, pastures, fruit trees and apiculture play both a productive and protective role. However, research on choice of species, tree crop interaction, and spacio-temporal dynamics studies should be undertaken to get maximum benefit from the systems.

Keywords: *conservation and livelihood, productive and protective functions, traditional agroforestry systems, tree-agriculture crop diversity*

PP5.5.4. Soil quality differences in a mature alley cropping system in temperate North America

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Although agroforestry alley cropping practices are believed to improve soil quality, long-term effects of alley cropping on soils for the temperate zone are limited in literature. The objective of this study was to examine the effects of management, landscape, and soil depth on soil bulk density, water stable soil aggregates (WSA), soil carbon (C), soil nitrogen (N), and enzyme activity in a Silver maple (*Acer saccharinum* L.) no-till corn (*Zea mays* L.)-soybean (*Glycine max* L.) rotation study site established in 1990 in northeast Missouri. Soils from crop alleys and tree rows were collected along three transects extending from upper to lower landscape positions at 0-10, 10-20, and 20-30 cm depths in 2011. Soil enzymes studied include: fluorescein diacetate hydrolase (FDA), β -glucosidase, β -glucosaminidase, and dehydrogenase. Soil bulk density, WSA, C, N, and enzyme activities decreased with soil depth in the crop alley and tree row except for the glucosaminidase activity. At the 20-30 cm depth C, N, and glucosidase activity were similar for both crop alley and tree row. The effects of measured soil physical and biological parameters were not significantly different between crop alley and tree row. The effect of landscape position was not significant for management and by depth. The results of the study show that introduction of trees improves soil quality parameters in crop alley areas as the system matures and these improvements extended throughout the soil profile.

Keywords: *claypan, corn-soybean, enzymes, water stable aggregates*

PP5.5.5. Assessment of cork production and carbon sequestration in new *Quercus suber* stands under future climate

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Most of the existing climate scenarios suggest a decrease in precipitation for Portugal, and this may have an impact for the tree growth rates, the tree cork production, and consequently in the cork debarking rotation periods used in current forest management.

Two equations that predict virgin and mature cork biomass production were added to the parameter-sparse Yield-SAFE model, recently calibrated for *Quercus suber*. These equations are dependent on tree diameter. The fact that cork prediction is made at tree level implied the need to establish rules for the allocation of stand basal area growth, predicted by the Yield-SAFE model, to each individual tree before estimating the respective diameter growth.

The study was made considering different new stands, planted after 1990, that have been installed not only in the south of Portugal where traditional agroforestry systems are located, but also in the northern part of the country in former agricultural land. The high-stocking densities that were recommended for these new plantations are also a differencing characteristic that originates uncertainty on the resulting cork production as this is related to light and water resource availability in particular water, the main limiting resource for most of the current cork oak stands.

Simulations for the next 40 years were made for several stands. They showed that going from the control scenario to the climate change scenario results in a decrease in mature cork yield and carbon stock values, ranging from 2.2% to 63.2% depending on the case study site location and soil characteristics. This evidences the importance of the maintenance and promotion of agricultural and/or pastoral activities as an additional income for some of these areas.

Keywords: *climate change adaptation, cork production, Yield-SAFE*

PP5.5.6. Modelling for climate change: is intercropping in North America heading toward increased competition or complementarity?

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Investigating the effect of climate change on the dynamics of intercropping systems in North America requires the use of modelling to improve our understanding of tree-crop associations and predict future productivity. We adapted the Hi-sAFe model, a mechanistic, biophysical model capable of simulating the complexity of interactions in an intercropping system, which was developed under the assumption that the sharing of resources (light, water and nitrogen) is the major determinant of intercropping system productivity. Using daily time steps, Hi-sAFe simulates resource sharing in a 3-dimensional intercropping environment, something beyond the limitations of a simple empirical model.

Using data from an experimental site in Québec (Canada), as well as data from literature, the model was parameterized and validated using hybrid poplar and winter wheat. Once validated, the model was used to test the implementation of different agroforestry systems in temperate southern Canadian climate. Using different climate change scenarios selected by applying a cluster analysis method to all the available regional and global climate simulation models, we explored theoretical hypotheses on complementarity, facilitation and competition in plant communities. Simulation results demonstrate that agroforestry can have a significant positive effect on system productivity both in the present climate and with climate change: the LER (Land Equivalent Ratio) is superior to 1, which means that the total relative productivity (trees and crops) is larger in an agroforestry system than in separate agricultural and forestry monocultures. The difference in the relative yields of crops and trees differ significantly depending on the climate scenarios simulated; the change increases with increasing climate change reflecting a change in the types of interaction processes occurring within the plant community. Our results also demonstrate that when using the climate change scenarios in the model, intercropping has a stabilizing effect on crop productivity.

Keywords: *climate change, Hi-sAFe model, intercropping, productivity modelling*

PP5.5.7. Olive, free-range chickens and wild asparagus: an agroforestry system in temperate climate

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Traditional olive cultivation is rapidly becoming unprofitable due to high harvesting costs. Intercropping olives with other economically viable crops/animals can provide economic sustainability. Here, a wild asparagus species (*Asparagus acutifolius*) was cultivated in the olive orchard, with free-range chickens for meat production. Two poultry cycles per year were carried out in spring and fall to avoid hot summers and cold winters for best performance, and to allow sanitation of

the soil between cycles. The animal load corresponded to 500 animals/ha per cycle. Chickens grew as expected for outdoor animals and had no measurable negative effects on the asparagus and the olive trees. Chicken manure provided about 85 kg/ha of N and about 110 kg/ha of P₂O₅ per year (i.e. two cycles), covering all fertilization needs of the olive orchards. Chickens also provided adequate weed control, but the distribution of the animal housing appeared important in order to spread the animals uniformly and avoid overgrazing and soil compaction in the areas surrounding the housing: weed control decreased with increasing distance from the shelters. Animals spent more time outdoors and ingested greater quantities of herbage when trees were present, compared to a similar outdoor system without trees. This corresponded to improved animal welfare and meat quality. The asparagus yield could not be measured because the young transplants need 2-3 years before achieving full yield. Preliminary observations on naturally occurring plants in the orchard suggest that the yield per plant is very similar to that reported for this asparagus species grown in pure stands. Overall, the system appeared capable of producing both olive and asparagus with similar yields as in pure stands, greatly increasing the land equivalent ratio, in addition to hosting chickens, which provide fertilization and weeding, while improving welfare and meat quality.

Keywords: agroforestry, asparagus, olive, poultry

PP5.5.8. Effects of canopy composition on wild leek (*Allium tricoccum* Ait.) growth in a forest farming system

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Wild leek (*Allium tricoccum* Ait.) is a forest perennial herb very popular in northeastern America for the taste of its bulb. Overharvesting of natural populations caused a major decline of its abundance in the last decades, and it is now endangered at least in part of its range. Recent studies indicated that wild leek is a good candidate for forest farming.

Wild leek takes advantage of high light conditions prevailing in deciduous forests between snow melt and canopy closure to accumulate carbon reserves through photosynthesis. Leaf senescence occurs soon thereafter. However, we reported that under constant light and temperature, senescence is delayed. The present study aims at establishing the impact of overstory canopy composition and density on light conditions prevailing in the understory in the spring and on the growth of wild leek. We posit that wild leek growing under late-bud bursting trees (e.g. *Quercus rubra*) will postpone their senescence, which should optimize its annual growth. Wild leek growth should also be favoured under a sparse canopy or in gaps.

Bulbs were planted in 31 plots in 2011 in southern Quebec, Canada, under canopies varying in composition and densities. Light conditions were estimated from hemispherical photographs and phenology of wild leek and trees was recorded throughout the spring. Other environmental factors (e.g. litter, weed cover, temperature, soil nutrients, etc) were also recorded. Wild leek growth was estimated from leaf and bulb width increments. Redundancy analysis (RDA) was conducted on the data.

Plants growing under late-bud bursting trees senesced later and produced larger bulbs, both years following plantation. Canopy sparseness and gaps tended also to favour wild leek growth. This later trend, from first season, needs to be confirmed with data collected this summer. These results will help producers identify the optimal locations to grow wild leek in their forest stands.

Keywords: *Allium tricoccum*, forest farming, light environment

PP5.5.9. Growth performance and soil enrichment potential of agroforestry tree species in mid hill zone of Himachal Pradesh

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Present investigation was carried out to study the growth and influence of fourteen multipurpose tree species on soil ameliorative potential under mid hill sub humid zone of Himachal Pradesh. These tree species were planted in year 1988 in compact blocks. The plantation has been kept away from any biotic disturbances and addition or removal in any form. The survival percentage varied from 20-100 percent, lowest observed for *Grevillia robusta* and highest for *Punica granatum*. Maximum height growth (12.5 m) was displayed by *Gmelina arborea* followed by *Melia composita*, *Albizia stipulate*, *Ulmus laevigata*. Collar diameter growth was found to be highest (16.25cm) in the species of *Melia composita*, which was closely followed by *Gmelina arborea*, *Albizia stipulate*, etc. The tree species *Acer oblongum* displayed minimum collar diameter growth. The soil physico-chemical properties improved with due course of time. Soil pH increased slightly under plantation over control, whereas the organic carbon increased at much higher rate (175%>500%) during last 25 years. The available nitrogen (10%>50%), Phosphorus (8%>40%) and Potassium (5%>15%) increased substantially over the time. The regression equations were also prepared for volume estimation of *Bauhinia retusa*, *B. variegata*, *Acer oblongum*, *Dalbergia sissoo*, *Alnus nitida*, *Acrocarpus fraxinifolius*, *Melia composita*, *Gmelina arborea*, *Robinia pseudoacacia*, *Ulmus villosa* and *Toona ciliata*.

Keywords: biotic disturbances, volume, survival percent, collar diameter, regression equations

PP5.5.10. Agroforestry silvo-arable systems with pollarded walnut trees: first evaluation by modelling and field monitoring

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In agroforestry systems (AFS) with annual intercrops, the competition for light, water and nitrogen plays a key role. Mature trees capture a larger part of the resources, and the yield of the intercrop decreases. When the tree stem density is high (>50 stems.ha⁻¹), the yield of the intercrop may therefore drop to unprofitable levels. A possible solution to that competition problem would be to reduce the size of the trees by pollarding. Pollarded trees produce both timber with the bole and biomass or fodder with the leaves and branches that are regularly pruned every 2 to 10 year. The reduction of the size of the crown would also be profitable to the intercrops, allowing a sustained and profitable yield even with old trees. The concept was evaluated both by modelling with the Hi-sAFe numerical model and by an experiment comparing standard walnut trees and pollarded walnut trees. Numerical runs of the model indicate that AFS with pollarded trees may reach very high levels of tree-crop complementary, achieving higher Land Equivalent Ratios than AFS with standard trees. However, the model predicts that the diameter growth of the trunk could be heavily reduced by the pollarding regime. These predictions should be confirmed by field experiment. We settled an experiment with walnut trees aged 16 years in spring 2013. During the first growing season after pollarding, the girth growth of the pollarded trees was surprisingly not reduced, as compared to standard unpollarded trees. Some

hypotheses to explain this behaviour are discussed. If this result is confirmed during the next years, the model should be modified to incorporate this aspect, and the productivity of the AFS with pollarded trees could be even higher.

Keywords: *alley cropping, land equivalent ratio, modelling, pollard tree*

PP5.5.11. Comparison of stemflow and throughfall in *Morus alba* and *Grewia optiva* based agroforestry systems in North Western Himalayas

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Rainfall is an important component of hydrological cycle of which proper distribution and utilization enhance the net productivity and assures global food security. Rainfall partitioning (throughfall, stemflow and interception losses) is a function of rainfall characteristics, meteorological conditions, vegetation structure and the interactions between these factors. An attempt has been made to measure the fractions of rainfall as throughfall, stemflow and interception losses in *Morus alba* and *Grewia optiva* based agroforestry systems in foothills of north-western Himalayas. The analysis revealed that the throughfall varied from 65-85 % in *G. optiva* and 52-83 % in *M. alba*. Stemflow varied from 4-16% in *G. optiva* and 4-21 % in *M. alba*. Interception losses varied from 4-24 % in *G. optiva* and 2-27 % in *M. alba*. It was observed that interception loss from *M. alba* was 1.33 times more than *G. optiva*. Out of 508 mm rainfall, resulted average stemflow from a *M. alba* and a *G. optiva* tree was 387.7 and 160.29 litres, respectively. Thus, 503.8 and 208.3 m³ stemflow can be harvested from 1 ha *M. alba* and *G. optiva* plantations with density of 405 trees ha⁻¹ and age 5 years. *M. alba* produces approximately 2.5 times more stemflow as compared to *G. optiva*. This stemflow if harvested and stored in polythene lined pond within the plantation can provide supplement irrigation during lean period. Thus, *M. alba* has greater potential of stemflow water harvesting than *G. optiva*.

Keywords: *agroforestry, interception, stemflow, throughfall*

PP5.5.12. Soil enrichment potential of land-use systems under mid hill condition of Himachal Pradesh

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The present investigation were carried out under mid hill and sub-humid zone-II of Himachal Pradesh, to study the influence of land use system, altitudinal gradient on soil enrichment potential with the objectives of identifying the land use system having high soil enrichment potential. For conducting this study three sites were selected randomly and each site was considered as replicates. Mountainous slope of each site was stratified into two altitudinal gradient viz., 900-1200 m asl and 1200-1500 m asl at three depths viz. 0-20, 20-40, 40-100 cm. In each altitudinal gradient eight land use systems i.e., agriculture, horticulture, agri-silviculture, silvi-pastoral, agri-horticulture, agri-horti-silviculture, forest and grassland. The data was analysed using Randomized Block Design (RBD) factorial. Maximum bulk density was recorded in the agriculture system (0.65 g cm⁻³) at par with grassland and minimum in forest system (0.59 g cm⁻³). This trend was same for magnesium and sulphur. Forest system recorded

maximum amount of particle density (1.69 g cm^{-3}), pore space (64.32%), pH (6.24), cation exchange capacity (10.97), organic carbon (0.67%), phosphorous (14.09 kg/ha), potassium (198.80 kg/ha) and calcium (3880.00 kg/ha) and all were at par with agriculture and grassland. Grassland recorded maximum nitrogen content (404.78 kg/ha) which was at par with agriculture system. However, the nitrogen content (331.10 kg/ha) was minimum in forest system. In altitudinal range, soil physio-chemical properties were found to decrease appreciably from 900-1200 m asl to 1200-1500 m asl. The study concluded that forest system is better land use system in comparison to other.

Keywords: *land use system, altitudinal gradient, agroforestry system*

5.6 The social science of agroforestry

PP5.6.1. Attitudes towards tree planting among smallholder farmers in Malawi

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Agroforestry has the potential to mitigate the consequences of poverty, food security and environmental degradation in Malawi. The effectiveness of tree planting activities will be largely determined by the degree to which we understand and address the factors which encourage or discourage farmers to plant trees. This paper examines farmers' attitudes towards tree planting in Malawi and explores the relationship with tree planting behaviour. Using the theory of planned behaviour as a conceptual framework, an attitude scale was developed to explore three attitude components: attitudes, subjective norms and perceived behavioural control. Household questionnaires containing the attitude scale were administered to 200 farmers in two districts in Malawi. The study found that in general, all three attitude components in relation to tree planting were positive. The attitudes and subjective norms were more positive in the south of Malawi compared to the north, whereas the perceived behavioural control was lower for female respondents than for male respondents. Respondents who planted trees on their land in the past five years had a more positive attitude, subjective norm and perceived behavioural control towards tree planting compared to respondents who had not planted trees on their land. Logistic regression analyses showed that attitude had a significant influence on whether or not the respondent had planted trees in the past five years, as predicted by the theory. A priority ranking exercise demonstrated that respondents considered household needs such as buying food, fertiliser and sending children to school as more urgent than investing money in tree planting. These findings suggest that although farmers recognise the benefits of tree planting and see it as a worthwhile investment, adoption of agroforestry technologies will be constrained by poverty until other, more immediate needs are met. Understanding and addressing these barriers to adoption is vital for accelerating the impacts of agroforestry.

Keywords: *adoption, barrier, behaviour, household survey*

PP5.6.2. Community based management of monastery sacred forests in eastern Himalayan region, Sikkim, India

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Sikkim is one of the most biodiverse states of India having 82.31% forest area. The entire landscape of Sikkim is unique and sacred mostly nurtured by monasteries, and worshipped by local people. Monasteries have their own traditional forest management systems. The study was conducted in south and west Sikkim, with the objective to understand the traditional ecological knowledge of local people and their role in management of monastery forests. Monastery forests are respected by people with religious sentiments, institutional sanctions with unique social fencing system and comprising two management committees. It was observed that the monastery's sacred forests are rich in biodiversity and forest health is maintained to high standards due to less anthropogenic pressure and encroachment as compared to village forests. Management practices like bans on felling of trees and grazing of animals and participatory monitoring are followed. The paper concludes that religious institutions like monasteries play a very significant role in conservation of local forests on cultural values by the people, which has been a financially suitable approach unlike heavy investment donor-driven initiatives. The management approach followed in monastery sacred forests not only serves as a tool but is also a success story of sustainable approach.

Keywords: *biodiversity conservation, monastery sacred forest, people's participation, traditional forest management systems*

PP5.6.3. A case study analysis of Agricultural Extension Services (AES) provided by public departments and marketing behaviour (MB)

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Agroforestry as a land use system offers potential for enhancing farm production and household farm income. Most research studies on agroforestry systems have dealt with knowledge and adoption behaviour with little emphasis on the impact of agroforestry and the marketing of agroforestry products. Hence the case study conducted in the villages of Bangalore rural district examined the impact of AES and MB of farmers practicing agroforestry. Data were collected by organizing focus group discussion meetings and by using interview schedule from five practicing agroforestry farmers. AKAP (Awareness, Knowledge, Adoption, and Product) sequence was used to analyze the impact of agricultural extension services. All the case study respondents opined that public extension systems provide valuable information and input services at the required time and that they are highly valued by farmers. The study also revealed that the increase in awareness and knowledge level of the farmers brought positive changes not only in the adoption of agroforestry practices but also in productivity. The study also explored the sources of availability of marketing information and different channels of marketing of agroforestry products. Lack of awareness about rules and regulations of marketing of forest products, non-existence of markets for forest products and lack of information about price and pricing of forest produce are the major problems faced by agroforestry farmers. There is a need to establish markets for forestry products, conduct more meaningful awareness programs about agroforestry and marketing aspects of forestry products. This study also revealed that agricultural extension services provided and the marketing behaviour of farmers practicing agroforestry are the important variables in enhancing farm production and household income under agroforestry systems. The study identified the channels of marketing the forest and horticulture products. Television is the best mass media to create awareness among farmers through broadcasting programmes like Annadata, Krishi darshan, etc.

Keywords: *agroforestry, agricultural extension services, marketing behaviour, AKAP sequence*

PP5.6.4. Traditional agroforestry systems of Mexico: ethnoecological and environmental perspective

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Traditional agroforestry systems of Mexico (TAFS) are important to the present. However, inventory and biocultural knowledge about such systems is difficult to complete. Questions for this study are: (a) what are the agroforestry systems of México; (b) where are these; (c) which cultural groups manage them; and (d) what is the cultural, ecological and biocultural importance? Information was reviewed from 716 studies on traditional agroforestry systems of Mexico. There are 20 traditional agroforestry systems in México. The review included the slash and burn agricultural systems: 'kool' in the Yucatán Peninsula and 'tlacolol' in Guerrero; the terrace called 'metepantle' in Tlaxcala; the drained fields 'chinampa' in the Valley of México and 'calal' in southwestern Tlaxcala; the arid land systems 'milpa-chichipera' in the Tehuacan Valley, 'huamil' in Guanajuato and oasis (*oases*) in the Baja California Peninsula; the agroforests 'kuojtakiloyan' in the Northern Sierra of Puebla, 'te'lom' in San Luis Potosí and 'cacaotales' in Soconusco region in Chiapas and Chontalpa region in Tabasco; and the homegardens 'ekuario' in Michoacán and other homegardens in Puebla, Oaxaca and Yucatán. TAFS maintains between 60 and 90 percent of local diversity and about 2000 plant species. Between 40 and 90 percent of plants registered in TAFS have 15 uses and offer 16 benefits to humans and ecosystems. The discussion emphasizes the importance of traditional agroforestry systems for the resolution of global, regional and local problems, strategies for their maintenance and perspectives for their study.

Keywords: *ethnoecology, México, traditional agroforestry systems*

PP5.6.5. A financial approach to improve the social and economic contribution of silvopastoral systems with sheep in Mali

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In Mali, sheep farming as well as sheep fattening during a short period before sale are important activities that can generate income to meet specific or ad hoc needs such as education and health. In addition, they have significant social and cultural dimensions. However, many constraints such as the cost of agroproducts, accessibility to fodder trees and shortage of financial resources limit their practice. The aim of this research was to question the profits and profitability of these activities for the people of the commune of Zan Coulibaly, Mali, especially for women. A monthly monitoring with 54 farmers (equal number of men and women) from four villages of the commune is conducted in order to describe the current situation in terms of financial profitability of sheep farming and fattening, and to determine the factors most likely to affect this profitability. The data collected about necessary investments, variable costs, selling prices and consumption, as well as the description of the herds, are used to develop an accurate picture of sheep farming and fattening, and to assess their profitability. Although on financial terms, these silvopastoral systems do not appear to be profitable, other indicators such as improved income, contribution to food security and job creation support their social importance for the different villages. Improving access to specific fodder trees as well as the introduction of new

fattening techniques and a better knowledge of sheep value chains could help to increase profitability. At the end, we expect a wider dissemination of a more profitable technology, especially among women who are already numerous to practice this activity.

Keywords: *fodder, silvipastoral system, profitability, sheep farming, social issues*

PP5.6.6. From “Finca” to forest: factors associated with leaving or planting trees in a Panamanian agricultural landscape

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This work explores the socioeconomic factors that lead farmers and agriculturalists to maintain or plant forest and trees integrated into the agricultural matrix through examining the case of Los Santos province, Panama. This presentation explores the different motivators that distinguish the passive act of leaving trees and/or forest in the agricultural landscape and the active planting of new species and/or forests within this landscape. A survey of 85 individual land managers in two Los Santos districts, Macaracas and Pedasí, indicates that the decision of whether to maintain forest in the agricultural landscape is associated with land-holding size, secondary occupation, inheritance status of land, and secondary school education (in Macaracas). The fraction of forest on their land maintained by those who do decide to maintain forest in Macaracas is associated with land-holding size, education level, and number of children working in agriculture. Participants' answers to questions about farm management practices reveal the species, reasons and locations of trees left and planted on their farms, and their strategies for management of live fences. These results suggest that to sustain the current trend of increasing tree cover in Los Santos and ensure that this increase promotes biodiversity the Panamanian government and non-profits should encourage live fence and riparian corridors, mixed native species carbon-timber plantations, and education about erosion and soil degradation.

Keywords: *farmers' preferences, Panama, silvipastoral systems, socioeconomic factors*

PP5.6.7. A case study analysis of Agricultural Extension Services (AES) provided by public department and marketing behavior (MB) of farmers practising agroforestry

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Agroforestry as a land use system offers potential for enhancing farm production and household farm income. Most research studies on agroforestry systems have dealt with knowledge and adoption behavior with little emphasis on impact of agroforestry and marketing of agroforestry products. Hence the case study conducted in the villages of Bangalore rural district, examined the impact of AES and MB of farmers practicing agroforestry. Data were collected by organizing focus group discussion meetings and by using interview schedule from five practicing agroforestry farmers. AKAP (Awareness, Knowledge, Adoption, and Product) sequence was used to analyze the impact of agricultural extension services. All of the case study respondents opined that public extension systems are providing valuable information and input services at the required time and they are highly valued by the farmers. The study also revealed that the increase in awareness and knowledge level of the farmers brought positive changes not only in the adoption of agroforestry practices but also in productivity. The study also explored the sources of availability of marketing information and different channels of

marketing of agroforestry products. Lack of awareness about rules and regulations of marketing of forest products, non existence of markets for forestry products and lack of information about price and pricing of forestry produces are the major problems faced by the agroforestry farmers. There is a need to establish markets for forestry products, conduct of more meaningful awareness programme about agroforestry and marketing aspects of forestry products. This study also revealed that the Agricultural Extension Service provided and marketing behavior of farmers practicing agroforestry are the important variables in enhancing farm production and household income under agroforestry systems. Study identified the channels of marketing the forest and horticulture products. Television is the best mass media to create awareness among farmers through broadcasting programmes like Annadata; Krishi darshan etc.

Keywords: agroforestry, agricultural extension services, marketing behaviour, AKAP sequence

6.0 Applying science to the future of agroforestry: policy innovation and global issues

6.1 Policy, governance and international frameworks

PP6.1.1. Action policy research to facilitate agroforestry adoption in Viet Nam

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Upland areas in Viet Nam are characterised by monoplantations of annual crops or fastgrowing timber trees, resulting in degrading environments that restrict farmers from improving their livelihoods. Despite having the potential to reduce these negative impacts, the uptake of agroforestry is very limited. Hence, what are the constraints and enabling factors for agroforestry adoption at the national and local levels in Viet Nam?

This paper presents methodology and results from a policy review and 10 stakeholder workshops conducted at district and province levels in Dien Bien, Yen Bai and Son La provinces (northwest region) and at a national level. Stakeholders including farmers, extension workers, leaders, NGOs and local enterprises identified (i) incentives and disincentives associated with policies related to agriculture and forestry, (ii) gaps between policy and implementation and (iii) factors potentially enabling agroforestry adoption and recommendations for policy options.

The review resulted in eight categories of policies. ‘Agroforestry’ was only mentioned in a handful of the policies and no policy facilitated the physical process of integrating of forestry and agriculture. The stakeholder workshops highlighted local variations in policy implementation, serving as case study examples for developing policy scenarios. Policy recommendations were ranked and passed on to the national workshop. Overall, higher priority should be given to enabling access to a wider selection of species and cultivars. For example, while private companies ‘subsidize’ hybrid seeds and inputs, district stakeholders said support should be available for traditional seeds as well to support farmers developing traditional integrated systems using species and technology that is familiar to them. Further, subsidies targeting poor households specifically for forestry plantation/protection were seen as

inefficient as these households generally had insufficient land resources for forestry. Policy scenarios based on the recommendations will be evaluated and discussed.

Keywords: *agroforestry adoption, policy review, policy scenario*

PP6.1.2. Intellectual property rights and concerns in agroforestry: an overview

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Agroforestry traditionally has been a way of life and livelihood contributing significantly to meet the demand of fuel, fodder, timber and livelihood support. Tangible creations of human intellect can be immensely valuable and IPR can be useful to fully utilize the value of these benefits. Any innovation made could be protected under IPR act for the benefit of researchers/farmers/ communities. Any IPR can protect the interest of a creator and their employers in creation. IPR, the legal rights exclude third parties for a certain duration of time from exploring the protected subject matter without authorization of the rights holder. These rights are territorial in nature and are applicable within the boundaries of the country. The awarding of IPRs is determined by national laws and international legal frameworks. The legal basis for IPR varies greatly between countries and is continually changing, both through litigation and new legislation. IPR's legislation covers patents, protection of plant varieties under either patent or *sui generis* systems. In agroforestry research and technology development efforts for intellectual investment may be as crucial as genetic or other resources. The conservation of plant biodiversity, geographical indicators, trade mark, traditional knowledge, domestication of forest, genetically modified crops are the categories of IPR that will play a crucial role under agroforestry. One of the primary steps towards the development and evolution of the national IPR regime could be capacity building in various fields related to the IPR area. The provision of IPR and international regulations in agroforestry would bring more investment in research and development. Institutions should scrutinize every item adopted into research programmes for ownership and IPR issues. Issues surrounding commercialization of genetic resources, benefit sharing and traditional knowledge and ways in which marginal and small farmers can secure their intellectual property rights on farmer-derived innovation need to be strengthened.

Keywords: *IPR, patent, plant biodiversity, geographical indicators*

PP6.1.3. Barriers to integrating forestry into agricultural system: analysis of forest legislation and policy in Nepal

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Agroforestry (AF) has now gained renewed momentum in the context of the increasing need of farm-based livelihoods and improving resilience to changing climate. Yet in many developing countries, there is still an absence of a clear and well-defined regulatory framework to encourage and promote agricultural practices that integrate AF species. This paper reviews the case of Nepal agroforestry-related regulatory framework to identify the gaps, challenges and constraint to incorporate AF species

in the farming system –a fundamental element of agroforestry system. Findings are based on the review of Forest Act 1993, Forest Rules 1995, and various government rules including recent case studies from Kavre and Lamjung districts of Nepal related to the trade of AF products. Findings mainly indicate the three important issues in connection to forest products cultivation and marketing in private land. Firstly, the registration of AF products from private lands is not differentiated for products from forests. The process set out by the Government to register private trees or NTFPs growing in private lands is unclear and there is a lack of clarity both related to provisions and their implementation. Secondly, there are issues of transit and taxation. Forest products and NTFPs from private lands require a transit permit for transportation to markets. Farmers have to pay royalties to the forest department for cultivated AF products which is a disincentive to reduce pressure on resources from forests. Thirdly, there are problems to establish community-based AF Product Enterprises. Even if the Industrial Enterprise Act mandates that no permission is needed to establish small industries, in practice, it is very difficult to register industries related with AF products. Finally, we conclude that there is a need for stronger and more robust evidence to question the underlying policy assumptions and then to contribute to more transformative agroforestry policy debate in Nepal.

Keywords: *agroforestry, policy, transit permit, community-based enterprises, marketing*

PP6.1.4. Finding the right policy track for tree-based intercropping systems: an analysis of cognitive referentials in Canada

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In most temperate regions, public support for tree-based intercropping (TBI) systems is still not sufficient enough to stimulate their adoption by farmers and private forest owners, despite the tremendous efforts made by agroforestry experts to promote these systems as sustainable and productive. The literature on public policy processes has stressed the importance of the ideas and cognitive constructs of stakeholders in the implementation of new policies, but few studies in agroforestry have focused on this aspect so far.

Using a conceptual framework based on cognitive referentials highlighting the role played by the ideas of stakeholders in the elaboration of public policies, our research investigates the receptiveness of agricultural, forestry and rural policies for TBI systems in the specific context of Quebec by comparing the ideas driving these policies with the ideas supporting TBI system implementation. Based on the analysis of formal publications and semi-directed interviews conducted with TBI system experts and policy stakeholders, results underline that TBI systems are featured more as multifunctional systems than productive systems by their promoters. The policy context analysis shows that policies that have integrated multifunctionality in their core ideas are supportive of TBI systems, while policies remaining largely focused on specialization and productivity are less receptive to TBI systems. Hence, the rural policy sector is the most multifunctional and the most receptive to TBI systems, while the forestry sector is the less multifunctional and the less receptive. Interestingly, some subsectors of the agricultural policy are slowly adopting a multifunctional vision, thus offering small-scale support to TBI systems. Major barriers to TBI system implementation remaining in some policy sectors are largely associated with the idea of productivism. This study suggests that featuring TBI systems as productive systems might be a necessary argument shift to tear down policy barriers and increase public support for these systems.

Keywords: *cognitive referentials, intercropping, multifunctionality, policy and institutional framework*

6.2 Ecology and economics of rubber-based agroforestry

PP6.2.1. Smallholder Rubber Agroforestry and Multifunctional Agriculture in Nigeria

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The current approach to plantation agriculture for cash crops like rubber in the humid tropics of West and Central Africa has deprived local communities of their natural life-support system – the forest resource and the traditional knowledge about indigenous species – despite timid initiatives to create employment opportunities or social services. A rubber agroforestry project in Nigeria takes an innovative approach to improving livelihoods of rubber farmers by developing and promoting rubber agroforestry models farms to:

- increase area of economically viable rubber smallholdings in 5 states in Nigeria through
- encourage the development of alternative livelihood options
- create income generating opportunities through demonstrations showing that high value arable crops can be successfully integrated with rubber, thus providing on average a sustainable income of 339; 2,067 and 2,145 USD respectively per farmer 2, 3 and 4 years after establishment while waiting for the rubber to start producing.

The project's philosophy is one of helping the smallholder rubber farming communities in five states in Nigeria to help themselves; firstly to become self-sufficient and economically independent, and then to be a hubs for the dissemination of knowledge and skills on rubber agroforestry (RAF) to neighbouring communities in rubber out-grower schemes within and beyond Nigeria.

Keywords: *agroforestry, livelihood, multifunctional agriculture, participatory domestication, rubber*

6.3 The science of scaling up and trajectory beyond subsistence

PP6.3.1. Upscaling of agroforestry in drylands for economical and ecological betterment

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Dryland ecosystems that cover one forth of earth surface are known to be fragile and interference without knowing the ecological linkages with these systems can result in their degradation which often is irreversible. Agroforestry traditionally followed in these regions is a complete and ecologically sustainable livelihood system. Although traditional systems (TS) are designed with long experiences of generations to minimize the risk of droughts they are rarely extensive and subsistence in nature. However, due to increasing biotic pressure and technologies imported from less environmentally stressed areas these TS are being replaced by intensive agriculture at a very fast rate and this is creating imbalance between ecological and economical returns of such production systems. It is now imperative to think broadly and plan holistically for the mutual sustenance of both dry lands and production system with upscaling.

Central Arid Zone Research Institute, Jodhpur, has developed improved systems with the use of rainwater harvesting, prudent management of organic input, and incorporation of high value crops in system and augments NWFPs. These new forms of agroforestry systems are not only ecologically balanced by using synergy of nature, natives (flora & fauna) and traditional socio-economical system but also economically sound fulfilling the needs of growing population. These systems are being upscaled by incorporation into the traditional systems as well as in the need based systems e.g. organic farming, livestock centric, crop based rehabilitation of spoiled or waste lands etc. and successfully demonstrated at various places. In the present day context possibilities have been explored to promote drylands as areas for carbon sink because timber is not the product from drylands. All these technologies can be used in the drylands world over with minor modifications.

Keywords: *carbon sequestration potential, drylands, organic inputs, traditional agroforestry systems*

PP6.3.2. Effective rural advisory service approaches for natural resource management practices: The case of the uptake of fodder shrubs in East Africa

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Natural resource management (NRM) practices have considerably lower adoption rates than many conventional improved seed and fertilizer practices, in part because they are knowledge-intensive and thus require much greater extension support. This paper reviews the role of effective rural advisory service approaches in the spread of fodder shrubs, an agroforestry practice taken up by over 200,000 farmers in East Africa. We present five key approaches that facilitated the spread of the practice and quantify, where possible, the effect of the approaches in terms of diffusion of seed and knowledge. The first, dissemination facilitators, were experts in fodder shrubs who trained trainers and backstopped non-governmental organizations and government extension services. They were important because these services lacked agroforestry knowledge and skills. Second, large international NGOs were important for introducing the practices to new areas and ensuring technical backup. Third, the establishment of community-based seed systems was critical, with private seed vendors accessing seed from small farmers and selling seed in small packets. Fourth, farmer-to-farmer extension was critical in areas where fodder shrubs had been introduced, as adopters distributed seed and information to an average of six other farmers over a three year period. Finally, civil society campaigns, particularly the Systemwide Collaborative Action for Livelihoods and the Environment (SCALE) approach, helped sensitize communities about new practices and linked them to trainers and organizations providing support. All five approaches were important for facilitating the uptake of fodder shrubs and in many ways, they complemented each other. Research is needed to assess the appropriateness of the approaches for different NRM practices, varying target groups (e.g. women) and different contexts.

Keywords: *extension, seed systems, adoption, civil society campaigns*

6.4 Landscape approaches

PP6.4.1. Applying the trees outside forests (TOF) assessment methodology to rice production landscapes: a pilot project in Asia

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Although trees and rice production are often seen as incompatible, evidence shows that agroforestry practices in rice production landscapes can provide numerous benefits in terms of environmental sustainability, rice field productivity and income generation. In a context where rice production systems in Asia are facing multiple stressors such as climate change, land degradation, and water scarcity, which put the region's food security at risk, empowering decision makers to take informed decisions about rice landscape management becomes crucial to ensure sustainability of rice production. However, user-friendly and accessible tools to gather information on the presence, roles and benefits of trees in rice production areas are generally unavailable. To build capacity and raise awareness on the benefits from trees in rice production systems, FAO developed in 2013 the project 'Assessment of trees outside forest in rice production landscapes in Asia', which aimed to build knowledge and capacity on applying to rice agroecosystems a methodology for assessing, at landscape level, the trees outside forests (TOF). Experts from Indonesia, Philippines and Lao PDR were trained to use this methodology (based on remote sensing analysis and information from local farmers on the ecosystem services provided by the trees), then apply it in pilot sites in their respective countries. The results will inform policy and decision makers on the extent of current agroforestry practices already integrated in rice production landscapes and their individual and collective benefits. This innovative methodology is based on a remote sensing analysis conducted on easily accessible, free (Google) maps software, which can be applied in any site and requires minimal training and software. The results of this work have been integrated in a comprehensive document, a guide for assessing TOF in rice production landscapes in Asia, which will constitute a reference tool for replicating and up-scaling the study at national and regional level.

Keywords: *agroforestry, rice production landscapes, ecosystem services, trees outside forests assessment, remote sensing, field interviews*

PP6.4.2. YieldSAFE estimation of modern cork oak silvoarable agroforestry contribution to CO₂ sequestration in Portugal

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Traditional cork oak (*Quercus suber* L) agroforestry with scattered tree distribution is part of the agricultural landscapes of Portugal. Modern alley cropping designs with trees aligned in rows and adapted to operating farming machinery have been suggested for Europe in the last decade.

Spatial modelling on Portuguese datasets estimated target areas where cork oak could grow on agricultural land. On this area different implementation scenarios were modelled with a hypothetical modern silvoarable agroforestry system (113 trees ha⁻¹ thinned at year 20 for establishing 50 trees h⁻¹a), considering soil water capacity as a growth indicator. The YieldSAFE process-based model was used to predict the biomass and carbon yield of cork oak under low and high soil water-holding capacity levels.

Approximately 353 000 ha are available for allocating new cork oak alley cropping plantations in Portugal. In this area from 5 x 10⁶ to 123 x 10⁶ Mg CO₂ eq could be sequestered in 80 years, depending on whether the implementation of these systems is made in 10% of the area characterized by low soil water-holding capacity (60 mm: 15 cm depth, coarse texture) or in 70% of the area with high soil water-holding capacity (1228 mm: 200 cm depth, very fine texture) respectively. Due to higher yields on more productive land, scenarios of small implementation in high productivity locations can sequester similar amounts of carbon as compared to wide implementation in low productivity land, suggesting an *a priori* land classification assessment for efficiently targeting land allocation for carbon sequestration.

Keywords: *agricultural lands, CO₂ sequestration, land use change, montado*

PP6.4.3. Spatial distribution analysis of homegardens in rural landscapes of Barak Valley, Assam, northeast India using RS & GIS

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The present study focuses on the spatial pattern and distribution analysis of homegardens in the rural landscape of the three districts of Cachar, Hailakandi and Karimganj in Barak Valley, Assam, northeast India, using a combination of remote sensing data and geographical information system (GIS) in order to better understand how other land use classes in a rural ecosystem besides different disturbance sources can influence distribution of homegardens. In the present study the main focus is on the patch of homegardens in the rural landscape which was mapped in great detail relative to other land use classes from IRS-P6 LISS-IV satellite data using visual interpretation technique in a GIS environment. Spatial analysis revealed a higher aggregated behaviour of the homegardens in Cachar district resulting in larger cluster of homegardens and a lesser complexity in interaction with other land use classes which might have positively influenced the higher diversity recorded from the homegardens in the district compared to the other two districts. Homegardens were found to be normally fragmented and dispersed in the landscape and the fragmentation parameter does not impact the ecological attributes of the homegardens unless the clusters of homegardens in the landscape, known as patch, is of very small size where the edge effect comes into play and the disturbance factors, such as urbanization and distance from roads, influence the homegarden structure and diversity in the rural ecosystem. Such studies on the spatial analysis of the homegarden distribution in the rural landscape can be useful for planning and designing sustainable agroforestry models and will help design proper conservation programs for long term maintenance of biodiversity with special management for areas where homegardens are prone to disappear due to different levels of disturbance.

Keywords: *diversity, fragmentation, homegardens, rural landscape*

PP6.4.4. The landscapes of trees outside forests in southern Europe: challenges and opportunities

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As a component of very old agrarian systems, arboriculture has historically contributed to the plant or landscape diversity of the territories. Past rural systems have used the tree as a structuring element. However, traditional landscapes of trees outside forests today are a threatened heritage and are still not paid much attention to in public policies.

From the 1960s, these extremely diversified wooded systems fell into disuse, were destroyed, or replaced by an intensive and standardized arboriculture, which radically changed these landscapes. The longevity of the trees can hide the trend to abandonment but many traditional agroforestry systems have lost their usefulness and their features. Some trees outside forest landscapes may thus be viewed as relics and one can even speak of a critical situation for the survival of certain complex traditional agro-sylvo-pastoral types, as for example those of wooded pastures or pastured-

orchards.

We will present results of a research conducted in France (Midi-Pyrenees), Spain (Andalusia) and Italy (Ligurian Apennines), about agroforestry evolution on sites selected by being concerned with landscapes in a crisis or abandonment situation: their recent history and dynamics in course, operating modes and resource uses. They represent a scientific and policy issue not only because of the problems and challenges they pose, but also by their ecological potential and social values.

Keywords: *heritage, history, resilience, traditional landscapes*

6.5 Agroforestry, water quality and nutrient export

PP6.5.1. Determination of surface runoff and soil erosion using the Soil and Water Assessment Tool (SWAT) model in the Nkam Water

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Soil erosion has been consistently cited worldwide as one of the major drawbacks of sustainable land management for agricultural purposes. A study was carried out to evaluate surface runoff generation and soil erosion rates for the Nkam watershed in Cameroon by using the Soil and Water Assessment Tool (SWAT) model. Calibration and validation of the model was performed on monthly basis, and it could simulate surface runoff and soil erosion to a good level of accuracy. The simulated surface runoff closely matched with observed data. Surface runoff generation was generally high in parts of the watershed characterized by heavy clay soils with low infiltration capacity, agricultural land use and slope gradients of over 16 percent. The estimated soil loss rates were also realistic compared to what can be observed in the field. The long-term average soil loss was estimated at 7.3 t ha⁻¹ yr⁻¹; most of the area of the watershed (~ 60 per cent) was predicted to suffer from a low or moderate erosion risk (< 5 t ha⁻¹ yr⁻¹), and only in ~ 3 per cent of the watershed was soil erosion estimated to exceed 10 t ha⁻¹ yr⁻¹. Expectedly, estimated soil loss was significantly correlated with measured rainfall and simulated surface runoff. Based on the estimated soil loss rates, the watershed was divided into four priority categories for conservation intervention. The study demonstrates that the SWAT model provides a useful tool for soil erosion assessment from watersheds and facilitates planning for a sustainable land management in the highlands of Camero.

Keywords: *soil erosion, soil loss, surface runoff, watershed management*

PP6.5.2. Influence of a silvopastoral system in the Brazilian savanna on soil physical parameters

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The savanna area in Brazil has nearly 200 million ha and produces annually 40% of soybeans and beef, 20% of rice, corn and coffee; and 10% of beans, sugarcane and manioc, of the totals produced by the

country. Tree contribution to soil structural improvement was assessed in a silvopastoral system (SP) and a control traditional pasture (CT), located in the Brazilian savanna, 19° 35' 36" S, 43° 51' 56" W. This SP exists since 1984 from natural regeneration of *Zeyheria tuberculosa*, with a density of 160 trees ha⁻¹. The forage on both treatments was *Urochloa brizantha*. Soil samples were collected in 2006 at depths: 0-10, 10-20 and 20-40 cm. There were greater contents of OM in the 0-10 and 20-40 cm layers of soil in CT (P<0.05). Both systems reduced the OM with the depth (P<0.05) and showed similar values of particle density and apparent particle density (P>0.05). There was no difference in porosity, macro porosity and micro porosity between systems and depths (P>0.05). The variables S-SO₄⁻², Ca/Mg, Fe, and Mn showed positive correlations (r>0.7) with physical parameters, and pH, H+Al, OM, and Ca+Mg/CEC7 had negative correlations. Only K and S-SO₄⁻² presented a positive weak correlation (r<0.4) with micro porosity. The trees contributed with 4.360 kg ha⁻¹ year⁻¹ of dry matter (DM) with 45.03% of lignin, which probably influenced the physical attributes, considering that the high content of lignin reduces the speed of decomposition carried out by soil microorganisms. The surface layers of both systems tended to present higher values of apparent density and particle density. The tree species studied, at this density, had little influence on the soil physical attributes compared to the pasture.

Keywords: *agroforestry, animal production, macro porosity, sustainability*

PP6.5.3. Agroforestry buffers for non-point source pollution reductions from corn-soybean watersheds

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Despite significant attention and demand for the adoption of agroforestry practices throughout the world, rigorous long-term scientific studies confirming environmental benefits of agroforestry practices are limited. The objective of the study was to examine effects of agroforestry buffers on non-point source pollution (NPSP) reduction from corn-soybean rotations in temperate North America. The study site consists of three watersheds in a paired watershed design in Central Claypan Areas established in 1991. Treatments of grass and agroforestry (tree+grass) buffers were established on two watersheds in 1997 after a six-year calibration period. Runoff water samples were analyzed for sediment, total nitrogen (TN) and total phosphorus (TP) for the 2008 to 2011 period. Results indicated that agroforestry and grass buffers significantly reduce runoff, sediment, TN, and TP losses to streams. Buffers were more effective during low rainfall years in the claypan region as compared to above-normal rain years. These differences could in part be attributed to the differences in soils, management, and landscape features. Results from this study strongly indicate that agroforestry and grass buffers can be designed to improve water quality while minimizing the amount of land taken out of production.

Keywords: *claypan, crop rotation, Missouri, oaks*

PP6.5.4. Augmentation of water resources through in-situ moisture conservation methods: a case study

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A project entitled 'Augmentation of water resources through water harvesting in hilly areas' funded by Indian National Committee on Surface Water (INSW), Ministry of Water Resources, Government of India, New Delhi, is being implemented by the Department of Soil Science & Water Management, College of Forestry, Dr Y S Parmar University of Horticulture & Forestry, Nauni-Solan, Himachal Pradesh. Under this project, various measures for catchment treatment and water harvesting such as contour trenches, earthen loose boulder structures, percolation ponds, gabion structures, afforestation, silvi-pasture development, etc. are being undertaken to mitigate the adverse effects of heavy runoff especially in the rainy season and to promote the ground water recharge. The impact of soil and water conservation (SWC) activities undertaken at the local level have not only checked soil erosion and impounded water that otherwise would have been lost due to runoff, but also revived many natural springs and small streams in the harsh climatic conditions prevailing in the project areas. With the increased moisture level as a result of SWC works, barren areas have been put into positive changes in adjoining project areas. The inhabitants themselves agreed that the construction of percolation ponds, staggered trenches and loose boulder check dams ensured water security in the hamlets for life saving irrigation for plants. Soil moisture and water levels in different water bodies is being monitored regularly in treated and untreated areas. Higher soil moisture content around various catchment treatment measures has been observed as compared to the adjoining untreated areas. Various water harvesting techniques are expected to improve base flow, increase irrigation potential and augment groundwater. The main challenge is the availability of low cost and affordable technology which farmers can adopt easily. As the water available to meet the human, animal and crop needs is decreasing day by day, more efforts have to be made towards conserving and utilizing maximum amount of rainwater and recharging ground water by adopting low cost, successful and environment friendly techniques and following afforestation activities. Therefore, a watershed approach needs to be followed on a community basis for proper water management and sustainable development.

Keywords: *rainwater harvesting, ground water recharge, afforestation, hilly region.*

PP6.5.5. Monitoring N-leaching and exploring coffee farmers adaptation strategies to higher N- fertilizers price in Costa Rica

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Agroforestry systems may sustain productivity while providing ecosystem services. Nevertheless, in Central America the production of fully-shade coffee is declining and coffee producers are increasingly depending on N-fertilizer to sustain high yields. This represents a threat to the environmental quality and water resources. As the future increase in N-fertilizer cost will not be offset by coffee price, it is unclear how farmers would respond to such market pressures and how it may affect water resources quality. This study monitored N-leaching in three farms with different N- applications (95, 193, 258 kg N ha⁻¹) using suction-cup-lysimeters and explored coffee farmer's adaptation strategies as a response to increased N-input price in Llano Bonito, Costa Rica. In order to carry out a scenario analysis on N-leaching as related to rainfall rate, results from weekly water balances were fitted into a generalised logistic curve and multiplied by the NO₃⁻-N concentrations.

Results demonstrated that N-leaching is an important N-loss as up to 8, 20, and 29 kg of NO₃⁻-N ha may be lost in the three field sites within a week following fertilization. Additionally, a total of 100 farmers were interviewed to study their perception regarding N-losses and their strategies to cope with increased

N-prices. Overall, 39%, 27%, and 14% of farmers perceived soil acidity, erosion and N-leaching being the factors limiting N-Use Efficiency (NUE), while 15% indicated other causes and 6% did not consider NUE to be an issue. Future trends of coffee and N-prices will stimulate farmers to reduce N-applications and to adopt new management techniques aiming to increase NUE. Farmers particularly recognized the benefits of agroforestry practices, identifying the re-establishment/increase in density of legume shade trees among the feasible strategies. Finally, agronomic practices proposed by farmers hold promises in reducing production costs and the environmental impact of local coffee systems.

Keywords: *coffee agroforestry, Costa Rica, farm management, N-leaching*

PP6.5.6. Monitoring water physicochemical features under agroforestry system in the Polo Regional Centro Norte, Pindorama, SP, Brazil

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This study was conducted at Polo Regional Centro Norte - APTA, located in the municipality of Pindorama –SP-Brazil, and aimed to evaluate the impact of the implementation of agroforestry system (AFS) with different soil management in the water quality of four ponds. The experimental area was the so called “Gully Watershed” because the plantation at the edge of the ponds is located in an area where there was gully erosion. The monitoring was made by determining in situ four physico-chemical parameters (pH, electrical conductivity, dissolved oxygen and temperature) from July to October 2011. To reduce the impact of environmental activities, protect riparian vegetation, generate income and produce food for subsistence for the rural population, the agroforests systems are considered an increasingly common strategy in Brazilian agribusiness. A monitoring of water quality was carried out in the four ponds under different management systems with samples collection before and after each activity.

The soil management in the area varied from no tillage, minimum tillage with annual cultures in between the lines to very intense tillage with no soil protection from pond 1 to pond 4. The monitoring concluded that the parameters evaluated in situ in the four ponds for water quality fit into the quality standards established by Brazilian laws (Resolution CONAMA 357/2005). Considering each pond separately, there was statistical difference between the management during the four months studied, confirming the expectations of influence of each management on water quality in the adjacent pond. The adoption of different forms of implementation of agroforestry systems with different activities significantly influenced differently the water quality of adjacent reservoirs in the study period. We suggest the continuation of monitoring of water quality for more consistent future results.

Keywords: *resource water, sustainable agriculture, agribusiness*

PP6.5.7. Assessment of benefits of agro-pastoral system in restoration of degraded hills of Uttarakhand

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Land and water are the two natural resources in hill and mountain agro-ecosystem of Himalayan region. Proper exploitation and management of these resources is of prime importance as these sustain life. Lands in these regions are more sensitive to degradation. The sediment and nutrient load in runoff water is important from ecological view point as these results in depletion of soil fertility and pollution of water resources.

In order to study the land degradation problem erodibility indices as well as soil nutrient losses from degraded sloping lands were assessed. The results revealed that erodibility indices viz., clay: moisture equivalent ratio (CMER), clay ratio (CR), percolation ratio (PR), surface aggregation ratio (SAR) and water stable aggregates (WAS) were highest while erosion and dispersion ratio were lowest in agro-pastoral system as compared to agricultural and cultivable lands indicating their less sensitivity to degradation and being less prone to erosion as compared to agricultural cultivable lands. Land degradation was also estimated in terms of sediment and nutrient loads in runoff water from these lands. Sediment and concentration of nutrients and organic carbon were highly variable depending on rainfall. Highest sediment load of 148 mg L^{-1} was recorded. pH of runoff water was slightly alkaline (7.4) with EC of 122 m s m^{-1} . Total soluble salts (TSS) varied from 110 to 180 mg L^{-1} with an average of 135 mg L^{-1} . The HCO_3^- and CO_3^{2-} constituted $>50\%$ Ca^{+2} , Mg^{+2} $>25\%$, Cl^- 10% and SO_4^{2-} , NO_3^- , PO_4^{2-} , Na^+ and K^+ together constituted 15% of total ion concentration in runoff water.

Keywords: erodibility indices, soil erosion, soil nutrient loss, soil sensitivity

PP6.5.8. Agroforestry system with Hevea brasiliensis (rubber tree) and Bixa orellana for gully stabilization, Pindorama, Brazil

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In the Polo Regional Centro Norte-APTA, Pindorama, Brazil, inadequate management resulted in gully erosion where four ponds were built in 1998 to stop erosion after which an agroforestry system plantation was planted in April 2011 which under preliminary evaluation. Pond edges received different plantation treatments: treatment 1 -native species, interspersed with rubber tree *Bixa orellana* in hollows with 0, spaced 3 x 2m, weed control using lines coupled to the tractor and mower without annual crops between rows; treatment 2 - trees species, interspersed with rubber tree and *Bixa orellana* L, without soil disturbance in hollows with, spaced 3.5 x 2m, weed control with herbicide Roundup WG and annual crops (corn) between rows in no-tillage system; treatment 3 - forest trees species, interspersed with rubber tree and *Bixa orellana* with soil tillage and furrow opening using soil disk and trencher, spaced 3.5 x 2m and annual corn crop planting under conventional tillage; treatment 4 - forest trees, interspersed with rubber tree (*Hevea brasiliensis* and *Bixa orellana* L with soil tillage and furrow opening and with soil disk and trencher, tree species planted in furrows, spaced 3.5 x 2m and no annual crops between rows.

The native species, the rubber tree and *Bixa orellana* L developed well in the field. Treatment 4 had higher liana infestation and higher incidence of invasive weeds. The rubber trees were attacked first by capybaras. After planting, corn capybaras attacked the maize plants. The spacing of 1 meter resulted in three corn rows between lines that should be changed two rows in the following years. In July-October 2011 ponds' water evaluation had statistical difference for determined in situ (pH, dissolved oxygen, electric conductivity and temperature). These data confirm the expectations of management of each influences the water quality of the adjacent pond and native species of flora and flora are sprouting in the area.

Keywords: rubber tree agroforestry system, soil conservation, tropical cultures used in agroforestry systems

6.6 Successful and scalable business models for agroforestry

PP6.6.1. Carbon augmentation of farmlands of Bohol through development of oil palm based agroforestry

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In the recent years, attention is drawn to the possible use of biodiesel to help mitigate climate change as it produce less harmful emissions than fossil fuels when used in generating electricity. According to Zah *et al* (2007) and Hill *et al.* (2006), use of biofuels instead of fossil fuels results to GHG emissions savings of 30% and 41%, respectively. In the Philippines, the enactment of the Biofuels Act in 2007 resulted to increased interest on bio-fuels (Maruyama *et al.*, 2009). Several biofuel processing plants have been constructed all over the country to meet the expected demand.

One of the potential crops that can be used as biofuel is *Elaeis guineensis*, commonly known as African oil palm. Currently, 43,000 ha have been planted to oil palm in the Philippines. The country imports US\$ 150 million worth of palm oil a year which is expected to rise to US\$ 280 million by 2020 (Pamplona, 2011).

Aside from the GHG savings that can be derived from using oil palm as biofuel, *Elaeis guineensis* also sequesters carbon from the atmosphere. A total of six oil palms with ages 2, 5, 6, 7, 8 and 9 years were selected and destructively sampled to assess the amount of carbon stored in the oil palm of different ages. Results of the study indicate that the biomass of the oil palm studied range from 0.021 ton to 0.90 ton per tree. As expected, the nine year old oil palm contains the largest amount of biomass while the two year old one has the smallest biomass value. Furthermore, nine year old oil palm plantation sequesters 6.1 t/ha/yr and a carbon density of 55 t/ha. Assuming that around 1 M ha of farmlands are converted into an oil palm plantation, around 55M tons of carbon will be stored.

Keywords: biofuel, carbon density, farmlands, oil palm

Additional abstracts

1.0 South Asia: agroforestry systems, income and environmental benefits

1.1 Policy on agroforestry and tree based farming systems

AD1.1.1. Effect of container type and potting media on the growth of seedlings of *Melia composita* Willd

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Melia composita Willd. is a fast growing deciduous tree. The uses of melia are multifarious. It has become a popular tree in agroforestry plantations in the northern states of India. As a result it is presumed that increasing interest of farmers in melia will certainly create a demand for quality seedlings in the coming years. An experiment was therefore laid out at the Experimental Farm of the Division of Agroforestry, Sher-e-Kashmir University of Agricultural Sciences and Technology of Jammu at Chatha, located at an altitude of 332 m above mean sea level. The study was conducted with the objectives to study the effect of container types and potting media on the growth of *Melia composita* seedlings. Three different potting mixtures were prepared by using soil, sand, farm yard manure (FYM) and vermicompost. Two types of containers were also tested which included root trainers with a volume of 300 cc and 250 cc and polythene bags of size 28 x 23 cm and 24 x 16 cm, respectively. The experimental trial was laid in factorial Completely Randomized Design. In all there were twelve treatments, replicated thrice. The findings reveal that the *Melia composita* seedlings grown in polybags of size 28 x 23 cm registered maximum growth among all the treatments. The use of FYM and vermicompost in the potting mixtures greatly benefited the growth and quality of the plants as compared to the potting mixture containing only soil.

Keywords: agroforestry, *Melia composita*, potting media, root trainers

AD1.1.2. Investigation on germination profile of *Acacia nilotica* under different salinity conditions

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Acacia nilotica is an important multipurpose, leguminous tree species grown widely under agroforestry systems in India, Middle-East Asia, and Africa. It is an important source of fodder, fuel, timber, gum and medicine. Keeping in view of the wide distribution and uses of the species, the present study was undertaken on 15 provenances of *Acacia nilotica* to: assess the salinity tolerance in geographically diverse population, study the intraspecific variation in germination and growth parameters under varying level of salinity and find the LD50 dose of salinity and most tolerant provenances of the species. The experiments were conducted in Petri plates and polybags. Observations were recorded on the parameters of seed germination. Among the 5 doses of salinity, the highest dose EC 15 dSm⁻¹ was found most deleterious to the seed germination (11.37% germination). Out of 15, ten provenances had more than 50% reduction in germination at 9 EC. Significant variation was recorded in the salinity

tolerance ability of 15 provenances. Nagpur, Raipur, Akola and Ujjain provenances were least affected by the increased level of salinity and hence can be called as most tolerant.

Keywords: *Acacia nilotica*, germination, salinity, study sites

1.2 Agroforestry for rural employment and income generation

AD1.2.1. Wood properties variations in some commercial poplar clones of North India

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Within-ramet radial, intra- and inter-clonal variations in the wood element's dimensions and specific gravity of commercial clones of *Populus deltoides* Bartr. ex Marsh of north India are described in the paper. Three clones were parent viz. G48, S7C8 (female) and G3 (male). Other clones represent hybrids of F1 generation. Ramet height and GBH as growth parameters were also considered for the study. The study material was collected from the commercial clones of *Populus deltoids* raised by WIMCO Plantations Ltd. at Rudrapur (Udhamsingh Nagar), India. The data was analyzed using multivariate analysis. Intra- and inter-clonal variations were significant for all the wood traits except vessel element length for intra-clonal variations. Within ramet variations due to pith to periphery radial location were significant for fiber length and specific gravity. The trend increased from the pith outwards. Clone x replication interaction was also significant for all the wood traits. GBH variations were also significant due to clones. The female clones showed significantly higher fiber length and specific gravity while male clones showed higher values for fiber wall thickness and vessel element length. F1 offspring showed higher values for fiber length than the parent clones due to the hybrid vigour for the trait.

Keywords: *fiber dimensions, specific gravity, vessel dimensions, fiber wall thickness*

AD1.2.2. Variations in climatic and edaphic parameters under different tree species in Tarai region of Uttarakhand, India

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A new Agroforestry Research Centre was established at Haldi in Govind Ballabh Pant University of Agriculture & Technology, Pantnagar of Uttarakhand state of India in 2005. About 75 tree species have been planted in an arboretum maintaining 20 trees of each species in a block of five rows of four trees in each row in a distance of 5 × 4m. 50 tree species among the planted trees were selected to study the effect of their canopy in penetration of solar radiation, temperature of air and soil and soil characteristics under each species. Air temperature at open was 40°C whereas it varied from 34°C (*Cassia sieamia*) to 36.5°C (Meetha Neem) under different tree species. Soil temperature under different tree species varied from 34°C (neem) to 42°C (chalta). During the study period the average solar radiation in open was 71 600 Lux whereas under different tree canopy it varied from 1850 Lux (*Cassia sieamia*) to 37 000 Lux (*Cassia fistula*) to 65 000 Lux (Imli). Soil moisture on air dry basis ranged from 0.13% (paper mulberry) to 14.025% (salix) and on oven dry basis from 0.31% to 14.33%. Similarly variations in soil pH, soil carbon, soil nitrogen and soil texture have also been recorded

under different tree species.

Keywords: canopy solar radiation, edaphic parameters, soil characteristics, tree variability

AD1.2.3. Influence of intercrop on survival of *Populus deltoides* in agroforestry plantations in north India

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Populus deltoides (poplar) is a prominent agroforestry tree in north-western India comprising parts of Punjab, Haryana, Uttar Pradesh, plains or outer valleys of Uttarakhand, Himachal Pradesh, Jammu and Kashmir. It grows fast and is popularly grown by farmers at a short rotation of six to eight years. Its wood is soft and light coloured which is highly valued by the plywood industry. Wood is also used for matches, paper, packing cases, fuel, etc. It is cultivated in block plantations or along field bunds in combination with field crops. The major crops are wheat, sugarcane, mustard, maize, berseem, jowar, sorghum, potato, vegetables, ginger, turmeric, mango, etc. While first-year survival of poplar in well maintained plantation is 95 to 100 percent, it is not uncommon to find plantations where poplar plants experience considerable mortality, sometimes as high as 100 per cent failure within a few months of planting. A study was made to examine the influence of intercrop on the performance of poplar in Saharanpur (Uttar Pradesh) and Haridwar (Uttarakhand) districts. The greatest post-planting mortality was observed in fields where poplar was planted in block plantation with wheat. However, this adverse effect of wheat could be primarily attributed to the management practice rather than to the crop per se. The failure was found to be related with the size of the entire transplant used by the grower. Measures are available that can reduce mortality in poplar plantations.

Keywords: intercrop, mortality, poplar cultivation, wheat

AD1.2.4. Agroforestry system for sustainable livelihood prevalent in Rajouri District of Jammu and Kashmir, India

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The need for integrating trees and livestock in the hilly regions of Rajouri district of Jammu and Kashmir is pressing due to the increasing paucity of grazing lands and the non-availability of green fodder during the winter season. Adoption of an agri-silvi-pastoral system which is a mixed land-use system for forage and wood production is gaining importance in the district and is a source of sustainable livelihood in the region. The system comprises of wheat- maize-paddy integrated with multipurpose trees such as *Grewia optiva*, *Celtis australis*, *Morus alba*, *Ulmus wallichiana*, *Quercus leu*, *cotricophora* along with perennial grasses like setaria and napier hybrid. Trees in agroforestry systems provide subsistence goods and supplement inputs for farming activities for example small timber and branches from trees viz., *Grewia optiva*, *Albizia lebbeck*, *Celtis australis*, *Luceanea lecocephala*, *Robinia pseudoacacia*, *Bauhinia variegata*, *Ulmus laevigata*, *Quercus himalayana*,

Dendrocalamus spp, *Acacia catechu*, etc are used in making ploughs, implement handles and provide fuelwood and fodder almost throughout the year. This farming system has a potential in the hills where cultivation is carried out on slopes if hedges are planted on contours. It can also be a successful soil erosion control measure in addition to other production functions. Shade tolerant and rhizomatic crops such as ginger, turmeric, garlic, etc. are also grown on a longer term basis under the agri-horti-silvi system with pear, apricot, plum, mulberry etc. as a source of additional income to farmers before the main trees/orchards start production. Fruits/fruit products of walnut, pecan nut, pear, apricot, plum, mulberry, guava and citrus provide additional income and are a source of nutritional minerals and calories on a sustainable basis.

Keywords: *agri-silvi-pastoral system, multipurpose trees, agri-horti-silvi system*

1.3 Land reclamation: bio-drainage and salinity control

AD1.3.1. Germination of selected nitrogen-fixing tree species moistened with crude oil contaminated soil water extracts

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The study investigates the germination of selected nitrogen-fixing tree species (NFTS) native to the crude oilfields of Nigeria. Germination experiments of 50 seeds each of the selected members of Fabaceae family NFTS: *Bauhinia monandra*, *Delonix regia* and *Tetrapleura tetraaptera* were conducted in Petri-dishes double-layered with Whatman No 1 filter papers for 10 days and moistened with varying concentrations of crude oil contaminated soil water extract (0, 25, 50, 75 and 100ml), with a view to determining the ability of these plants to germinate and establish in soil polluted with crude oil. The mean percentage germination of each tree species was thus determined. All the NFTS germinated, but the germination was concentration dependent, as percentage germination decreased with an increase in oil concentrations. Evaluation of the initial growth responses and tolerances of these NFTS in oil-polluted soil may provide useful information about the potential of these plant species for phytoremediation.

Keywords: *Fabaceae, germination, phytoremediation, pollution*

2.0 South Asia: climate change, multifunctionality, livestock and fish systems

2.1 Agroforestry for climate change mitigation and adaptation

AD2.1.1. Variability, heritability and association studies among different clones of Eucalyptus tereticornis planted at two sites

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Tree plantations under farm and agroforestry are an important source of timber, fuelwood and other raw material requirements for industries in developing countries due to non-availability of the same from natural forests and can play a vital role in mitigating climate change effects. Eucalypts are widely planted in farm forestry systems throughout the world and in India as well due to their high productivity and adaptability to wide geographical conditions. According to a report by Forest Survey of India, Eucalyptus is the most preferred tree species by farmers of Punjab in both rural and urban areas. Farmers in India have shown keen interest in the recent past in planting of eucalypts on their farmlands due to the availability of genetically proven highly productive clonal planting stock of Eucalyptus with manifold increase in productivity as compared to seed raised plants. Productivity of each clone can be further increased with the careful matching of each clone most adaptable to each site. With this hypothesis in mind, a study was conducted to evaluate the performance of twenty clones at two sites. The estimates of phenotypic coefficients of variation and genotypic coefficients of variation clearly reflected the presence of large amounts of genetic variability for clearbole height and unforked height at the age of six and a half years after planting. The estimates of heritability and genetic advance clearly suggested the potentiality of the clonal material for improvement of clearbole height and unforked height. Highly strong positive association was observed among clearbole height and unforked height in both the environments. Significant positive correlation was observed among total height and diameter at breast height (dbh) in better environment (Environment 1) whereas in Environment 2, non-significant negative correlation was observed between height and dbh.

Keywords: clones, correlation, *Eucalyptus tereticornis*, genetic parameters

AD2.1.2. Storage patterns of sequestered carbon in different tree-components of some multipurpose trees from Bundelkhand, Central

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In view of the dwindling forest cover, agroforestry has been considered as a potential and low cost method for sequestering atmospheric carbon. Different agroforestry trees sequester varying amounts of carbon, hence, accurate and realistic estimates of carbon stock in trees are essential for determining their potential of sequestering carbon dioxide (CO₂), and role in mitigating global warming and climate change. Therefore, this study was conducted at the National Research Centre for Agroforestry, Jhansi to assess storage patterns of sequestered carbon in different tree-components of eight important multipurpose tree species viz. *Eucalyptus tereticornis*, *Albizia procera*, *Azadirachta indica*, *Acacia nilotica*, *Butea monosperma*, *Dalbergia sissoo*, *Anogeissus pendula* and *Embilica officinalis* of Bundelkhand region in central India. About 250 g of wood, bark, branch, root and foliage samples were taken from selected trees from existing agroforestry models at the Research Farm and carbon content estimated by dry ashing method. From ash, carbon content was calculated by using the equation: carbon content (%) = 100-[ash (%) + molecular weight of O₂ (53.3%) in C₆H₁₂O₆]. From moisture content and estimated biomass, total carbon content of each tree was computed. Findings revealed that the carbon content varied significantly among tree species (38.28-42.07%) as well as tree-components (35.86-44.35%). The order of carbon content in different tree species was *Eucalyptus tereticornis*= *Azadirachta indica*= *Acacia nilotica*= *Butea monosperma*> *Albizia procera*= *Dalbergia sissoo*> *Embilica officinalis*= *Anogeissus pendula* and in tree-components, branch = stem > root > foliage> stem bark = branch bark. Among trees, *A. procera* was found to be the most efficient in capturing C (127.74 kg C/tree) and removing CO₂ from the atmosphere (46.83 kg/tree/year) while, *A. pendula* was the least with corresponding carbon (8.22kg C/tree) and CO₂ (3.01kg/tree/year),

respectively. Positive correlation existed between carbon content and tree growth attributes (height and dbh).

Keywords: *agroforestry, carbon mitigation, CO₂ removal efficiency, tree-biomass*

AD2.1.3. Climate change in agriculture in the hilly region of Himachal Pradesh and the role of agroforestry

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The impact of climate change is most seriously felt in mountain regions because of the most vulnerable ecosystems. Evidence of climate change could be clearly observed by changes in receding snowfall in the Himalayas, disrupted rainfall patterns and increasing temperature. Agricultural production system is affected by short and long-term climate changes. The study observed that different factors responsible for climate change in the state indicated a decreasing trend in the amount of precipitation, decrease of snowfall and decreasing trend of flow of water in different rivers. The forest and pasture area decline over a period indicate negative signal to environment. The productivity of different crops is less than their production potential. The study revealed that significant numbers of farmers believe that temperatures have increased and precipitation has declined along with the late onset and early withdrawal of monsoon with long dry spells which need to adjust to the cropping pattern with a changing trend of climatic factors and the development of crop varieties that will be resistant to climate change. The age, farming experience, education level, innovativeness, consciousness to environment and exposures to mass media had a positive and significant relationship with farmer perceptions to climate change. Adaptations made by farmers revealed that use of water conservation techniques and agroforestry were the important adaptations in response to climatic change. They were in agreement about adoption of a combination of tree plantations with crops to reduce the pressure of climate change and increase crop productivity. There is need to develop suitable resistant crops to climate change and planting trees with crops helps to reduce adverse climatic changes and increase crop productivity. Both short term and long term strategies need to cope with climate change.

Keywords: *climate change, agriculture, Himachal Pradesh*

AD2.1.4. Carbon sequestration assessment of block plantations at JSW Steel Limited

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JSW Steel Ltd. is one of the premier steel producers in India with a current capacity of 10 MTPA at its Vijayanagar Works in the Bellary district of Karnataka, India. As the fastest growing steel

company in India, it aims at quantifying the CO₂ sequestered through green belt development activities in its campus. The National Research Centre for Agroforestry (NRCAF), Jhansi simulated the CO₂ sequestered under the existing greenbelt using CO₂FIX model. The block plantations assessed across the steel plant are 4MT (303 ha), 7MT (81 ha), 10MT (81 ha) and Township (101 ha). The soil of the site is reddish/brown in colour and clayey loam in texture. The average annual rainfall of the plantation area is 667 mm. The number of existing trees per hectare in the green belt of four assessed plant areas varied from 475 to 934. The dominant tree species observed were *Eucalyptus tereticornis* (38.69%), *Leucaena leucocephala* (31.39%) and *Pithecellobium dulce* (24.82%) in 7MT area; *Leucaena leucocephala* (20.36%), *Azadirachta indica* (14.51%) and *Peltophorum ferrugineum* (13.15%) in 4MT area; *Cassia siamea* (26.31%), *Pongamia pinnata* (23.68%), *Azadirachta indica* (15.78%) and *Acacia auriculiformis* (13.15 %) in 10MT area; *Leucaena leucocephala* (29.37%) and *Eucalyptus tereticornis* (14.75%) in the township areas. The carbon sequestration potential of existing green belt in 4MT, 7MT, 10MT and township areas of JSW campus has been estimated to the tune of 2.65, 1.63, 3.01 and 3.7 tonnes CO₂ha⁻¹.yr⁻¹ (or equivalently 9.71, 5.97, 11.03 and 13.60 tons CO₂ha⁻¹.yr⁻¹). Overall, the carbon sequestration potential of the existing plantations varied from 1.63 to 3.71 tons C.ha⁻¹.yr⁻¹.

Keywords: block plantations, carbon sequestration, steel plan

AD2.1.5. Carbon sequestration potential of mixed tree species existing on agricultural lands in Bundelkhand regions of India

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Carbon (C) sequestration through agroforestry is a potential viable option to mitigate climate change. The amount of C storage by trees, crops and soil depends on the nature of the tree, tree density, environmental and socioeconomic factors. Bundelkhand region has 13 districts and the total geographical area is 7.06 m ha out of which 3.88 m ha is agricultural land. A field survey was conducted through transect walk during 2009-2012 in 10 districts at village level (six village in each block). All trees more than 1.5 m in height and more than 5.0 cm diameter at breast height (dbh) were enumerated. The data was obtained for the number of trees for each tree species and dbh for each tree. In this way the data was generated for different tree species and their density for a particular village. The tree species were classified as slow, medium and fast growing based on the growth rate of stem volume for example; slow growing < 10 m³ ha⁻¹ yr⁻¹, medium growing 10-20 m³ ha⁻¹ yr⁻¹ and fast growing >20 m³ ha⁻¹ yr⁻¹. Specific species or generic volume equations were used to convert dbh in to volume (m³ ha⁻¹). Simulation of above- and below-ground biomass of trees and crops, soil carbon and total C was done using CO₂FIX 3.1 model. The most common trees in the region are: *A. nilotica*, *A. catechu*, *Zizyphus mauritiana*, *Azadirachta indica*, *Butea monosperma*, *Madhuca latifolia*, *Acacia leucophloea*, *Inga dulcis* and *Leucaena leucocephala*. The results indicated that the value of biomass (tree + crop), soil C and C sequestered were 29.61, 9.34, 23.13 t ha⁻¹, respectively in base year (2010) and the corresponding values for 2030 would be 41.38, 18.38 and 37.84 t ha⁻¹ respectively over baseline.

Keywords: field survey, transect walk, biomass, soil carbon, CO₂FIX 3.1 model

AD2.1.6. Soil organic carbon profile in homegardens as influenced by age and size in Aizawl district of Mizoram, northeast India

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Traditional homegardens (HGs) are the second most widely practiced land-use systems in Mizoram, after shifting cultivation. HGs are considered to have higher carbon sequestration potential (CSP), thus gaining global attention for their stability and role in long term surface reservoir (carbon sink), natural low cost and ecofriendly means towards combating issues of global warming and climate change. This paper examines the soil organic carbon (SOC) distributed at different soil depths as influenced by age and size of HGs. Soil samples were collected at four depths (0-20, 20-50, 50-80, 80-100 cm) from 12 stratified randomly selected HGs with three size classes, viz. small (<0.5 ha), medium (0.5-1.0 ha) and large (>1.0 ha); and two age classes, viz. young (<10 years) and old (>10 years). SOC and soil carbon stock were determined. Results indicated that the SOC at different soil depths was directly related with the age of the HGs. The relative difference (%) of SOC between old and young HGs ranged from 24.69 to 70.23% with a median value of 53.509 %. SOC concentration is inversely related with the size of HGs in both age groups with a significant difference in young HGs ($p < 0.05$) and non-significant difference in old HGs ($p > 0.05$). Overall, within 1m profile, soil carbon stock ranged from 88.920 tC.ha⁻¹ to 284 tC.ha⁻¹ (tC = 10⁶ g). The relative difference (%) of soil carbon stock between old and young HGs over small, medium and large HGs was 47.96, 55.36, and 44.20 % respectively. Soil carbon stock, especially below 50cm, was higher in the old HGs than in the young HGs. This study provides useful baseline data and strategic research needs to implement soil carbon sequestration (SCS) through homegarden agroforestry systems as a mitigation option for the increasing atmospheric CO₂ level.

Keywords: *soil organic carbon, soil carbon stock, homegardens, climate change*

AD2.1.7. Estimation of soil organic carbon stocks in the croplands and grasslands of India

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Climate change is presently an urgent and complex problem of concern to people across the world. Estimation of carbon stock and carbon stock changes in different land use systems is important to understand the role played by different land use systems in promoting or mitigating climate change. Estimation of carbon stock under croplands and grasslands of India was done based on secondary data sources, viz., research articles, reviews, thesis, reports and other available sources. 214 data entries in the database were analysed for the purpose and results analysed state wise, AEZ/sub AEZ-wise and also according to different cropping systems. The analysis showed the average soil organic carbon (SOC) stock under croplands and grasslands in India to be 68.53 (SD \pm 93.84) tonnes per hectare. Highest carbon stock was found in the croplands and grasslands of Assam, followed by Maharashtra and Madhya Pradesh, while the minimum is reported from the states of Himachal Pradesh and Sikkim. Among the AEZs, carbon stock ranged from 1.18 tC/ha in the Eastern Plateau (Chhotanagpur) and Eastern Ghats, hot subhumid ecoregion, Eastern Coastal Plain to 190.01 tC/ha in

the Assam and Bengal Plain, hot subhumid to humid (inclusion of perhumid) ecoregion. Based on cropping systems, maximum SOC stock was found in cotton-based cropping system, followed by sorghum-based and groundnut-based cropping systems while the minimum was under plantation crops in agriculture followed by barley-based cropping systems. Many problems were encountered while estimating, like different methodologies used in different studies for SOC estimation, lack of clarity on the methods adopted in many studies and not following a uniform reporting format for SOC estimation. There is therefore a need to adopt a common framework or methodology for reporting carbon stock of soil with increased accuracy.

Keywords: carbon stocks, croplands, grasslands, climate change

AD2.1.8. Growth, biomass production and C-sequestration by three predominant tree species in North- Western Rajasthan

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The importance of tree species as sinks for carbon sequestration is receiving wider recognition. Agroforestry offers the suitability of arid soils for their conservation, vegetative carbon storage and improved soil organic carbon. However, very few C storage data of tree species are available in the arid north-western part of Rajasthan. Hence the present study was conducted to estimate biomass production, carbon storage and soil carbon sequestration under 28-year-old *Acacia tortilis*, *Acacia senegal* and *Colophospermum mopane* in Bikaner, Rajasthan. A significant variation in plant height, collar diameter and biomass was observed among the three species. The biomass of tree species ranged from 22.23 to 108.64 kg plant⁻¹ on dry weight basis. The highest biomass was observed in *Acacia tortilis* followed by *Acacia senegal*. Considering the weight loss during drying, maximum weight loss (40.5 %) was observed in the above-ground biomass of *C. mopane* and lowest (42.7 %) in *A. senegal*. The *A. tortilis* produced the largest C storage in bole+branches C (16.09 t ha⁻¹) followed by *A. senegal* (11.89 t ha⁻¹) and *C. mopane* (8.27). Soil organic carbon (SOC) density for a metre of soil profile was 2756, 2580 and 2284 g/m² under *A. tortilis*, *A. senegal* and *C. mopane*, respectively, which were significantly higher than soils under long fallow (877.5 g/m²). SOC density increased by 210%, 190% and 157% under *A. tortilis*, *A. senegal* and *C. mopane*, respectively over long fallow on similar soils. These tree species could sequester 6.84, 6.20 and 5.11 kg/m² more atmospheric CO into the soil equivalent to 18.98, 16.91 and 13.95 tC/ha. In this study, *A. tortilis* and *A. senegal* were reported as faster in growth and higher carbon storage in above-ground biomass compared to *C. mopane* which is slower in growth and less carbon storage.

Keywords: biomass, C-sequestration, *Acacia tortilis*, *Acacia senegal* and *Colophospermum mopane*, arid

AD2.1.9. Introduction and evaluation of *Paulownia fortunei* based tree-crop intercropping systems in Doon Valley, India

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The wonder tree *Paulownia* is an ideal agroforestry tree that was introduced in India from China in 1993 at the Forest Research Institute, Dehradun. But its systematic introduction as an agroforestry species was initiated for first time at Doon Valley in Uttarakhand at CSWCRTI, Dehradun in 1998. *Paulownia* tree effectively protects under storey crops and favourably modifies microclimate and therefore plays a vital role in yield improvement of various field crops under agroforestry land use system.

The study was carried out in farmers' fields in Doon Valley to evaluate the performance of different genetic materials of *Paulownia* and *Populus* as the tree component of the agroforestry system in combination with maize-wheat rotation under rainfed conditions. The climate of the area is sub-tropical with 1700mm rainfall. One-year-old plants of *Paulownia* (C020, C03 and Guozhou Provenance) and *Populus* (G-48 and D-121) were planted in pits (45X45X60cm) at 6x5m spacing along with crop rotation of maize (in kharif) and wheat (in rabi).

In this study, *Paulownia* has grown successfully in association with maize and wheat crops with a higher survival rate of more than 150% over poplars. The height of the trees among the different clones does not differ significantly when grown under rainfed agroforestry situations and the leaf size of *Paulownia* reduced gradually with age. The *Paulownia* clone-GP outperformed all the clones of the two species and recorded maximum survival and growth. *Paulownia* and poplar did not have any significant negative effect on almost all the growth and yield parameters of maize and wheat crop when grown in association with different clones which indicates the compatibility of both crops with *Paulownia* and poplar trees. Thus, it was inferred that the species has great potential as an agroforestry tree in India under similar edapho-climatic conditions.

Keywords: agroforestry model, new tree introduction, *Paulownia*, wheat and maize

AD2.1.10. Carbon storage potential and bioeconomic appraisal of land use systems in dry temperate north western Himalayas

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The present investigations were carried out in the Kinnaur district of Himachal Pradesh, which falls under dry temperate north-western Himalayan ecosystems with the objectives of identifying the land use system having high carbon storage capacity and economic returns. For conducting this study, three sites were selected randomly and each site was considered as replicate. Mountainous slope of each site was stratified into three altitudinal gradients viz., 1900-2170m, 2171- 2440m and 2441-2710m a.s.l. In each altitudinal gradient six land use systems i.e., agriculture, horticulture, agrihorticulture, agri-horti-silviculture, silvipastural and barren land, which were common to all the three altitudinal levels were selected. The data was analyzed using Randomized Block Design (RBD). Maximum total biomass (104.10 t ha⁻¹) was recorded in the silvi-pasture (T) land use system and total biomass production of different land use systems followed the order: silvipasture > agri-horti-silviculture > agrihorticulture > horticulture > agriculture > barren land, respectively. This trend is the same for biomass carbon density (t ha⁻¹) of different land use systems. Carbon stock increased with the increase in altitudinal level. Maximum soil carbon density (155.77t ha⁻¹) in (0- 100cm) layer was in the agrihorticulture land use system. Total ecosystem carbon density (soil+plant) followed the trend agrihorticulture > agri-horti-silviculture > silvipasture > horticulture > agriculture > barren land, respectively. Maximum net profit

was attained by agrihorticulture system (INR 1 310 000), which was closely followed by horticulture (INR 1 165 852) land use system. Net profit obtained increased appreciably as we moved from the lowest to the highest elevation range. The study concluded that agrihorticulture systems are better land use as they provide very high economic returns and carbon storage potential in comparison to other land use systems in general and agriculture in particular.

Keywords: *land use system, altitudinal gradient, agroforestry system, plant and soil carbon density*

AD2.1.11. Assessment of carbon sequestration in coffee-based agroforestry system in central Western Ghats of Kodagu district

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This study assessed the potential of carbon sequestration in coffee-based agroforestry systems in the watershed areas of Cauvery River in the Kodagu district of central Western Ghats of India. Coffee-based agroforestry system has been classified into two distinct agroclimatic conditions such as evergreen and moist deciduous vegetation where coffee is grown under the shade of *Grevillea robusta* alone. Mixed native tree species shade were used for comparative assessment of carbon sequestration. Results indicate that carbon sequestration was highest in mixed shade trees (70.90 t/ha) compared to *Grevillea* trees (39.23 t/ha). It was mainly due to higher girth, height and tree density which resulted in higher basal area. It is also due to species composition of two vegetation types and the age. Poor growth of *Grevillea* in evergreen vegetation indicates its unsuitability for this region; although farmers prefer it as a source of secondary income and useful for pepper cultivation. Leaf litter which is another source of soil carbon was highest in evergreen vegetation type (3.43 t/ha) compared to moist deciduous vegetation (1.84 t/ha). Soil organic carbon did not differ among different vegetation types studied. The total soil carbon in coffee plantations was highest in native plantations under evergreen vegetation type (831.76 µg/g) and least in exotic plantations of evergreen vegetation (669.46 µg/g). The variation in carbon stocked in coffee plantations in these different vegetation types is mainly due to above-ground biomass of the standing trees of different species and age. The species diversity was highest in coffee plantations of evergreen vegetation compared to moist deciduous vegetation. The total number of tree species in the coffee plantation was 165. High diversity of species is due to variations in climatic conditions.

Keywords: *carbon sequestration, climate change, agroforestry, coffee plantations*

AD2.1.12. Canavalia: a multipurpose future legume for agro-forestry systems for sustainable development

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Agroforestry is an age old practice in India for thousands of years to cater the various needs of human being as well as animal population also. Integration of suitable understory crop under different multipurpose tree species is prerequisite for successful agroforestry system. *Canavalia* is an under-exploited, understory legume which is predominantly used as a pulse, vegetable, forage and medicine

by ethnic people of India. It is considered to be a cheap source of protein, vitamin and minerals for human and livestock. Eleven indigenous and seven exotic accessions of four species of *Canavalia* (*C. gladiata*, *C. virosa*, *C. ensiformis* and *C. brasiliensis*) have been collected, and evaluated for food and forage yielding traits in the semi arid region of Bundelkhand of Central India. *C. gladiata* gave highest response for plant height (10-22m), no. of leaves (54-118), leaf length and width (4-16cm and 2.5-9cm), pod length and width (3.5-22cm and 2.8-4.2cm), no. of pods/plant (2-43), no. of seeds / plant (2-16), 100-seed weight (18.4-24.4g) seed length and width (2.0-3.2cm and 0.4-0.5cm), no. of seeds per pod (2-16), seed hilum length (2.5-3.1mm), palatability and preference (+++) of livestock among the four species. However, *C. brasiliensis* was found to be the lowest seed yielder (3-6 seeds/plant) and showed poor response for grain and vegetable yielding traits but it was found good source of green fodder yield due its maximum number of foliage and vigorous growth. Thus, *Canavalia* can be a suitable option as an understory crop in various agroforestry systems in India. Further, a systematic research on production potential, nutritional quality and anti-nutritional factors under various agroforestry systems is needed to improve this important crop for good quality vegetable pods, high yielding pulse crop and for high herbage attributes to overcome the problem of malnutrition in human and livestock worldwide.

Keywords: *L-Dopa, medicinal plant, tribal pulse, vegetable*

AD2.1.13. Carbon sequestration and emission reduction through tree and energy based interventions for mitigating climate change

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Carbon has become a tradable commodity due to the Kyoto and Cancun Protocol, whose market value was \$176 billion in 2011. The small holders collectively qualify for the minimum tradable carbon amount through carbon sequestration and emission reduction but are usually left isolated, mainly for the rigid and expensive CDM protocol. The alternative protocol developed by ICRAF comply the carbon trading rules in the CDM. In this approach, farmers are allowed to continue doing their normal farming practices, but are encouraged to incorporate carbon sequestering and/ or emission reducing practices. The protocol took a grid based approach and it was located between 29° 34' 40" and 29° 37' 16" latitude and 79° 33' 33" and 79° 36' 31" longitude in Almora district, Uttarakhand, India, which covered 2624 ha area and 13 villages having 1062 householders. Horticulture in private lands and silvi-pasture in common land were implemented for carbon sequestration. Replacement of Edison bulb with CFL, fuel-wood with biogas and solar cooker, and kerosene lamp with solar lantern were implemented as carbon emission reduction interventions. The tree based interventions i.e. 58,768 propagating materials of fruit and 8,700 oak saplings were planted in private and community land, respectively with help of small and marginal farmers during 2010 to 2013, which covered 30 ha area. The energy based interventions i.e. 2032 CFL, 68 solar lantern, 10 solar cooker and 6 biogas plants were installed in the grid area for carbon emission reduction. The standard methods were followed for estimation of carbon sequestration and emission reduction. The potential certified emission reduction (CER, 1 CER = 1 ton CO₂) through carbon sequestration from the grid area could be 18865. The carbon emission reduction was about 251 CER year⁻¹. The reduction in electricity bill was estimated as \$ 17,000 year⁻¹ by using

CFL. Kerosene consumption was reduced by 1224 litre year⁻¹ with the use of solar lantern. The fuel wood consumption was reduced by 32 ton year⁻¹ with the use of solar cooker and biogas plant in the grid area. Thus, the farmers' socio-economic status will be enhanced through increased livelihood opportunity. Further, the community will be benefitted from carbon trading and will be able to help in mitigating the climate change through the implemented interventions.

Keywords: carbon sequestration, carbon emission reduction, carbon trading, climate change mitigation

2.2 Tropical home gardens: multifunctionality and benefits

AD2.2.1. Prevalence of homestead gardens in hilly regions of Uttarakhand state of India

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Homestead gardens are recognised worldwide as a significant and sustainable part of agroforestry systems, particularly in hilly regions. They can be characterised as a land use system located close to the house where woody and non-woody species are intimately arranged in several overlapping canopy layers, sometimes in association with domestic animals. The basic objectives for maintaining this agroforestry system is to ensure availability of multiple products such as food, fuel, vegetables, fruits, fodder, medicines besides generating income and employment. Agroclimatic conditions of Uttarakhand are favourable for home gardens due to small villages and diversified requirements. The study examines the species composition, diversity, role in livelihood and economy and prospects. The study was conducted in different villages of Kumaun and Garhwal regions of the Uttarakhand. The resource use efficiency differs from farmer to farmer mainly due to variations in access to input use particularly land, fertilizers, irrigation facilities and socioeconomic conditions of farmers. The process of intensive agriculture leads to decrease in the tree/shrub population, ignoring the ecological problems. Home gardens have traditionally been managed and adopted by farmers especially in hilly regions of Uttarakhand. Prevalent tree species in homestead gardens were found to be poplar, mango, *Ficus species*, *Haldina cordifolia*, *Bauhinia species*, Eucalyptus, *Toona ciliata*, *Spindus*, etc. in Kumaun and *Grewia optiva*, *Celtis australis*, *Ficus species*, *Quercus species*, *Boehmeria rugulosa* in Garhwal region and many fruit bearing trees such as apple, plum, peaches, walnut, guava, citrus with various agricultural crops. Homestead gardening exists as the subsistence and non-commercial farm forestry in hills of both the regions. The structural and functional study of home gardens offers the opportunity to understand the trends in socioeconomic sustainability and how these relate to economic and ecological sustainability.

Keywords: hill agriculture, homegardens, homestead gardens, subsistence farming

AD2.2.2. Homegarden agroforestry system: a food zone for household security and sustenance

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Homegardens are traditionally well known agroforestry systems. Home gardens are also known as mixed, backyard, kitchen, farmyard, compound or homestead gardens. This system is the finest family food production system. A survey was conducted in 15 homegardens in NERIST campus, Nirjuli, Arunachal Pradesh to elucidate species diversity, utilization patterns and their importance with respect to food security. Vegetable species like *Abelmoschus esculentus*, *Raphanus sativus*, *Solanum spp.*, *Cucurbita maxima*, fruit species like *Mangifera indica*, *Musa spp.*, *Ananas comosus*, *Carica papaya* and leafy vegetable species like *Spinacia oleracea*, *Brassica juncea*, and *Corchorus capsularis* were major plants in homegardens. *Moringa oleifera* and *Mangifera indica* constituted the top storey; *Carica papaya*, *Musa spp.*, *Psidium guajava* formed the third storey; *Colocasia esculenta*, *Solanum melongena* formed the second storey; and *Capsicum spp.*, *Solanum tuberosum*, *Raphanus sativus*, *Ananas comosus*, *Spinacia oleracea* formed the first storey. Climbers like *Cucurbita maxima*, *Phaseolus spp.*, *Lagenaria spp.* were found. All the vegetable plant species found in the homegardens were cultivated. Households are the main source of labour. Both men and women contributed time for land preparation, cultivation and harvesting of home garden produce. The households surveyed were categorised into three income groups namely the highest, middle and lowest income families. It was found that the lowest income group families were the most dependent on the homegardens as compared to the highest income groups. Most of the vegetable requirements of the diet came from the homegardens. The homegarden products were used for fulfilling household food requirements and not sold in local markets. This was a low input and high output system. The families could get organic, nutritious and fresh produce on a daily basis. Thus, homegarden agroforestry system can be a sustainable strategy for improving food security.

Keywords: food security, homegarden, species diversity, utilization pattern

3.0 The business of agroforestry: applying science

3.1 The viability of trees as crops: agroforestry, pulp and wood-based enterprises, cocoa, coffee

AD3.1.1. Role of the private sector in the promotion and sustenance of commercial agroforestry

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The private sector is one of the key stakeholders in the promotion and sustenance of agroforestry in India. It has developed symbiotic partnerships with farmers to grow trees in association with agricultural crops on their fields. This practice of growing trees and intercrops together on farm fields for sale is often referred to as commercial agroforestry which is now happening in many parts of the country. Acute shortage of wood raw material with its rising demand, declining availability from government forests, and inability of private sector to hold agricultural land for captive plantations forced many of them to promote tree culture to ensure adequate wood availability. It is also promoted under corporate social responsibility (CSR) by some and many others developed it as an independent business line. Paper & pulp and safety matches industries have been promoting tree culture for a few fast growing tree genera like *Eucalyptus*, *Populus*, *Casuarina*, *Leucaena*, *Ailanthus*, *Acacia*, etc. Short rotation cycles and high biomass production potential of these trees with assured buy-back arrangements for wood led to the large scale adoption and sustenance of commercial agroforestry. The sector is actively engaged in sustaining the activity through production and supply of planting stock of

genetically superior cultivars; developing new productive cultivars; providing extension, credit and R&D support; ensuring wood procurement at market competitive prices; and acting as a single window for agroforestry solutions on selecting site specific tree species and cultivars, technical inputs on tending operations for quality wood production and integrated crops.

The country faces a chronic shortage of wood raw material for industrial and domestic needs. This land-use for its production is likely to continue, and even grow over the years. Policy and institutional reforms are urgently needed to strengthen back-end and front-end linkages for long-term sustenance of this land use system.

Keywords: private sector, promotion, sustenance, commercial agroforestry

3.2 Biofuels: using trees as a sustainable energy resource

AD3.2.1. Effect of pre sowing treatments on seed germination of *Hydnocarpus pentandra* - a potential biofuel tree

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The world is facing twin crises of fuel shortage and environment degradation, indiscriminate extraction of fossil fuels has reduced the supply and we are in urgent need of new sources of fuel. Biofuel is one of those sources. Our forests have many such trees still unexploited and which produce seeds with high oil content that can act as source of raw material for biofuel production. *Hydnocarpus pentandra* is one such species belonging to genus *Hydnocarpus*. The seeds contain about 63.25 per cent of oil called *Hydnocarpus* oil which is non edible and hence can be used in biofuel production after proper research. It also has medicinal value in treatment of *Lepromatous leprosy* and is effective in decreasing size of nodules, anaesthetic patches, skin lesions and has a antihelmintic action against human tapeworm. As a result of the high medicinal properties of the oil, exploitation of wild fruits is going on and is one of the reasons for the reduction in natural population of this species. Delayed germination also hinders natural regeneration of this tree. Hence there is need to determine a suitable pre-treatment for germination of this species. This will ease in domesticating it by raising plantations and utilize its potential as biofuel species. The current study was carried out to assess the influence of different pre sowing treatments on the germination of *Hydnocarpus pentandra*. A total of thirteen treatments were applied with the treatment of alternate wetting and drying in cow dung slurry for fifteen days showing significant maximum germination at 72.67 per cent and other germination parameters over control. This was followed by treatment of alternate wetting and drying in water for 3 days. Lowest germination was observed in treatment with bleaching powder. Hence cow dung slurry treatment can be used for successful propagation of this species and thus remove hurdle in its future research.

Keywords: biofuel, cow dung, *Hydnocarpus pentandra*, seeds

3.4 Building livelihoods on tree products

AD3.4.1. Farmers tree preferences: opportunities and challenges for agroforestry product value chain development in Ethiopia

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Key challenges facing many developing countries like Ethiopia are food insecurity, unsustainable natural resource management and vulnerability to climate change. Agroforestry has been proposed as having the potential to produce food in a more sustainable manner. This study aims to identify key tree products that can be used in an agroforestry system in the east and west Shewa zones of Ethiopia based on their market potential, and to understand the opportunities and constraints in their value chains. Key informant interviews and focus group discussions (FGDs) with key actors along the tree products value chains were used to collect data. Findings reveal that in general tree products are of less priority to farmers who tend to be more interested in food crops mainly cereals. The most important tree products as ranked by farmers in east Shewa included eucalyptus, papaya, coffee, mango and gesho. In the west Shewa zone the key products include coffee, eucalyptus, khat and mango. Major constraints in the value chains of the prioritized species are drought especially in the east Shewa, inadequate supply of germplasm and lack of extension information for highly ranked species. Analysis of the competitiveness of the prioritized species indicates that for most of the tree species there is a high level of demand which exceeds its current supply meaning there is no threat of competition among traders and producers. Furthermore, there are diverse sources of germplasm supply and hence no threat of substitutes which can erode profitability. It is recommended that for further promotion of the prioritized species there is the need to deal with water supply problems, provide extension services to the seemingly neglected species like khat and eucalyptus, supply planting materials and enhance better regulations for tree planting.

Keywords: *Porter's five forces, priority setting, tree planting*

AD3.4.2. Eradication of poverty and sustainable livelihoods security through tree products

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Tree products offer a highly diverse array of income earning opportunities for gatherers, hunters, traders, producers and processors. Trees provide a range of livelihood options and employment opportunities through managing natural stands and raising plantations and marketing of timber and non-timber products. For centuries, small farmers have nurtured trees for the social, economic and environmental benefits they provide. Such plantations (agroforests) generate cash income and ensure reliable supply of food, home grown medicines and substitutes for products they cannot afford to buy, for example, nitrogen-fixing tree plants instead of mineral fertilizers, green fodder instead of dairy meals, and biofuels instead of petroleum products.

The tropical and subtropical drylands face the gravest threats to lives and livelihoods of about 2.5 billion people. Improved food security and resilience can be achieved through planting of cultivated fertilizer trees, fruits and nut trees and woody leafy vegetables. Livestock can represent a ladder out of poverty for millions of smallholders, agropastoralists and pastoralists. Livestock already accounts for some 40 percent of total agricultural GDP globally. Trees and shrubs provide green fodder throughout the year, which enables the poor to rear milch cattle and for livelihoods security.

About 40 percent of the world's population relies on fuelwood or charcoal as their primary source of energy for cooking and heating. Biomass energy production could represent a significant opportunity for livelihoods security. Forest industry and small and medium forest enterprises (SMFEs) contribute to more than 1 percent of global GDP. They provide livelihoods to about half a billion people. Non-wood forest products (NWFP) are large contributors of livelihoods including via SMFES. For achieving sustainable livelihoods through tree products more serious policy attention, increased green investments, legal and governance changes are needed.

Keywords: *biofuel, biomass-energy, green-fodder, NWFP*

AD3.4.3. Enhancing harvest value of agroforestry trees: the effect of ethephon on gummosis and gum quality in *Butea monosperma* Lam.

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Ethephon (2-chloroethylphosphonic acid) has been used for enhancing gummosis in several plants including gum arabic. Through this study we made an effort to extend the use of ethephon for inducing gummosis in *Butea monosperma* (Lam.) and enhance the harvest value of naturally growing stands (10-15 trees/ha) of an important multipurpose tree species of agroforestry in Bundelkhand of central India. We evaluated the effects of ethephon on gummosis and the physical and chemical properties of gum from *Butea monosperma*. Field trials conducted at the Research Farm consisted of three methods of ethephon application viz., spray on stem before knotching, spray on stem after knotching, injection in a hole at base of tree trunk and control (only knotching); and three doses of active substance of ethephon viz. 390, 780, 1170 mg/4ml. The gum was analyzed in a laboratory for physical and chemical properties. The findings revealed that the yield of gum-butea significantly increased by application of ethephon, however, doses of ethephon had no effect on gum yield. On average, the maximum amount of gum-butea was obtained when ethephon was sprayed on the surface of tree stem before knotching. Use of ethephon significantly increased moisture, compressibility index and ash content, and reduced bulk density, nitrogen, protein and sugar content of gum-butea. However, various doses of ethephon solution had no effect on quality parameters. Based on the comparison of quality characteristics of gum-butea in this study with its previous reported characteristics and international standards of gum arabic (*Acacia senegal*), it is concluded that gum-butea appears to be at *par* with gum arabic and deserves a fair price in the commercial market. *Butea monosperma* based agroforestry systems offer potential livelihood options in poverty-stricken arid and semi-arid regions and agricultural resilience against climate change. Further research is needed to standardize seasons of tapping gum-butea with the application of ethephon for confirming its utility.

Keywords: *agricultural resilience, arid and semi-arid region, Bundelkhand, gum characteristics*

AD3.4.4. The tree seed industry in Malawi and Zimbabwe: A tale of two contrasting systems Betserai Isaac Nyoka¹, Mduduzi Tembani², Henry S Phombeya³, Michael Likoswe⁴, Godfrey Kundhlande¹, Gudeta W Sileshi¹, Livai Matarirano⁵, Tembo Chanyenga⁴

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There is debate about the sustainability of tree seed supply systems in many countries in sub-Saharan Africa when a large proportion of the end users are mostly resource-constrained smallholder farmers. A sustainable seed system is one that ensures that high quality seeds of the preferred sources and species are produced and widely available at the right time, and at affordable prices to farmers and other stakeholders. We report on two contrasting formal tree seed supply systems in Malawi and Zimbabwe in relation to production, distribution, markets, quality control mechanisms, seed pricing and ultimately sustainability. The tree seed industry in Zimbabwe is largely centred on species used in commercial forestry while in Malawi seed of species used in agroforestry systems form the bulk of the seed passing through formal channels. Over 95% of the seed sold in Zimbabwe is sourced from seed orchards compared to 10% in Malawi. The major producers of the seed are smallholder farmers in Malawi and to a limited extent, the government and an international organisation. In Zimbabwe, most of the seed orchards are owned by a quasi-government agency and a few by an international organisation. The major buyers of tree seed in Zimbabwe are commercial forestry companies; while NGOs are the major buyers in Malawi. In both countries, government seed purchases constitute a small proportion of the total seed sales. Both governments do not support resource-constrained smallholder farmers to access seed at affordable prices. The tree seed purchased by NGOs and the little from the government is distributed to smallholder farmers for free. Smallholder farmers' decision to buy tree seed is constrained by cash as they face many competing household needs especially for food. The tree seed industry in Malawi has limited control mechanisms for ensuring seed quality; and centralisation and pricing perhaps restricts farmers' access.

Keywords: *high quality germplasm, NGOs and commercial companies, smallholder farmers, sustainable seed supply system*

AD3.4.5. Standardization of agrotechniques for cultivation of Sarpagandha (Rauvolfia serpentina) under Poplar (Populus deltoides)

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Sarpagandha (*Rauvolfia serpentina*) belongs to the Apocyanaceae family, and is a medicinal crop. The part containing more than 30 alkaloids mainly serpentine & rescinnamine are age-old practices for the remedies of high blood pressure, fever, dysentery and insomnia. During recent years farmers of eastern & western Uttar Pradesh have started the cultivation of Sarpagandha under agroforestry system using suitable management practices. A study was conducted at the research plot of the School of Forestry & Environment SHIAT, Allahabad on a project entitled "Standardization of techniques for cultivation of Sarpagandha (*Rauvolfia serpentina*) under Poplar (*Populus deltoides*) based agroforestry system" during the year 2009-2011, sponsored by CST, Lucknow. In the first trial there were three spacings (45 cm x 30 cm, 45 cm x 45 cm, 45 cm x 60 cm) and four levels of inorganic fertilizers (N15 P20 K15 Kg/ha, N30 P40 K30 Kg/ha, N45 P60 K45 Kg/ha, N0 P0 K0 Kg/ha) were taken under poplar based agroforestry system. In the second trial four levels of organic manures and three levels of irrigation schedule were applied. From the first trial it was observed that treatment **S2F3** [Spacing **S2** (45cm X 45cm) with inorganic fertilizer dose **F3** (N45 P60 K45)] was found to be superior under poplar based agroforestry system. Maximum economic returns were obtained in treatment **S2F3**. From the second trial it was observed that treatment **I2F3** [Irrigation schedule **I2** - once in 15 days

during the hot dry season and once in 30 days during winter and organic manure dose F3 (20 t/ha)] was found to be superior under poplar based agroforestry system. Highest economic return was observed in treatment **I2F3**.

Keywords: *alkaloides, agroforestry, standardization of techniques, organic manures, irrigation*

AD3.4.6. The business of Nepalese agroforestry: applying science to improve livelihoods

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Forests are an integral part of the farming system in Nepal and form a vital resource for livelihood especially in rural areas. Forest resources are mainly used for domestic purposes although trading of some amount of Non-Timber Forest Products (NTFPs) prevails in the country. A large share of Nepalese population, approximately 70%, is forest dependent and about 64% use firewood as the primary source of fuel for cooking. Even though 23% of Nepal's forests are under community forestry management, the rural population still has inadequate forest-livelihood opportunities and food insecurity is common. Out-migration in search of employment has resulted in significant areas of under-utilised and abandoned agricultural land which exacerbates food security problems.

In this context, development of agroforestry systems that generate livelihoods and provide food security are crucial for economic prosperity and political stability in rural Nepal. To set the trajectory for agroforestry development, we must first understand the nature of existing agroforestry systems, some of the commercial opportunities and the social, institutional and policy environments impacting this development.

This paper begins with a description of the traditional agroforestry systems and species that emerged under subsistence economy, and recent (last 20 years) agroforestry systems and species which have been developed to improve productivity of subsistence farmers, or part-time commercial activity. Essentially these can be divided into farm-based and forest-based agroforestry systems. In particular it describes systems incorporating fodder species and NTFPs. We then propose innovations that could enhance commercial opportunities of land owners, options, and possible problems with agroforestry systems on under-utilised private land. This section focuses on the mid-hills region of Nepal.

The social, institutional and policy environment impacting agroforestry development is then described, as well as a methodology for equitable development of agroforestry innovations.

Keywords: *food security, livelihood, Nepal, NTFPs*

AD3.4.7. Agroforestry's contribution in enriching soil fertility to improve livelihoods of the subsistence farm households in the Hills of Nepal

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Livelihoods of subsistence farming communities in the hills of Nepal have been threatened owing to stagnant agricultural production, depleting forest resources, small fragmented land holdings and

intensive use of land. Confronting with dwindling forest and on-farm fodder supply and restriction on free fodder collection and livestock grazing in community managed forests; farmlands have experienced soil fertility depletion. Livestock keeping as an integral part of the farming systems to supply farmyard manure largely depends on availability of fodder. There is growing evidence that promotion of suitable agroforestry systems for marginal lands can be a potential solution to improve soil fertility. This paper assesses the potential role of agroforestry to improve soil fertility on marginal farmlands with reference to initiatives undertaken by Nepal Agroforestry Foundation (NAF). The on-farm plantation of suitable fodder and grass species has made a positive contribution to soil fertility, with soils under agroforestry system containing relatively higher amounts of soil nutrients (OM, N, P and K) compared to the conventional system. The spatial distribution of farmland parcels showed that irrespective of type of land they possess- rainfed upland (*bari*) or irrigated (*khet*) land, parcels located closer to farm houses had concentration of agroforestry species, received higher inputs, better management and had higher cropping intensity. The households involved in promoting existing system by planting exotic agroforestry species on terrace risers, edges of farmlands and fallow lands have benefitted from improved soil fertility. Thus, in the hills agroforestry has great potential for increasing farm productivity through its positive contributions to soil fertility and better utilization & enrichment of marginal farmlands.

Keywords: agroforestry, fodder and grass species, soil fertility, soil nutrients

4.0 Sustaining development through agroforestry

4.1 Meeting development challenges with integrated approaches

AD4.1.1. Bamboo-based silvipastoral system in rainfed condition of Madhya Pradesh

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A field experiment was conducted at Dusty Acre Research Farm, Department of Forestry, JNKVV, Jabalpur during 2008-2009, 2009-2010 and 2010-2011 comprising 8 treatment combinations i.e., 2 bamboo species viz., *Dendrocalamus strictus* and *Bambusa arundinacea* with *Sesbania gradiflora* (Agast) planted within bamboo rows at a spacing of 5 m in main plot and 4 grasses viz., *Dicanthium annulatum* (Marvel grass); *panicum maximum* (Guinea grass); *Cenchrus ciliaris* (Anjan grass) and *Pennisetum purpureum* (Hybrid Napier) with stylo as inter row in sub plot under split plot design with 3 replications. The bamboos were planted in 5m x 5m spacing. Results showed that growth parameters of bamboo species were influenced by different grasses. Significantly maximum height (413cm), collar diameter (29.7 cm), clump circumference (113 cm) was recorded in *C. ciliaris* at par with *D. annulatum* and *P. maximum*. In all the three years, bamboo species showed no significant effect on green fodder production of grass and stylo. *Pennisetum purpureum* recorded significantly higher green fodder yield of 29.66, 373.5 and 32.49 t ha⁻¹ in the first cutting, whereas 105.41, 77.3 and 7.30 t ha⁻¹ in the second cutting during 2008, 2009 and 2010, respectively and was significantly superior to other grasses. *Panicum maximum* recorded green fodder yield of 67.96, 371.1 and 29.49 t ha⁻¹ during 2008, 2009 and 2010, respectively, which was significantly inferior to *Pennisetum purpureum* but superior to *C. ciliaris* and *D. annulatum*, which were at par in all the three years of experimentation. Total green fodder (grass + stylo) production under bamboo species showed no significant difference in both the cuttings in all the three years. Different grasses showed significant difference in total green fodder production in both cutting during 2008, 2009 and 2010. *Pennisetum*

purpureum with stylo grass recorded significantly higher green fodder yield of 105.41, 504.3 and 4.6 t ha⁻¹ during 2008, 2009 and 2010, respectively. It has been also observed that grass production was low in the first year i.e. establishment year, and increased and maximum in the second year and further reduced with increasing age. This is true in all the four species grown with bamboo. Hence it is concluded that in bamboo-based silvipastoral system growing of *P. purpureum* is most productive and remunerative as compared to *P. maximum*, *C. ciliaris* and *Dicanthium annulatum* under rainfed condition of M.P.

Keywords: *silvipastoral, Dendrocalamus strictus, Bambusa arundinacea, pennisetum purpureum, panicum maximum, Dicanthium annulatum and Cenchrus ciliaris*

AD4.1.2. Growth and canopy spread of C. mopane and H. binata under silvipastoral system in arid environments

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A field experiment was conducted during 2001 to 2011 at Central Arid Zone Research Institute, Jodhpur to assess the growth of *Colophospermum mopane* and *Hardwickia binata* tree species silvipasture system in arid environments. 96 trees of each species were planted at 9 x 5 m spacing while *Lasiurus indicus*, *Cenchrus ciliaris* and cowpea were sown at 60 cm spacing between the rows of trees. The pasture components were grown with and without fertilizer. The survival of *C. mopane* and *H. binata* was 98% and 60%, respectively. Both tree species differed in plant height and canopy area. During the early growth stage, branching and growth of *C. mopane* was higher than *H. binata*. At later stages (10th year onward), the plant height was higher in *H. binata*. At 10 years of age, plant height and canopy area of *C. mopane* was 313 (± 7.32) cm and 8.55 (± 0.73) m²/tree, while for *H. binata* corresponding values were 326 (± 14.89) cm and 3.76 (± 0.82) m²/tree, respectively. The mean annual increment in plant height of *C. mopane* was 32 cm/ year up to six years and 22.3 cm for *H. binata* indicating slower growth of *H. binata* as compared to *C. mopane* at initial stages of growth. However, after six years the growth rate of *H. binata* (40 cm/year) was higher as compared to *C. mopane* (19.4 cm/year). The application of inorganic fertilizers in grasses had a positive effect on the growth of both the tree species during the early growth stages. Further cropping systems also affected the height and canopy area of *C. mopane* and *H. binata* tree. Growth of both trees was greater in grass-legume strip cropping as compared to sole strip of grasses. The study indicated that *H. binata* was more suitable for silvipastoral system having higher fodder value and less competition with grasses whereas *C. mopane* was found hardier and could be used for rehabilitation of degraded wastelands.

Keywords: *trees, silvipasture*

AD4.1.3. Succession of insect pest and population dynamic studies in Acacia nilotica (L.) Willd

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Studies on insect pest succession as is evident by the field incidence in thirty different treatments respectively revealed that about nine species of insects (four major pests and five minor insect) were observed to be associated with various weeks over four months (i.e. August to November) of rainy season on *Acacia nilotica* at Dust Acre Research Farm, Department of Forestry, College of Agriculture, Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur Madhya Pradesh in central India during 20011-2012. The first major group of insect pests observed attacking in the vegetative stage were bagworm *Eumeta crameri*, webworm (*Ethmia Hiramella*), green beetle (*Eumeta crameri*), hairy caterpillar (*Calltera grotei*) along with some minor insect pests such as green bug (*Coreidae*), geometrid caterpillar (*Ascotis infixaria*), black carpenter bee (*Xylocopa latipes*), larvae (*Lymantria incerta*), and tree hopper (*Oxyrachis Tarandus*). Bagworm was observed during the last week of July in all the three replications of crop habitat. The pest was present on the crop up to the last week of November i.e. whole season of vegetative growth stage of the *Acacia nilotica*. Webworm larvae were observed during the first week of August with the highest population which gradually decreased till the last week of November. Tree hopper was observed during the first week of August, constant population was observed in all the three replications of crop habitats, pest was present on the crop during the reproductive stage and remained available up to the last week of November. Green bug was observed during the first weeks of August. Pest was present on the crop from the vegetative stage and remained available up to second week of November i.e. end of the season of vegetative growth. It is necessary to identify the status of various insect pests of *Acacia nilotica* and it has become very essential to concentrate or focus on the bioagents, their status and reasons for their unavailability in the *Acacia nilotica* agroecosystem. Bagworm moth and webworm are gaining importance. The possibilities of getting resistant material should be explored. For exploiting biological control as a potent, low cost and environmentally safe tools for pest management in agroforestry research should focus on understating the influence of ecological and management factors on the dynamics of insect pest natural enemy population. Studies give indication that habitat manipulations have been found very promising.

Keywords: pest complex, crop habitat, *Acacia nilotica*

AD4.1.4. Management of degraded lands through innovative soil-water conservation practices for establishment of aonla-based horticulture

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Globally land degradation affects about one sixth of the world population. In India about 158.6 m ha areas are affected with land degradation. Under such a situation, a horti-pasture system provides the best and most economic alternative for utilization of class V and VI lands. In central India, water is always a critical factor under semi-arid situation. Establishment of horti-pasture in such areas becomes a challenging task due to topography, soil and water-related constraints. Growing fruit trees with fodder grasses gives an opportunity for better soil productivity, income and employment in mixed farming situations. Intercropping of the best adaptable fruit with grasses in the marginal soils can bridge the gap for forage availability to livestock.

A study was conducted at IGFRI, Jhansi during 2007-2012 for evaluation of the different innovative soil-moisture conservation practices for establishment and sustainability of aonla-based

horti-pasture system. Out of the five approaches tested, staggered trenches method was superior for available soil moisture at both the depths (0-15 cm and 15-30 cm) during the month of October and November. Due to this establishment of aonla was better. Rainwater harvesting at micro-level provided wetness near root zone which in turn increased survival and productivity. The pasture productivity recorded increasing trend (0.87t DM/ha to 7.24 t DM/ha) in the fifth year also. Results indicated that component-wise pasture productivity was variable with rains received. Even rainfall patterns produced grass and legume biomass in good proportion but deviation showed variable trend. In the drier season, *Stylosanthes seabrana* performed better than *Cenchrus ciliaris*. Biomass production of *C. ciliaris* & *S. seabrana* ranged from 4.95-5.95 t dry matter /ha. During the initial two years, legumes (*S. seabrana*) contribution in forage production was more (60-70%) which reduced in subsequent years up to 20-30% as compared to grass (*C. ciliaris*).

Keywords: aonla, degraded lands, horti-pasture, soil water conservation

AD4.1.5. Agroforestry-based composting from leaf litter: a new option for sustainable rural employment

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Evaluation of compost and vermicompost prepared from leaf litter of teak and bamboo and the effect of these activities on tree growth were studied. *Trichoderma viridi* was applied as a decomposing bio-agent along with earthworm (*Acina fotidii*) and cowdung slurry. It was observed that teak leaf litter produces better quality compost than bamboo leaf litter when treated with 10% cowdung slurry and *Trichoderma viridi* culture @ 1 kg/t. Also the decomposition of teak leaf litter was found faster than bamboo leaf litter.

In a process of vermicomposting it was observed that different combinations of cowdung and leaf litter influence significantly the nitrogen content of the vermicompost.

Maximum N% (1.04), P% (0.42) & K% (1.40) was recorded under treatment leaf litter and cowdung when mixed in proportion of 1:1. The effect on organic carbon content was non-significant.

Stakeholders are required to encourage village communities to run compost making, eco-friendly and mutually benefitting enterprises to generate employment in rural areas by protecting the environment.

Keywords: agroforestry, compost, leaf litter

AD4.1.6. Soil organic carbon and available nitrogen under different agroforestry systems

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The soil, an important natural resource, is influenced greatly by tree plantations in many ways. This study was conducted to find out the impact of different agroforestry systems on soil organic carbon and available nitrogen. Seven agroforestry systems viz *Pseudium guajava*, *Azardircahta indica*, *Jatropha curcas*, *Hardwickia binata*, *Bambusa vulgaris*, *Eucalyptus tereticornis* and *Acacia senegal* were selected for assessment of organic carbon and available nitrogen. The associated crops were chickpea (*Cicer arietinum*), wheat (*Triticum aestivium*), barley (*Hordeum vulgare*), lentil and mustard. From each agroforestry system, soils were analysed at different depths 0-15, 15-30 and 30-60cm. It was found that the soil organic carbon and available nitrogen were higher under the canopy when compared to outside the canopy. The *Jatropha*-based agroforestry system recorded 315.59 kg ha⁻¹ nitrogen followed by *Hardwickia binata* (314.12), *Acacia senegal* (288.32) and the lowest was noticed in control (250.67). At different depths the nitrogen was found to be (281.54 kg ha⁻¹ (0-15 cm), 267.65 kg ha⁻¹ (15-30 cm) and 216.16 kg ha⁻¹ (30 – 60 cm) and after the canopy 281.68 kg ha⁻¹ (0-15 cm), 255.50 kg ha⁻¹ (15-30 cm) and 254.82 kg ha⁻¹ (30-60 cm). In the case of soil organic carbon, *Pseudium guajava* recorded highest (4.4 g/kg), followed by *Bambusa vulgaris* (3.9 g kg⁻¹) and *Jatropha curcas* (3.5 g kg⁻¹). The lowest was noticed in control (2.1 g kg⁻¹). At different depths under the canopy it was 3.8 g kg⁻¹ (0-15 cm), 3.4 g kg⁻¹ (15-30 cm) and 3.5 g kg⁻¹ (30-60 cm) and outside the canopy it was 4.0 g kg⁻¹, 4.0 g kg⁻¹ and 3.6 g kg⁻¹ respectively. Soil organic carbon and available nitrogen decreased with the depth and were found higher under the canopy than outside the canopy as compared to control.

Keywords: agroforestry systems, available nitrogen, organic carbon, tree Canopy

AD4.1.7. Crop productivity and soil moisture variation pattern of agri-horti system in the arid zone of western Rajasthan

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In the arid zone of western Rajasthan, the inclusion of perennials in the cropping system under agri-horti system proved a boon for obtaining higher productivity per unit area and also as insurance against complete crop failure during adverse climatic situations. Introduction of canal and tube well irrigation in the area made it possible to integrate trees and crops together with minimum use of water with high water-use efficiency through drip irrigation system. The present investigation was carried out at the research farm of Central Arid Zone Research Institute, Regional Research Station, Bikaner on eight-year-old drip irrigated fruit trees i.e. citrus (*Citrus aurantifolia*), 'bael' (*Aegle marmelos*) and 'gonda' (*Cordia myxa*) plantation with intercropping of rainfed legumes and grasses to increase the system productivity per unit area and time. The highest plant height (340cm), stem girth (61.6cm) and canopy cover (18.0m²) of citrus was recorded with intercropping of mothbean which was 5.18, 50.24 and 59.43 percent higher over sole planting. The same trend was observed with bael and gonda. The variation in growth parameters of different tree species were found to be at par with intercropping of sewan (*Lasiurus indicus*) and aloe vera over no intercropping.

The growth, yield and yield attributing characters of both legumes i.e. mothbean (*Vigna aconitifolia*) and clusterbean (*Cyamopsis tetragonoloba*) were highest in intercropping with citrus but the effect was significant only with clusterbean. *Lasiurus indicus* grown as rainfed intercrop with citrus gave the highest plant height (92.3cm) and total dry matter yield (6.5 t/ha) which was 259.6, 185.58 and 437.19, 245.7 percent higher over intercropping with bael and gonda,

respectively. Aloe Vera intercropped with citrus gave highest green pad yield of 94.4 t/ha which was at par with bael.

Keywords: *agri-silvi-pasture system, clusterbean, Lasiurus indicus, mothbean, Citrus aurantifolia*

AD4.1.8. Livelihood dependency of Jhum farmers in north eastern India: a case study

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The north eastern region (NER) of India encompasses a broad range of ecological habitats from grasslands to closed humid forests, and distributed secondary formations to almost virgin natural forest. About 65 percent of the area is under forest. Unlike other parts of the country, the major portions of the forests are owned by communities or individuals. Shifting cultivation, locally known as 'jhumming', is a way of life for many of these tribes since time immemorial. About 19% of the total area under shifting cultivation in the hills accounts for 0.76 m ha that supports 4.43 lakh families for their livelihood. As a part of the flagship programme of the institute on 'jhum improvement', Sonidan village, Ri-Bhoi district, Meghalaya was adopted and suitable technological interventions were initiated for enhanced productivity and natural resource conservation. Their main livelihood source is from shifting cultivation and partly from forests. They belong to the Khasi tribal community and most of them practice jhum cultivation even up to 80 percent of the slope. The present jhum cycle is 6-7 years in the village. They grow ginger as a cash crop in the larger areas besides paddy and broomstick along with 7-10 miscellaneous crops in the jhum fields. Even though rice is the staple food, the area under rice is decreasing and the area under ginger increasing due to a better market price for ginger. They used to make bunds along the slope for ginger cultivation which accelerated the soil erosion. Pig rearing is a common practice in this village as most of them are non-vegetarian. Some farmers have back yard poultry with local breeds. There are forty fish ponds in this village. No household has LPG connection and hence they depend heavily on either the jhum fields or the forest for fuel. They mainly depend on the forest for timber, fuelwood, raw bamboo, bamboo shoots, broom sticks, and some leaf vegetables etc. The price for bamboo is fixed depending on the location. It is more expensive if it is near the approach road. The major share is taken for transportation. Farmers have now realized the evil effects of shifting cultivation and are showing interest in improving their jhum lands through planting of multipurpose trees and soil conservation measures.

Keywords: *livelihood, shifting cultivation, integrated agroforestry approach, north eastern India*

AD4.1.9. Extent of and factors influencing adoption of conservation agriculture and agroforestry in sub-Saharan Africa

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When implemented judiciously, conservation agriculture and agroforestry have the potential to reverse land degradation, improve water use efficiency, provide plant nutrients, fodder, firewood and other tree products, prolong the growing period, and build resilience to climate change for sustainable agro-ecosystems productivity. However, these benefits notwithstanding, the adoption of the two innovations by smallholder farmers in sub-Saharan Africa is dismal compared to countries in Asia and Latin America. In this paper, the reasons for the limited adoption of conservation agriculture and agroforestry in sub-Saharan Africa were studied focusing on four countries namely Ghana in West Africa, Kenya and Tanzania in East Africa and Zambia in southern Africa. The study specifically examines the extent of adoption of conservation agriculture and agroforestry, analyzes factors that influence adoption and assesses the potential for joint scaling up conservation agriculture and agroforestry. Conducted across varying agroecological zones, the study used both primary and secondary data sources. For each country a sample size of 360 smallholder households was selected using the simple random sampling technique. Primary data was sourced from semi-structured questionnaires, focus group discussions and key informant interviews. Secondary data included both print and electronic media relevant to conservation agriculture and agroforestry. Results show that adoption of conservation agriculture and agroforestry in the study countries is limited. Less than five percent of smallholder farmers in these countries adopted all the three principles of conservation agriculture (minimum tillage, crop rotation and adequate soil cover). Meanwhile, farm size, livestock keeping and agroecological conditions affected adoption of agroforestry. Information is required on how conservation agriculture and agroforestry can be packaged together and targeted for different agroecological and social economic conditions to enable policy and decision makers in devising appropriate strategies for wide scale adoption of conservation agriculture and agroforestry in the region.

Keywords: *agroecosystems productivity, land degradation, scaling up, sub-Saharan Africa*

AD4.1.10. Response of farmers for diversification of their agriculture land use to agroforestry in north India

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This study is based on a field survey involving 100 farmers regarding diversification of their agricultural productive land-use in Pilibhit district, Uttar Pradesh, north India which is known to grow paddy-wheat and/or sugarcane. There is a gradual acceptance of trees on farmland with agricultural crop production. As a result tree-based agroforestry is now expanding. Of the 100 respondents, 35% were holding <5 acres land, 35% 6 to 10 acres, 20% 21 to 40 acres and the remaining 10% >50 acres land. The findings revealed that poplar has emerged as the main choice among the planted trees as it is harvested at a short rotation of five to seven years, gives higher consolidated net returns, has wide marketing network and industrial use in the nearby wood-based industrial units and can be grown in integration with a variety of crops and vegetables during the greater period of their retention on farmland. Other trees accepted for their growing in agroforestry are clonal and seedling eucalypts, kadam, teak and a few others, while some like jatropa were grown for some time and rejected. The factors that affect the adoption level of tree species in agroforestry have been identified as size of landholding, soil type, net returns from crops and trees, alternate sources of income and occupation of landowners, labour availability, water drainage, awareness and experience in agroforestry. Agroforestry provided tremendous economic strength and financial security and has undoubtedly improved the lives of farmers. Net returns

from poplar-based agroforestry for the six-year period vary from INR 60 000 to INR 100 000 per acre per annum, and were the maximum among all other tree-crop combinations.

Keywords: *diversification, agroforestry, farmers' response, agriculture*

AD4.1.11. Generating greening movements through applying and building on lessons learnt in Niger Republic

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Between 1984 and 2012, tree density on Niger farms increased from about 4 to 50 trees per hectare and over five million hectares were reforested. This occurred with minimal NGO or government support. The uptake appears to have spread largely from farmer to farmer, by word of mouth. Building on the lessons learnt from this 'bottom up movement' could make a significant contribution towards achieving similar results in other countries.

World Vision reviewed success factors for the Niger Regreening movement and since 2010 has been identifying and addressing gaps for rapid scale up at national and regional levels elsewhere in collaboration with various partners. The current approach includes:

1. Identification, training and enabling of champions.
2. Application of behaviour change communication approaches through multiple outlets, (radio and print media, peers, government services, religious leaders and theatre) to reach all stakeholders in multiple ways, times and forms.
3. Creation of an enabling environment giving individuals and communities confidence to invest time and money into re-greening (access to markets, security of tenure or user rights, ability to control risk such as fire, theft, livestock).
4. Build on social capital.
5. Exchange visits to successful sites.
6. Regular and consistent follow up by responsive extension agents.
7. Networking and partnering.
8. Local to national level government endorsement, collaboration and support.

Keywords: *enabling environment, follow up, peer champions, user rights*

AD4.1.12. Evaluation of *Dalbergia sissoo* Roxb. progenies at field stage under semi-arid regions of Punjab

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Dalbergia sissoo Roxb. commonly known as shishm/tahli is an important timber species of India and is a state tree of Punjab. Its heartwood is durable and is used for furniture. It is grown in the fields across the state. Punjab Agriculture has undertaken tree improvement work for the last two decades. Plus trees from different zones of Punjab, Haryana and Himachal Pradesh were selected for growth

and stem straightness on the basis of 'base line method'. The survey was conducted along roads, railway lines, canals and from the scattered trees in the fields. Open-pollinated seeds from the thirteen plus trees were raised under nursery and were planted at Regional Research Bathinda by following RBD and three replications. Significant differences were found for diameter at breast height (DBH), tree height and D^2H at all ages i.e. 4, 6 and 10 years. After 10-year growth in the field, progeny No 6, 11 and 8 were found to be the most superior with respect to tree volume. Considerable variation was noticed for stem straightness, clear bole and branch traits. Heritability for DBH, tree height and D^2H were found to be 0.54, 0.46 and 0.76, respectively. The vegetative propagules from the superior genotypes from progeny trials have been used to establish the hedge orchard. Moreover, the introductions from Nepal and selections from other progeny trials have been used to develop the new clones which are under investigation. The future thrust is breeding for tolerance to root rot, stem straightness and wood traits.

Keywords: *Dalbergia sissoo*, heritability, open-pollinated, vegetative propagules

AD4.1.13. Community structure, biodiversity value & management practices of traditional agroforestry systems in Tripura, NE India

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A study was conducted to understand the structure, importance and indigenous management practices of traditional agroforestry systems practiced by Tripuri, Chakma, Lushai, Mog and Bengali communities of Tripura. The study reveals that the agroforestry systems of Tripura are diverse with a great deal of socially valuable plant species. The selection of principal crop species varied among the ethnic communities and depends largely on their traditional ecological knowledge. The farmers of these traditional systems maintain a multistoried system. However, they categorize the plants indigenously on the basis of light requirement. The plants prevalent in most of the agroforestry systems are *Albizia procera*, *Areca catechu*, *Parkia javanica*, *Anthocephalus cadamba*, *Mitragyna rotundifolia*, *Dillenia indica*, *Toona ciliata* in upper storey; *Cajanus cajan*, *Baccaurea sapida*, *Solanum melongena*, *Citrus reticulate*, *Solanum torvum* and *Musa* species in Middle storey; *Colocasia esculenta*, *Homalonema aromatic*, *Zingiber officinale*, *Curcuma domistica*, *Ananas comosus*, *Capsicum* species and other vegetables in ground storey. The farmers of the study sites maintain a good tree-crop association in their fields. Species composition of traditional agroforestry systems also varied with structure and size of the systems, residue management, soil and species adaptability of the sites. The intimate mix of diversified agricultural crops and multipurpose tree species fulfills most of the basic needs of the local inhabitants while the multi-storied configuration and high species diversity of the agroforestry system helps to reduce the environmental hazards that are commonly associated with massive rubber plantations in the state. Some of the management practices of traditional agroforestry systems like burning of the crop residue, tree-crop combination, use of cover crops, management of weeds, soil conservation measures adopted by these communities through experiential learning have ample potential of replication elsewhere and also offer excellent opportunities for finding solutions to the problems of self-reliance in agricultural development of the region.

Keywords: agroforestry, biodiversity, traditional practices, Tripura

AD2.1.14. Pollinators-ecosystem services and agricultural sustainability in a mountain ecosystem through citizen science approach

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Forests play an important role in the sustainability of agro-ecosystems especially in the case of mountain ecosystems where agriculture is totally dependent upon the flow of ecosystem services from forest ecosystem i.e. nutrients, water, manure, etc. Insect pollinators are significantly important both for the preservation of diverse natural ecosystems and for agricultural sustainability. Insects help make pollination possible, which can produce larger fruits with more viable seeds and enhanced genetic diversity.

Native bees require a natural habitat to provide flowering plants for forage throughout the season, and nesting sites for rearing young bees. Native bee species require a diversity of floral resources to provide nectar and pollen throughout the season. Farms near natural habitats have higher insect population. Although a natural ecosystem provides insects for free pollination services, non-sustainable land use is potentially eroding these benefits. Considering this, Earthwatch and Govind Ballabh Pant Institute of Himalayan Environment and Development have initiated a project to strengthen the link between 'Pollinators-Ecosystem Services and Agricultural Sustainability'.

It is envisaged that the project would contribute towards enhancing livelihood options and quality of life; improving ecosystem resilience; strengthening participatory research methodology and tools; and acting as a prototype with potential for wider replication. As part of this project, an effective **citizen science model** is being promoted that fosters partnership between citizen volunteers, science and scientists. The value of these volunteers extends beyond data collection. Field scientists find that the citizen scientists generate enthusiasm and offer a fresh perspective on research projects. This unique model of citizen's participation in scientific agriculture projects is a stepping stone for a way forward to assess and monitor changes in agricultural productivity, phenology, biodiversity (plant) and pollinators due to climate change and assist in preparing management plans for sustainable mountain agriculture.

Keywords: *agricultural sustainability, citizen-science, mountain ecosystem, pollinators*

AD4.1.15. REDD+ as a “C” producing mechanism: carbon or conflict. Understanding multi-ethnicities relations the landscape

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In the context of climate interventions, social safeguards have been recognized as precautionary measures to protect vulnerable communities, especially indigenous and local people, from any infringement on their rights to land, natural resources, knowledge, culture and practices. However, if social safeguards are procedures to protect the rights of indigenous and local communities, it could potentially have the counter effect if these definitions are not well understood.

Among these so-called vulnerable groups, it is important to understand that there is no identical interests and equal rights; in other words, there is not a homogenous 'community of interest' and power relations and dominant social relations will shape negotiations and expected benefits.

The paper addresses the problem that a technical application of social safeguards which does not understand properly these notions will result in community conflicts and thus will fail in enhancing rights and further undermine the multifunctionality of agroforest landscapes. We hypothesize that the application of social safeguards will require the understanding of the concept of indigenes in landscapes of multiethnicity in Indonesia. The recognition of Adat forest, a time-tested forest garden with biodiverse agroforestry is a way to legitimate indigenous rights and territories collectively as future beneficiaries under a REDD system. However, research in west Kalimantan shows that there is no one single and homogenous customary community, and that there are different ethnic groups who each use the debate on REDD to claim historical identity and territorial rights to access land and to legitimize ownership over land and access to natural resources. These communities have traditional land use practices that are ruled by different customary norms and practices and these have to be taken into account lest conflicts and contesting claims among these indigenous people jeopardize the multifunctions of agroforests.

Keywords: *customary rights, land tenure, livelihood security, safeguards*

AD4.1.16. Adoption of natural resource management technologies for sustainable land management: experience and lessons from Uganda

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Despite many efforts over the last 10 years, (1995-2005) with support from landcare and other Natural Resource Management projects through ICRAF and other partners, variable achievements towards improving land management have been realized. A study that aimed at understanding NRM practices, reasons for practice and non-practice was conducted in five districts in East and South Western parts of Uganda (Kapchorwa, Bukwo, Kween, Kabale and Kisoro Districts). Focus group discussions (FGD's), case studies and household surveys were conducted. A sample of 398 respondents (219 Males and 179 Females) was drawn through proportionate random sampling procedure from the sub-counties where ICRAF had been conducting research for over these years. Both qualitative and quantitative data was collected and analyzed descriptively using special package for social scientists (SPSS). Cross tabulation was used to draw relationships among different variables. A score of one was allocated to a practice adopted while zero was allocated to a practice adopted between 1995-2005. Respondents were asked to list their most practiced NRM technologies. NRM projects in the five districts resulted into a high proportion of farmers practicing a range of NRM practices most noticeably: Soil and Water Conservation (SWC) and tree planting. Sites which had ICRAF interventions between 1995-2005 demonstrated higher levels of practices than those that started after 2005. Availability of inputs, access to quality seed, capacity building trainings and formation and facilitation of effective NRM bylaws are likely to improve the practice of these technologies. Promotion of NRM technologies should focus on SWC and tree planting in the highland areas of Eastern Africa if high practice levels are desired.

Keywords: *Technology uptake, soil conservation, collective action, conflict management*

AD4.1.17. Conservation and livelihood impacts of agroforestry system: a case study of Kavrepalanchok district of Nepal

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Agroforestry has been recognized as one of the most important systems to support the livelihoods of many rural farmers in the Nepalese hills. However, its conservation value has received little attention. Moreover, there is no solid information that tells us precisely how agroforestry system has changed over time, and what are its causes and consequences in terms of biodiversity conservation and livelihood improvement. Hence, this paper aims to investigate the changing impacts of agroforestry systems on improving people's livelihoods and delivering biodiversity conservation outcomes. This research analyses a case study of a local government area of Mahadevsthan in Kavrepalanchok district of Nepal. Mixed methodological approach (household survey and PRA) was used for data collection. The results indicate that the practice of agroforestry system has changed considerably over time, as a result more agroforestry species have appeared in private lands. A total of 145 different species were recorded, of which 56 species were medicinal plants followed by fodder trees and grasses and fruit trees. Study further revealed that species' richness has increased mostly in upland terraces. This resulted in increased livelihood benefits to local people. Meat production from goats and milk from buffalos have increased considerably. The high income benefit is mainly associated with introduction of various fodder trees and grasses in private farmlands. It is concluded that there is a great need for agroforestry system to integrate conservation benefits with livelihood of rural people. One way to promote this integration is to improve policy and practices with a view to initiate and support farming co-operatives in the commercialization of agroforestry products and market the conservation values in the changing climatic context.

Keywords: conservation, livelihood, Kavrepalanchok

AD4.1.18. Overview for scaling up impacts of agroforestry in conjunction with watershed management: an experience from Gujarat

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Watershed Management (WSM) has emerged as a new paradigm for planning, development and management of land, water and biomass resources with more focus on social & institutional aspects apart from bio-physical aspects. Present study is focused on the hypothesis that for judicious conservation & management of land & water it is not only the physical or mechanical treatment of watersheds, rather it enormously needs, micro level conjunctive application of Agro-Forestry (AF) concept to ensure and complement overall efforts in WSM. Paper include the views & food for thought for scaling up Impacts of AF based real field experiences & models, as attempted in Gujarat state of India for their probable replications & integrations with land and water treatment measures/plans at watershed scale. Gujarat happens to be the most industrialized state of India, leaving very little scope

for enhancement of area under forest lands. Even under this situation when the forest cover is relatively low, Trees Outside the Forests (TOF) are very towering being 2nd highest (TOF tree cover as 7837 km²) in country. The historical and innovative efforts & approaches as emerged from the Social Forestry concept (conceived & implemented 3 decades ago with assistance from Japanese Bank for International Cooperation), have paved a successful path, where cumulatively more than 5000 million seedlings are distributed/placed at the fields with farmers/institutions/ individuals. A case study of Anand a (non forest district of middle Gujarat, having good canal irrigation facilities) is presented, where it has been transformed into one of the greenest district of country, having highest tree density & cover (68.4 trees/ha; 20.12 million trees on TOF). With excellent effort from Department of Forest (Govt. of Gujarat) it has been nationally popularized as Anand Model of Tree farming. The paper encompasses a detailed screening, analysis, and derivations of inferences for possible integration of this successful model with vast WSM projects being implemented at micro catchment level (even 500 ha or less) in the region. The qualitative & quantitative influences from hydrological or climatic point of views are summarized & presented for scaling up the application of AF based components in regionally synthesized location specific WSM work plans at micro watershed level. It could generate supportive decision support system for integrated replications and location specific refinements.

Keywords: agroforestry, land and water, soil erosion, watershed

AD4.1.19. The agroforestry challenge in India: need for changed perspectives & meeting issues and challenges of the future times

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Agriculture and forestry have been two essential sectors in developing India which already is burdened with a rapidly burgeoning population. The ultimate consequence has been that agricultural production and forest protection & conservation have come to a state of head-on conflict given the rapid rate at which accessible forest lands in India have given way to agriculture & other land uses.

It was in this context that agroforestry as a discipline founded on concepts derived from both agriculture and forestry was evolved as a sustainable cropping system that optimally combined trees, agricultural production and even livestock on the same unit of land simultaneously or sequentially with resultant improvement in productivity (tree + crop yields) per unit area and the associated increment in income generation. The agroforestry trend has been in vogue for quite some time in India.

But the grim reality of the present scenario is that there is an urgency to revise and redirect our perspectives to bring the practice of agroforestry in tune with the needs of the present as well as future times to come.

The major leap has to take place in terms of the attention shift from increased crop yield (quantity-production) to the protection and restoration of the fragile ecological balance (quality-service), as trees are the most dominant entity that alters landscape dynamics.

Another area of focus should be the effective implementation of the agroforestry research projects on fields. This must be stressed upon because it is most often the implementation part where India so miserably fails. Some of the multiple challenges that agroforestry in India must address in times to come include:

- Integration of agroforestry projects with rural welfare schemes such as MGNREGS etc.
- Incorporation of local and traditionally adopted practices into what has been advocated by research.
- Dispelling the farmer's resistance to agroforestry by far-reaching forestry extension.
- Wasteland reclamation en masse by reforestation under suitable agroforestry systems.
- Controlling the pilferage of forests and shifting cultivation (restructuring of legal framework included).
- Creating more avenues for involving women in agroforestry.

Keywords: *challenges, future focus, Indian scenario, new perspectives*

AD4.1.20. Betta land development and village level agro-forestry concept - a case study in Sirsi Taluk, Uttara Kannada District

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The paper describes the recent developments in the thinking of the local communities towards the development of the Betta land and agro-forestry concept to manage the land resources in a better and more efficient way, there by contributing to the conservation of ecology and environment of the area.

The traditional method of manuring the soil by collecting the leaves of the wild trees from the adjoining forest land is still continued. It may be noted that allotment of forest land (also called as **Soppina betta** in the local terms) to orchard owners during the early years of the last century, ranging between four to nine acres per acre nut garden is unique in this district, mainly to collect the dry leaves for the use of maintaining the soil moisture, to prevent soil erosion and also as manure to the plants. This allotment was initially done towards enhancement of revenue to the Government. The farmers were/are dependent on Betta land for fuel, fertilizer and for fodder for their cattle.

When the Soppina betta land started degrading on account of continues increased use for collection of leaves for manure, fire wood etc; the local agricultural community came forward with the concept of development of agro forestry(development of forest along with agriculture in whatever the best way possible) alongside with the development and conservation of Soppina betta forest land. This concept not only has generated new confidence in the participating rural/village community who are the stake holders of major benefit derived out of conservation of environment and ecology of the area. The forest regulating authorities are also supporting the people participation in enhancing and maintain the forest land.

Keywords: *Soppina betta, agroforestry, multi cropping system, Sirsi taluk, Uttara Kannada district, Karnataka*

AD4.1.21. Indigenous fruit development - unlocking the potential in rural areas of South Africa

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In South Africa there are numerous indigenous fruits that are well known and highly prized by rural communities who often depend on these trees for food security. This wide diversity of fruits is a source of vitamins, minerals, amino acids and trace elements to rural communities and plays an important role in their diet especially in times of food scarcity. Indigenous crops can enhance food security, increase global competitiveness and increase diversification of the agricultural sector. In addition to addressing nutritional food security in rural areas a number of our indigenous trees have potential to be developed on a small scale and some on a larger scale if correct market development is undertaken. Adding value to these fruits will result in economic activity and eventually to a local and export market, job creation and improved quality of life in rural areas.

The indigenous fruit programme at ARC-ITSC has over the past ten years focused on the development of indigenous fruit species and has included surveys of fruits utilized in rural areas of Limpopo and Eastern Cape provinces. Indigenous knowledge was collected as to the uses and importance of the species in the rural communities. Selections of superior trees in the wild have been made and the nutritional status of the fruit has been assessed as this can be very important in rural diets where food insecurity and especially nutritional deficiencies are common. Propagation protocols have been developed for species identified as most important and work is on-going on other species. Product development from selected species has been undertaken.

Fruit trees are planted as part of an integrated farm system in rural areas where vegetable and maize production is also carried out. An integrated production system has been developed using locally produced manure, compost and mulch and no synthetic chemical sprays. Ongoing technical training is undertaken in the villages on all aspects necessary to ensure that farmers are capacitated to produce high value crops as an economic enterprise. Training on business development and marketing are also covered.

The research is on-going and refinement of selected products is currently being undertaken and the development of small agri-businesses in rural communities has commenced. The challenge lies in ensuring that the benefits accrue to the participating communities who have made their vast indigenous knowledge available to assist the research initiative.

Keywords: *indigenous fruit trees, production, rural development, product development, integrated farming systems*

AD4.1.22. Understanding smallholders' motivations for managing trees on farms for food security in the Central African Highlands

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Rwanda is one of the most densely populated countries in Africa. Its economy depends on the agricultural sector, dominated by subsistence smallholders. Over 80% of the population still resides in rural areas, where the majority of the poor are found. The population is about 11 million in 2012 and

expected to be over 17 million in 2030, putting further pressure on scarce arable land. Continuous cultivation of plots on often steep hillsides has led to land degradation. Sustainable intensification of smallholder agriculture can make a critical contribution to food security, poverty alleviation and economic growth. Rwanda is among the few African countries in which tree cover has recently increased, following widespread deforestation before and during the civil war. Agroforestry is already practised by many Rwandese farmers, because it diversifies and sustains production of food and fuel and so provides a range of social, economic and environmental benefits within a limited land area. The success of further promoting adoption and adaptation of agroforestry technologies is dependent on targeting of appropriate tree species and management options to sites and circumstances in order to optimize the capture and use of scarce environmental resources, while fulfilling farmer's needs for timber, fuel, mulch, fodder and staple food. We present results from a socio-economic baseline survey carried out in two contrasting agro-ecologies; semi-arid (Bugesera) and sub humid (Gishwati). Smallholders had marked preferences, reasons and strategies for managing trees and shrubs on their farms. We examine the impacts of plot fragmentation, tenure conditions and land use policies prevalent in Rwanda on the adoption of specific agroforestry options and their relation to food security. We then use the baseline to identify scaling domains for agroforestry options not only in Rwanda but also in relevant areas of Uganda and Burundi.

Keywords: *adoption behaviour, agroforestry, agricultural extension services, marketing behaviour, AKAP sequence, baseline, food security, climate change adaptability, economic independence, livelihood improvement.*

AD4.1.23. Role of farming system in ensuring livelihood security of farmers in Tehri district of Uttarakhand: A case study

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A field study was undertaken in Tehri district (20 villages) of Uttarakhand with an objective of improvement of livelihood status of farmers through farming system approach. Study revealed that about 80 % of the working population in remote hills is engaged in agriculture and animal husbandry. The land use system reveals that irrigated land is a very small fraction of the total agricultural land. The conventional system of farming involves combined production of crops, fodder, tree crops and livestock. There were two prominent cropping seasons – *rabi* and *kharif* in the study cluster. Farmers undertake cultivation of various cereals like *Zea mays*, *Triticum aestivum*, *Oryza sativa*, minor millets viz., mandua (*Eleusine coracana*) and jhangora (*Echinochloa frumentacea*) along with the vegetables like *Cucumis sativus*, *Solanum tuberosum*, *Lycopersicon esculentum*, *Brassica oleracea*, *Spinacea oleracea*, *Capsicum frutescens*, *Capsicum annum*, *Lagenaria ciceraria*, *Abelmoschus esculentus* etc for domestic consumption. Different fruit trees like mango, citrus, plum, pear, peach, aonla etc are grown by farmers of the region. The major woody species grown in the agro-forestry system are *Celtris australis*, *Grewia optiva*, *Pinus roxburghii*, *Bauhinia variegata* and *Toona ciliata*. Important role played by *Gewia optiva* (Bhimal) a multipurpose tree in the existing agro-forestry system is worth recognizing. Apart from fuelwood, fibre, fodder, soaps & detergent and medicine, the bark and stem are used to make baskets. The agro-forestry system of the region is mainly organic and cattle dung is used for fertilizing the agricultural land. Changing climatic conditions, erratic rainfall pattern, soil loss, lack of extension efforts, migration of youth in search of employment is adversely affecting the agricultural production. Initial results of the study revealed that through adoption of proper technological interventions in farming system perspective in holistic manner, livelihood of poor farmers could be improved significantly.

Keywords: agroforestry, farming system, hills, Uttarakhand

AD4.1.24. Transformation of lives due to agroforestry in the Toledo District- a case study of the Indigenous Maya facing the challenge

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Toledo District is the southernmost district in Belize with a population of 30,538. It is the poorest (46.5%) and most rural district with 83% rural and mostly indigenous peoples. The majority are Maya Kekchi. This abstract shows how agroforestry has transformed the lives of the Indigenous Mayas from a traditional slash and burn system to one which is more sustainable.

Until a few years ago most farmers produced corn and beans for food and rice for the market. Obviously, this was unsustainable since farmers had to cut virgin forests annually to plant their crops. This system was not only unsustainable but the market was insecure.

In the early 1980s a few farmers were exposed to cacao production. They began planting their own and in 1984 organized an association. Today the Toledo Cacao Growers Association has a membership of 1,100 members in 55 communities. They market organic cacao to Mondelez International, formerly Green and Black. Recently, an American based company, Maya Mountain Cacao, entered the local market in 2010 and began buying unfermented cocoa beans. They export to markets in the U.S.A.

Due to secure market for cacao, more farmers are getting involved. Bot organizations mentioned above as well as other institutions and Community Based Organizations are providing technical and financial assistance to the farmers.

The organic cacao production system integrates tree species for shade, timber, firewood, food for humans and livestock and compost. Cacao production also creates small scale entrepreneurs that add value and generate income for rural households. There are several cacao farms with trails to showcase the system to tourists. Tours also include herbal plants, butter flies and bird watching, among others. This agroforestry based development also creates other services such as local cultural crafts, foods, and accommodation. Thus, the promotion of agroforestry-based development contributes to the transformation of rural livelihoods.

Keywords: indigenous, agroforestry, Maya

4.2 The gender dimensions of applying agroforestry innovation

AD4.2.1. Role of heterogeneity in water management: case studies from India and the United States

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In developed and developing countries, collaborative partnerships have emerged to address water quality and quantity. The U.S. Federal government spends over \$200 million annually each year to address nonpoint source water pollution through the Clean Water Act Section 319, while states spend

millions more (Hardy and Koontz, 2007). In India, over \$550 million is invested annually in water projects by the Indian government as well as international donors (Kerr 2006). A key rationale for these approaches is the notion that “community” is better than “centralized” governance. However, the reality is that communities are not homogeneous entities.

Communities are divided across class, caste, race, gender, resources, interests, and values. Scholars of collective action and common pool resource management have identified heterogeneity as variously helping or hindering success. These inconsistent results stem from a lack of specificity regarding the dimension of heterogeneity, and the context. In this proposal, I identify conditions and incentives for heterogeneous communities for developing effective natural resource management policies. In particular, I focus on which institutional mechanisms best enable heterogeneous communities undertake successful collective action.

This research will contribute to the Common-Pool Resource Theory, and more pressingly, the design of effective natural resource management policies in heterogeneous communities. This research will be conducted in India and Appalachia, U.S., therefore, studying institution formation in different contexts will illustrate strategies developed by communities to mediate the effect of heterogeneity. This research can contribute towards formulating solutions for building stronger institutions with government support to improve rural livelihoods.

Keywords: *collaboration, water management*

4.3 Adapting to climate change

AD4.3.1. Carbon stock assessment and oxygen production in Simarouba-based (Simarouba + Mustard) agroforestry system

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Agroforestry is a potential way and low cost method to sequester atmospheric carbon and can be a good climate change mitigation option. Trees play an important role in global carbon cycle and regulating the biospheric climate. An attempt was made on loamy sand soil at Agroforestry Research Farm, S.D. Agricultural University, Sardarkrushinagar (Gujarat) to measure carbon sequestration, oxygen production and biomass productivity in the agroforestry system i.e. simarouba (*Simarouba glauca*) with mustard crop during 2010-2011. The experimental site's soil was loamy sand in texture, low in organic carbon (0.17%), medium in available phosphorous and potash (200 kg K₂O₅ ha⁻¹) and in reaction (pH 7.82). Seven treatment combinations comprising simarouba sole (T₁), simarouba + mustard without fertilizer (T₂), simarouba + mustard with 50% RDF (T₃), simarouba + mustard with 100% RDF (T₄), mustard sole without fertiliser (T₅), mustard sole with 50% RDF (T₆) and mustard sole with 100% RDF (T₇) were tested in randomized block design replicating four times. Simarouba tree had more height (3.98 m) and diameter at breast height (9.45 cm) under tree crop interface treatment than tree alone at seven years age. Fruit yield (703 kg ha⁻¹) and oil yield (515 kg ha⁻¹) of simarouba seed was significantly higher when simarouba trees were intercropped with mustard crop along with a full dose of chemical fertilizers. Mustard yield was higher (19.24 q ha⁻¹ seed and 47.61 q ha⁻¹ stover yield) with full recommended dose of chemical fertilizer (50 kg N ha⁻¹ and 50 P₂O₅ ha⁻¹). Total dry biomass (56.06 t ha⁻¹), carbon content (42.61%), equivalent CO₂ (28.97 t ha⁻¹), soil organic carbon stock (2.70 t ha⁻¹) and CO₂ storage potential (116.01 t ha⁻¹) were highest in agrisilviculture system of agroforestry under simarouba tree mustard crop interface giving full dose of

fertilizer.

Keywords: *simarouba, agroforestry, diameter at breast height, mustard RDF*

AD4.3.2. Imparting resilience to climate variability through rejuvenation of land and water resources

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The cluster of villages Vidyasagar and Gadimajhila in Nawada district is predominantly inhabited by scheduled castes. The farmers are basically agricultural labour having very small holdings. Their lands remain fallow over time. A few of the enterprising farmers now and then broadcast seeds of horse gram or red gram and harvest some grains. Some efforts were made by KVK Nawada, Bihar to rejuvenate these lands by laying bunds across the undulating patches of land. Scientists of KVK evolved a programme to bring the cultivable fallow land back into crop production by motivating the farmers to participate by bunding and levelling. Each farmer had to contribute his labour in laying out the bunds while the project facilitated scraping of the undulated portion and putting the soil on the borders. The farmers then shaped the bunds using spades. The height of the bund was increased. It helped to harvest more rainwater in situ and prevent erosion. The process of laying bunds started during the later part of the kharif season (2011) and went on until the beginning of summer 2012. Those who could complete bunding and levelling early planted pigeon pea and short duration paddy. The experience of these farmers was encouraging and many farmers started participating in this programme with renewed vigour and enthusiasm. As a result, about 15 ha was planted with pigeon pea during kharif 2012 leading to a harvest of 10 000 kg of pigeon pea worth INR 350 000. For the first time, the farmers of these villages realized such a harvest and this helped them to appreciate the worth of their land due to bunding and levelling. In the next year the area was expanded to 24 ha which helped to get a successful crop of chick pea.

Keywords: *climate variability, bunding and levelling, cropping intensity*

AD4.3.3. Carbon sequestration potential of agroforestry system in different climates

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Global warming risks from emissions of greenhouse gases (GHGs) by anthropogenic activities have increased the need for the identification of ecosystems with high carbon sequestration capacity as an alternative mitigation strategy. The importance of agroforestry systems as carbon sinks has recently been recognized due to the need of climate change mitigation. Agroforestry focuses on the wide range of trees grown on farms and other rural areas. Planting of trees in agroecosystems such as agroforestry, and trees outside forests can mitigate green house gas (GHG) emissions under the Kyoto Protocol. Agroforestry, the practice of growing trees and crops in interacting combination, is recognized worldwide as an integrated approach to sustainable land use. Farmers have practiced agroforestry since ancient times. Agroforestry systems are believed to have better climate change mitigation option than oceanic, and other terrestrial options, because of the secondary environmental benefits such as

helping to attain food security, increasing farm income, restoring and maintaining above-ground and below-ground biodiversity, maintaining watershed hydrology, and soil conservation. Agroforestry also mitigates the demand for wood and reduces pressure on natural forests. Past and present evidence clearly indicates that agroforestry, as part of a multifunctional working landscape, can be a viable land use option that in addition to alleviating poverty offers a number of ecosystem services and environmental benefits. This realization should help to promote agroforestry and its role as an integral part of a multifunctional working landscape the country over. There is need of robust country-wide scientific studies aimed at better understanding the potential of agroforestry for climate change mitigation and human well-being. Several workers have quantified the carbon sequestration in agroforestry systems across the world. In this review we tried to summarize the carbon sequestration potential of different agroforestry systems like alley cropping, agri-silviculture, silvi-pastoral etc world wide.

Keywords: *Carbon sequestration, agroforestry, climate*

AD4.3.4. The effect of long term (19 years) practice of early fire, grazing and selective tree cutting on water infiltration

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Infiltration is the process of water soaking into the soil. It can be restricted by poor management and disturbances such as grazing, fire and tree cutting. In this case, water does not readily penetrate the soil and it moves down slope as runoff. That could negatively affect soil carbon stocks. Knowledge of their possible impact on infiltration is then necessary to approve or not approve their use as management tools for carbon sequestration in the context of climate change. We studied the effect of 19 years (1992-2011) of early fire, grazing and selective tree cutting on water infiltration in two experimental sites characterized by deep and shallow soils in Sudanian savanna-woodland ecosystems of Burkina Faso. Measurement was carried with a single ring infiltrometer at intervals of 5, 10, 20 and 30 minutes during 2 h30 minutes. We found high significant difference between site for infiltration rate ($P<0.0001$) and cumulative infiltration ($P<0.0001$). Interaction between the three factors is not significant ($P=0.357$) for infiltration rate but is highly significant ($P<0.0001$) for cumulative infiltration. The main effects of grazing, cutting and fire were highly significant ($P<0.001$) for infiltration rate. Fire has a positive effect on infiltration rate on the deep soil of Tiogo whereas it has a negative effect on the shallow soil of Laba. In contrast grazing and selective wood cutting had negative effects at both sites. In Laba, the highest infiltration (9.51 mm/min) was found with interaction of grazing enclosure, selective wood cutting and fire protection, while the lowest one (1.78 mm/min) was found with simultaneous occurrence of grazing and fire interaction. In Tiogo, the highest infiltration (1.75 mm/min) was found with interaction of grazing and fire, while the lowest one (0.55 mm/min) was found on grazed and no cutting and no fire's interaction. The result suggested clay soil assumed to have higher carbon content is most exposed to erosion. Therefore, projects which aim to manage or increase soil carbon stocks must take into consideration soils type and plan anti-erosion actions, especially in clay soils.

Keywords: *early fire, grazing, infiltration, single ring*

AD4.3.5. Agroforestry: agent of change for the community life around West Rinjani forest management unit, Lombok, Indonesia

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The high activity of the community around West Rinjani forest management unit from 1990-2010 has led to significant changes in land cover and decreasing forest functions in terms of ecological, economic and social. It is very influential on the lives of forest dwellers. Various efforts towards improvement of forest conditions in the early 2000s have not been able to compensate for the damage and improve their livelihoods. This was due to a variety of patterns improvements at first concentrated by planting woody species only, while the needs of forest in the community are vary. Realizing this, the community and the government began to develop a pattern of land management by combining forest plants and various agricultural and plantation crops (Agroforestry). Using the 14 villages of the 39 villages that surround Rinjani Barat Forest Management Unit as the sample shows that agroforestry has led to changes in land cover on a large scale and providing better livelihoods for local people.

Keywords: agroforestry, livelihood, West Rinjani, forest management unit

AD4.3.6. Agroforestry as a climate change mitigation and adaptation tool for agriculture

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The fourth assessment report of the Intergovernmental Panel on Climate Change (IPCC 2007c) includes increased evidence that current climate change is to a large extent due to human activity and that it will profoundly alter the living conditions for all humans, flora, fauna, and ecosystems. Climate change around the world is already apparent in changing precipitation patterns and more frequent or erratic extreme weather events such as floods, droughts, and heat waves. These impacts may have diverse effects on forests and farming systems, including compositional and functional changes and changes in their capacity to provide ecosystem functions, products, and services. The IPCC has projected that if greenhouse gas (GHG) emissions, the leading cause of climate change, continue to rise, mean global temperatures will increase 1.4–5.8°C by the end of the 21st century (IPCC 2001 a,b).

Agroforestry can add a high level of diversity within agricultural lands and, with it, an increased capacity for supporting numerous ecological and production services that impart resiliency to Climate Change impacts (CC). The mixing of woody plants into crop, forage, and livestock operations provides greater resiliency to this inter-annual variability through crop diversification produced seasonally, as well as through increased resource-use efficiency. Agroforestry increases soil porosity, reduces runoff, and increases soil cover, which can improve water infiltration and retention in the soil profile thereby reducing moisture stress in low rainfall years. It can offer greater economic stability and reduced risk under CC by creating more diversified enterprises with greater income distribution over time. Like alley cropping, a silvopasture system mitigates risks associated with climate variability and fluctuating prices by providing short-term and long-term income sources

Keywords: agroforestry, climate change, mitigation, production stability

4.4 Bridging science and development

AD4.4.1. Rejuvenating superior eucalyptus and corymbia hybrids through micropropagation

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Eucalyptus and Corymbia are promising agroforestry species credited with high growth rates and multiple uses and are planted extensively in India due to their adaptability in different eco-climatic zones. *Eucalyptus* (*E. camaldulensis* Dehn × *E. tereticornis* Sm) and *Corymbia* (*C. torelliana* Muell X *C. citriodora* Hook) hybrids developed by Forest Research Institute, Dehra Dun, have shown three to five times growth parameters over their parents and hence possess a high degree of hybrid vigour. Micropropagation has been a powerful tool for the multiplication of such valuable hybrids by maintaining their hybrid vigour. Nodal shoot segments from newly developed shoots of 35-year-old Eucalyptus and 8 year old Corymbia hybrids were treated with citrimide, 50% WP, carbendazim (1%) and either mercuric chloride (0.05-1%) or sodium hypochlorite (10-40%). These explants were incubated in Murashige and Skoog (MS) medium supplemented with 3% sucrose, BAP (1-3 mg/l) and NAA (0-1 mg/l) for axillary bud induction and shoot initiation at 25°C, 16 h light/8h dark cycle. Shoot multiplication and regular subculturing was carried out on MS with BAP (1 mg/l). Rooting was induced using IBA (0.75 and 1.0 mg/l respectively) and rooted plantlets were hardened in-vitro in vermiculite supplemented with ½ MS and *ex-vitro* in mixture of soil, sand and manure (1:2:1) in the glass house. These plants were used to harvest fresh nodal shoot segments after 1 year and treated with 0.1% mercuric chloride for five and two minutes respectively. This resulted in bud break after a week on MS medium supplemented with 3% sucrose and BAP (1 mg/l). The bud break increased from previous 7 and 2% to 58 and 80% in Eucalyptus and Corymbia hybrids respectively. This response may be attributed to the juvenility of the 1-year-old plants raised through micropropagation as compared to those of the fields.

Keywords: *bud break, juvenility, rooting, tissue culture*

AD4.4.2. Genetic improvement in Acacia nilotica for high yield, drought tolerance, quality fodder and seed production

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Acacia nilotica is an important tree of agroforestry and social forestry throughout the semi-arid and tropical regions of Asia and Africa. The tree supports the economy of farmers and landless people by providing ecosystem services like timber, fuelwood, fodder, gum, tannin, etc. In the changing climatic scenario, breeding for abiotic stress assumes much significance. In this context, results of breeding work taken in *Acacia nilotica* have been presented in the paper. Ecomorphological variability, drought tolerance, nutritive quality, characters association and genetic divergence have been analysed among the 29 seed sources (accessions) of *A. nilotica* collected during 2003-2005 from north-western and

central parts of India. Significant differences ($P < 0.001$) were recorded between the 29 seed sources for the 14 morphological traits of parent trees and their progenies. The major part of total variance was under genetic control (high GCV), while environment has low share (low ECV). All the traits, except seed quality and clean bole of tree, showed high heritability (≥ 40). High yielding elite genotypes (PT-1, PT-2, PT-14) identified from the plus tree progenies showed 6-22% superiority over mean values in timber yielding traits. Physio-biochemical properties revealed that accessions of Sagar, Rajnandgaon, Jabalpur and Kawardha were tolerant to drought ($P < 0.05$), while accessions of Malkapur, Guna and Indore were drought susceptible. Nutritionally rich quality fodder accessions i.e. Rewari, Jaipur and Dausa were identified, which have 21-22.5% crude protein (CP) and low contents of lignin, NDF, ADF and cellulose. Divergence analysis has classified the 29 seed sources into six clusters, comprising 1-9 members. Cluster pattern showed genetic variability, geographical differentiation, soil quality and environment are important parameters for delineation of seed zones. Rainfall and soil quality are the most important parameters in determining the seed sources superiority and suitability for afforestation. Altitude and rainfall showed positive associations with seeds/pod, pods size, clean bole and height of tree. Seed quality and tree girth decreased with increase in altitude. The study revealed that diversity in acacia was directly related to genetic variability and geographical differentiation, which are noteworthy for mitigating abiotic stresses and ecosystem services in changing climate scenarios. Findings are also important in seed certification and quality seed production.

Keywords: *abiotic stress, genetic diversity, quality fodder yield*

AD4.4.3. Tree improvement research is essential for enhancing productivity of agroforestry systems

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Woody perennials are the essence of any agroforestry system and play a specific role as well as provide a number of tangible and non-tangible benefits to the society. It is a well recognized fact that several MPTS and shrub species across the globe have a role to play in different agroforestry systems. Most of these MPTS exist in the wild and are likely to exhibit wide natural variability. Such populations are expected to respond well to selection and breeding resulting in increase in yield and adaptability under different agroforestry systems. In the agroforestry sector, the true potential of tree improvement particularly for tropical species is yet to be fully exploited and to date very few and sporadic efforts have been made for tree improvement research which is limited to the commercially important fast-growing tree species such as poplar and eucalypts. In most of the other plantation programs, locally collected seeds are generally used which are not genetically tested, resulting in low productivity and returns from the plantations. Efforts were made under the national program to collect the seeds of important MPTS for agroforestry from a whole range of natural geographical distribution to capture natural variability to select the best germplasm. Concerted efforts made during the last three decades have resulted in the collection of a large germplasm of 184 tree species in different agroclimatic regions. The species include *Morus alba*, *Grewia optiva*, *Salix spp.*, *Azadirachta indica*, *Dalbergia sissoo*, *Acacia spp.*, *Anogeissus*, *Prosopis spp.*, *Tectona grandis*, *Gmelina arborea* and biofuel species such as *Jatropha carcus*, *Simarouba* and *Pongamia piñata*. The reproductive biology has been studied for some tree species and their vegetative propagation techniques have been standardized. In a few cases seed orchards have also been established. The effective utilization of superior germplasm of these species

based on multilocation trials will increase the productivity and returns of agroforestry systems many fold.

Keywords: *natural variation, germplasm, vegetative propagation, seed orchard*

AD4.4.4. Evaluation of six bamboo species in pan India: results from multi-location trials

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Despite the fact of the world's second largest resources of bamboo in India, one of the constraints inhibiting the development of value-added enterprises in the bamboo sector is the availability and accessibility of superior bamboo species for a specific region and adequate raw material at reasonable prices and of the required quality and maturity, which is widely suitable for managed cultivation regime. To make available quality plant material as well as a standardized package of practice for farmer/entrepreneur level plantation, Agroforestry Research Centre (AFRC), G. B. Pant University, Pantnagar under National Mission on Bamboo Applications (NMBA), a tenth Plan initiative of the Department of Science & Technology, Government of India undertook the responsibility to frame and coordinate bamboo research in the different agroecological zones across the country with the objective to identify the cultivars/species. Seven centres of different agroecological regions across the country were selected as part of the coordinated program. A common framework for multilocal trials had been followed at all the locations with two local and six common species viz., *Bambusa bambos*, *B. balcooa*, *B. nutans*, *B. tulda*, *Dendrocalamus asper* and *D. hamiltonii*. Multilocation trial was initiated in 2005 and concluded in 2010. Among these species, *Bambusa balcooa*, *B. nutans* and *B. vulgaris* were superior in most of the centres. It is expected that the results will be of great practical significance in shaping bamboo research at the national level in the times to come.

Keywords: *bamboo growth parameters, bamboo species, bamboo variability, multilocation trial*

AD4.4.5. Biocontrol of wilt-causing fungal pathogens of Shisham (*Dalbergia sissoo* Roxb) mortality

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Shisham (*Dalbergia sissoo* Roxb) is one of the indispensable tree species of India owing to its importance for timber, fuelwood, and fodder as well as for shading, soil erosion and nutrient management. In the recent past, a number of reports have been received from different parts and throughout the distribution zone pertaining to the mortality of this indispensable multipurpose tree. Several biotic and abiotic factors have been reported to be responsible for the drying of shisham trees in large scale. One of the major causes of shisham mortality is the severely damaging wilt complex/dieback disease and few fungal phytopathogens have been reported to be responsible for the wilting of the trees. *Trichoderma* species is known as a potent biocontrol agent and it parasitizes several phytopathogens. Therefore, in the present investigation, efforts were made to study the in vitro

and in vivo biocontrol potential of *Trichoderma* species against incitans of sissoo wilt. Three fungal pathogens were isolated from the infected bark and roots of dying shisham trees and identified as *Ganoderma lucidum*, *Rhizoctonia solanii* and *Fusarium oxysporum*. Among various *Trichoderma* cultures tested for in vitro antagonism against the three fungal pathogens, *Trichoderma virens* SE6 showed superior reaction. When tested for extra-cellular lytic enzyme production, *T. variens* SE-6 showed both glucanase and chitinase activities.

Zymogram analysis through native PAGE revealed production of two iso-forms for each of the glucanase and chitinase enzymes. In vivo glasshouse pot culture experiment trials revealed that *Trichoderma* application in pathogen infested soil has significantly reduced the disease incidence in shisham seedlings. Maximum reduction in disease incidence was shown by *Trichoderma* inoculation against *F.oxysporum*. Rotting of host root tissues by the wilt pathogen (*G. lucidum*) and its control by inoculation with *Trichoderma* culture was further validated by Scanning Electron Microscopy (SEM).

Keywords: *biological control, NTFPs, Shisham mortalitysissoo, wilt complex*

AD4.4.6. Agroforestry: an adaptation for enhancing resilience to climate change in Coastal Odisha, India

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Odisha is a state in eastern India which lies in sub-humid tropics with a large coastline of the Bay of Bengal. In view of the changing climate, the state is now climatically vulnerable and experiences a number of extreme events such as frequent floods, drought, oceanic depressions, cyclones and super cyclone, etc., causing massive damage to agriculture and allied sector, natural forests and plantations and severely affecting the livelihoods of thousands of smallholders.

The coastal land-use is very much potential on rice-based cropping system. But due to vulnerability and effects of extreme events, the net productivity is in a declining trend. However, in a pilot study it is observed that agroforestry based land-use in coastal ecosystems has brought back potential productivity by preventing further degradation, enhancing carbon pool, restoring nutrient cycle and benefiting smallholders thereby enhancing resilience to climate change effects. Therefore adaptation of agroforestry through suitable agroforestry interventions especially comprising species of soft timbers, fruit trees and seasonal agriculture/horticulture crops provides an additional source of income thus improving livelihoods of smallholders.

Keywords: *resilience, climate change, Odisha*

AD4.4.7. Olax scandens: A rich source for clean energy

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Energy crisis and environmental pollution due to increase in demand are the major concern in the world today; this has prompted the search for alternate sources of fuel. Biomass, a renewable source of energy, offers the most affordable natural route to meet growing energy needs. Recent environmental and economic concerns have put emphasis on the use of biofuels as an alternative to fossil fuels. Presently, the Government of India embarked upon an ambitious National Biodiesel Mission to meet 20 percent of the country's diesel requirements. Clean energy from biofuel offers a number of environmental, social, and economic advantages, including lower emissions of harmful pollutants, decreased greenhouse gas emissions, increased employment, increased energy security especially in rural areas, decreased dependence on oil imports and desired fuel properties for vehicles.

In the Indian tropics, *Olex scandens* is a multipurpose, drought tolerant perennial shrub having great potential for the production of clean energy. The kernels produce 55-60% oil which has been modified to be used as biofuel in diesel engines. Preliminary lifecycle energy and greenhouse gas (GHG) balances are positive but the GHG balance is very dependent on the type of land to be diverted to *O. scandens*. A pilot study was taken up to evaluate the clean energy potential with respect to environmental, biophysical and socioeconomic considerations.

Keywords: energy, biomass, greenhouse gas, *Olex scandens*

4.6 Building development abilities through education and capacity development

AD4.6.1. Adoption of agroforestry practices by limited resource farmers in North Carolina, USA.

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The purpose of this study was to assess the adoption of agroforestry practices by limited resource farmers in North Carolina. Respondents were knowledgeable about the benefits of agroforestry and highlighted the following benefits: increasing of income, improving of wild life habitat, soil protection, improving water quality, increasing biodiversity, and increasing shelter for livestock and product diversification. A questionnaire was developed to gather respondents' knowledge about agroforestry practices. A 70 percent response rate was received. The study found that most respondents lacked adequate information on agroforestry practices. Respondents reported that the barriers for adopting agroforestry practices were: no market for products, expenses of additional resources, lack of technical assistance, lack of information about agroforestry, lack of demonstration sites, and insufficient land. However, it was found that respondents were willing to adopt agroforestry practices such as alley cropping silvopasture, riparian forest buffer, forest farming and wind breaks. Based on the findings, there is a need for incentives that will encourage farmers to adopt agroforestry as an income-generating venture. Limited resource farmers should be assisted to join cost-share programs provided by State and federal agencies. These cost-share programs may be used to prevent these barriers of adopting agroforestry practices in the form of equipment and other agricultural inputs. More importantly, agricultural policies need to be enacted to address farmers' needs and ensure agroforestry is part of the agriculture agenda for improving land productivity.

Keywords: education, capacity building, agroforestry

AD4.6.2. Farmer forest groups in forestry development, where are they? A study case from Indonesia

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There are several arising questions: what is the position of farmer forest groups in Indonesian forestry development? Are they inside or outside the development program? Are they involved or excluded from the development program? Even though it has been stated that farmers play an important role in forestry development in Indonesia, their existence and attention for them are not yet obvious. Profound information from the research on social capital of farmer forest group in Indonesia, specifically Bulukumba District, South Sulawesi Province and Sumbawa District, West Nusa Tenggara Province, has shown that farmers belonging to farmer forest groups were involved in forestry projects even before the project was started.

However, this situation did not continue after the completion of the project since there was no simultaneous effort to support the group and to monitor the existing groups resulting in many groups existing in name only. Agroforestry exists as an option of diversifying farmer groups from the above situation and for increasing farmers' social capital. If we are to improve the communities around forest welfare through forestry development, the government needs to provide an alternative such as providing support for farmers and the groups. The government also needs to obtain sufficient information on the available benefits for farmers to increase their livelihood as well as increasing the social capital farmers through agroforestry.

Keywords: *agroforestry importance, farmer forest group, forestry development, social capital*

5.0 Applying science to the future of agroforestry: breakthroughs and innovations

5.2 New tools and paradigms

AD5.2.1. Phytochemical constituents and pharmacological activities of *Mitragyna parvifolia* (Roxb.) Korth

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Mitragyna parvifolia, a medicinal and endangered tree, belongs to the family Rubiaceae. The bark and roots of the tree are used to treat fever, colic, muscular pain, burning sensation, poisoning, gynecological disorders, cough, edema and as an aphrodisiac. Antioxidant activity of methanolic leaf and bark extracts of *M. parvifolia* was evaluated using the free radical scavenging activity of the 1, 1-diphenyl-2-picrylhydrazyl radical (DPPH) and total antioxidant capacity (TAC) which having scavenging activity of 82.04% and 92.74% respectively. In addition, polyphenolic compounds

(phenols, flavonoids, flavonols, tannins, proanthocyanidins) in the leaf and bark extracts were determined. The results obtained in the present study indicated that *M. parvifolia* is a potential source of natural antioxidant. Methanolic extract of leaf and bark also exhibited antibacterial potential against *E.coli*, *B.subtilis* and *P. aeruginosa*. The highest activity of leaf extract (31 ± 1.4 mm zone of inhibition) and bark extract (31.5 ± 2.12 mm) was found against *Escherichia coli*. Minimum Inhibitory Concentration (MIC) was also determined, for leaf extract it is 14 mg/ml against *P. aeruginosa*, 12 mg/ml (*E. coli*) and 8mg/ml (*B. subtilis*) whereas the bark extract showed MIC of 8 mg/ml against *P. aeruginosa* 12 mg/ml (*E. coli*) and 4 mg/ml (*B. subtilis*). The major compounds identified by GC-MS analysis in the leaf and bark extracts of *M. parvifolia* were isobutanoic acid, 2-ethylhexyl ester, 4 methyl mannose, mitraphylline, isomitraphylline and 1, 2 Hydrazine dicarboxylic acid, diethyl ester, α , α -dimethyl mucconic acid, isobutanoic acid, 2-ethylhexyl ester, α -D-glucopyranoside, α -D-glucopyranosyl respectively. Among these compounds found in the leaf of *M. parvifolia*, a pentacyclic oxindole alkaloid mitraphylline is known for its anti-inflammatory, ntiproliferative activities and α -D- glucopyranoside, α -D-glucopyranosyl used in the treatment for dry eye syndrome. This study may serve to illustrate the continuing value of plant-derived secondary metabolites as viable compounds for modern drug development.

Keywords: *antibacterial activities, antioxidant activities, GC-MS analysis, Mitragyna parvifolia*

AD5.2.2. Use of information and communication technologies for promotion of agroforestry in the Pacific

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The forest sector within Pacific Island Countries and Territories (PICTS) is at the cross roads in terms of fighting against the negative impact of climate change, growing demand for an ever rising population and high intensity of natural disasters.

Forests have for generations provided for the social, cultural and economical needs of Pacific Island Communities and now it is the time for the communities to manage their only resource in a sustainable manner for them and for future generations to benefit.

'Outside the box' approach is needed to protect, conserve and adapt our forest ecosystem from these calamities so that the current and future generations continue to enjoy the goods and services provided by forests.

The age-old concept of agroforestry is coming to the forefront now and various opportunities need to be explored to promote these models for sustainable management of resources. Breakthroughs in ICT for development have given us new rays of hope to reach the remotest communities in the Pacific to spread the gospel of adopting agroforestry for a sustainable future.

Despite so many conferences, meetings and international negotiations, we continue to face forest degradation and upon a careful look, all this points into just one direction and that is that our communication is either inadequate or ineffective.

So through this paper the presenter will explore different opportunities available in the ICT field to create awareness on agroforestry as well as other forestry issues. Farmers and tree growers have started to use mobile smart phones and are connecting to other web-based tools via the internet

especially social media (web 2.0 tools). These tools should be explored to create the much needed awareness.

Due to the smallness of the Island countries in the Pacific region, agroforestry is the way forward and use of ICT for knowledge transfer is an ideal platform to create an enabling environment to address issues such as food and nutritional security, climate change adaptation, income security and meeting cultural and social needs of the communities that are closely knit to nature.

It has been the norm that those in forestry should stay away from advancement in technology but now this is the opportunity to embrace it for better management of our sector (forestry sector). So it's time for foresters to embrace technology and take advantage of it. Let us do smart agroforestry with ICT.

Keywords: *agroforestry models, soil fertility and SFM, biodiversity and conservation, food and nutritional security, media for development - communications*

AD5.2.3. Seedling Bioassay to Assess Fodder Cowpea Tolerance to Different Herbicides

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Weed competition in fodder crops at an early stage has become a serious problem. The existing recommendations of herbicides have become ineffective against existing and shifting weed species and thus there is a need for devising new recommendations. This experiment was conducted at the field level to find out the best suitable herbicides and doses for fodder Cowpea. Though the commonly followed field experiment is accurate and effective, it has many disadvantages like requirement of long time, land resources, labour and involvement of huge investment. Besides, the efficacy of herbicides is influenced mostly by abnormal weather conditions like heavy rain and other environmental factors. To overcome these disadvantages, the seedling bioassay experiment (Tal et al. 2000) was performed in Petri-dish to determine the selectivity of different herbicides for fodder Cowpea under *in vitro* condition at Indian Grassland and Fodder Research Institute, Jhansi. In this experiment, three pre-emergence herbicides viz., Pendimethalin (@ 0.5, 0.75 and 1 kg a.i./ha), Imazethapyr (@ 0.1, 0.15 and 0.2 kg a.i./ha) and Alachlor (@ 0.75, 1.0 and 1.5 kg a.i./ha) were tested at the mentioned doses to evaluate germination percentage and radical and plumule growth of fodder cowpea seeds. Germination percentage of fodder cowpea was found to be 99% in all treatments. However, Imazethapyr at a concentration of 0.2 kg a.i./ha was found to be significantly superior and produced maximum relative root length (145.94 %) and shoot length (49.88 %), followed by Pendimethalin at a concentration of 0.5 kg a.i./ha @ 71.17% and 46.67 % respectively. Thus the maximum root length was observed in Imazethapyr 0.2 kg a.i./ha (14.01 cm) and followed by Pendimethalin 0.5 kg a.i. /ha (6.78 cm). Hence, Imazethapyr at a concentration of 0.2 kg a.i./ha was found to be effective pre-emergence herbicide for fodder cowpea. Thus the seedling bioassay method was found to be rapid and reliable in determination of selectivity of herbicides for Fodder Cowpea.

Keywords: *fodder cowpea, herbicide, bioassay*

AD5.2.4. Comparative biology of *Clostera cupreata* (Butler) on different poplar clones and its management

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The studies on comparative biology and management of poplar leaf defoliator, *Clostera cupreata* (Butler) (Lepidoptera:Notodontidae), on poplar were conducted in screen houses at Forestry Research Area and in Forest Protection Laboratory Punjab Agricultural university, Ludhiana and farmer's field at villages Nurpur Bet and Khaira Bet (Distt. Ludhiana). Biological studies revealed that clones PL7, L47/88 and G 48 had no effect on the duration of eggs, larvae, pupae and adult longevity. The egg, larval, pupal stage and adult longevity ranged from 2.66-3.96, 10.3-34.3, 4.10-116.7 and 4.00-7.70 days, respectively. The defoliator had nine generations/year and the time taken to complete one generation varied from 22-148 days. The size measurement of larvae, pupae and adult varied from 4.14-27.56 mm, 11.3-15.4 mm and (26.70 to 29.40 mm wing expanse & 12.30-13.24 mm body length) respectively. Clones did not influence oviposition behavior however lower leaf surface was preferred for egg laying in all the clones. PL7 was less preferred for feeding compared to L47/88 & G48. Pupation occurred in thin hairy cocoon between two leaves held together by silken thread. Fecundity varied from 143.33-250.00 eggs among the clones. Maximum adult emergence and mating took place during 5.00am to 9.00am. Young larvae skeletonised the leaves and the older larvae consumed on entire leaves of poplar. The peak activity period extended from August to September. Per cent damaged leaves were more in no intercropped (3.80-48.46 per cent) and less in intercropped (2.20-44.50 per cent) plantation. *Aleoides percurrens* lyle (Larval parasitoid) and *Canthecona furcellata* wolff (Larval predator) were recorded as natural enemies. Quinalphos 25EC, profenophos 50EC and carbaryl 50 WP @ 0.075 and 0.1 per cent concentration effectively controlled *C. cupreata*. It was concluded that PL7, L47/88 and G48 did not show any resistance against *C. cupreata*. Cultural practices and the above insecticides can help in the management of the insect.

Keywords: *bioecology, Clostera cupreata, seasonal history*

5.3 Biodiversity and agroforested areas

AD5.3.1. Necessity of agroforestry system to sustain the use and conservation of *Mimusops andongensis* Hiern in Benin

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Mimusops andongensis is a multipurpose species. The wood is used for construction to produce charcoal and as firewood. Its bark, roots and leaves are used for local healthcare needs, fruits and bark for alimentary uses. This use, together with habitat destruction, limits its availability for rural dwellers and its population conservation. We assessed the population viability of the species in Lama Protected Forest (its main habitat) with different human pressure levels using structural characterization to highlight the necessity to grow it in agroforestry system. Dendrometric characteristics and diameter size distributions were assessed through forest inventory. Adult trees were found in 92% of plots in

non-degraded forest, 71% in degraded forest and only 7% in preforest fallow. Tree-density (in stems/ha) in non-degraded dense forest (42.7 ± 35.0) is 2-23 times higher ($p < 0.001$) than in degraded dense forest (23.1 ± 39.02) and preforest fallow (1.8 ± 7.79). Similar trend was obtained according to the regeneration density (106.2 ± 117.3 , 83.5 ± 140.0 and 17.0 ± 74.0 stems/ha respectively). Diameter size distributions were positively asymmetric showing relative dominance of young or small diameters individuals in non-degraded and degraded dense forests while in preforest fallow, it was similarly exponentially declining indicating a population in extinction. The low density of sexually mature trees accompanied with low regeneration in degraded forest and preforest fallow may negatively impact the long-term viability of the species, despite protecting the forest to prevent products harvesting. Thus, vegetative propagation tests will help to grow the species in agroforestry system to sustain its use by local communities and its conservation.

Keywords: *agroforestry importance, anthropogenic pressure, *Mimusops andongensis*, population viability*

AD5.3.2. Traditional agroforestry systems towards nature conservation and sustainable livelihoods in ICCAs

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There is increasing recognition that the territories and areas managed by indigenous communities (ICCAs[1]) contain significant levels of biodiversity, and that the knowledge and practices of these people have contributed to conservation of ecosystem, species, and genetic diversity. Indeed, a combination of sustainable and biodiversity-friendly use of natural resources and landscape conservation aims characterises many ICCAs. Besides their contributions to the conservation of biodiversity, ICCAs secure the needs of millions of people for water, food, energy, medicine, shelter, fodder, income, recreation and spiritual sustenance.

Therefore, understanding the development of traditional production practices in ICCAs will provide valuable information to design ecologically sustainable land use systems such as agroforestry. In this context, an exploratory study through PAR[2] has been conducted in some determined ICCAs with the help and supervision of ICCA Consortium to explore the traditional agroforestry systems practiced by the indigenous communities and the socioeconomic significance of those practices. An inventory was also made on the customary conservation approaches of the selected ICCAs elaborated especially by the community elders.

The study showed that several traditional agroforestry systems based on the communities' needs and site-specific characteristics have developed over thousands of years in ICCAs. Examples are as abundant as human cultures and biomes, from village-managed nut and fruit forests in Central Asia to traditional river fisheries in Laos; from tribal pastoral territories in Mongolia to community forests in the Italian Alps and South America Forests. Among all cases, homegardens have the most compatibility with the need of communities and the climatic conditions of ICCAs. Finally, the outcomes of this study could be used for recommendations of some effective sustainable agroforestry systems modelled after the adopted traditional agroforestry practices in studied ICCAs with easy acceptance by local communities.

[1] Indigenous and Community Conserved Areas

[2] Participatory Action Research

Keywords: *biodiversity conservation, ICCAs, sustainable livelihood, traditional agroforestry practices*

AD5.3.3. Genetic diversity of the wild and domesticated *Dyera polyphylla* (Apocynaceae) from Indonesia as determined by Amplified

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Dyera polyphylla ('jelutong', Apocynaceae) is a native tree species of peat swamp forests that occurs in Southeast Asia, mainly in Sumatra and Borneo islands. Despite their economic benefit, little is known about the genetic diversity of *D. polyphylla* from wild and domesticated populations. Amplified fragment length polymorphism (AFLP) analysis was performed to study genetic diversity of seven populations of *D. polyphylla* that grow naturally in the forests and were cultivated on-farm peatland, originated from Jambi and Central Kalimantan, Indonesia. Sample size of each population varies between 9-20 individual trees. Using five selected primers, AFLP analysis has revealed 255 polymorphic loci. Shannon's indices of diversity (*I*) and *Nei*'s gene diversity (*h*) were 0.5757 and 0.3919, respectively. Analysis of variance (AMOVA) confirmed the coefficient of gene differentiation (*Gst*) was 0.1498. The AMOVA showed total differentiation among all populations was 0.345 (*PhiPT*) of which 0.298 (*PhiPR*) was due to populations within a region and 0.068 (*PhiRT*) was due to regions component. The cluster analysis of *Nei*'s distance matrix based on a UPGMA algorithm indicates that population of Senyerang was apparently in the outermost part of the diversity spectrum (5.415), although it is geographically located in the Jambi region. In contrast, the genetic distance between populations of planted jelutong in peat forest reserve of Tanjung Jabung Barat (Jambi) and Tumbang Nusa in Central Kalimantan (both wild and domesticated was low (0.915), although they are geographically far from each other. Reforestation in peat forest reserve of Tanjung Jabung Barat may reduce gene flow among regions. The genetic makeup of the existing *D. polyphylla* populations should be considered in the decision of peat rehabilitation program and domestication.

Keywords: *agroforestry, biodiversity, conservation, domestication*

AD5.3.4. Ecological characteristics between commercial economy and sufficiency economy of home gardens in northern Thailand

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Ecological characteristics between commercial economy (ComHgs) and sufficiency economy (SufHgs) of home gardens at Phrae province in northern Thailand were studied in a total 30 home gardens which included in 18 ComHgs in Denchai district and 11 SufHgs in Muang Phrae district. The ages of the studied in ComHgs and SufHgs were 21 and 25 years ranging from 2 to 55 years and 4 to 58 years of ComHgs and SufHgs, respectively. The sizes were 822 and 402 m² in ComHgs and SufHgs, respectively. In total of ComHgs, 176 plant species were recorded, of which 43.3 %

were tree species, followed by shrubs (29.0 %), herbs (14.8 %) and climber species (13.1 %). The largest group of the uses was foods (30.7 %), ornamentals (25.6 %), fruits (16.5 %), building materials and medicinal were 10.8 % and other (5.7 %). In total of SufHgs, 127 plant species were recorded, of which 43.3 % were tree species, followed by shrubs (26.0 %), herbs (17.3 %) and climber species (13.4 %). The largest group of the uses was foods (36.2%), fruits (20.5 %), ornamentals (18.1 %), medicinal (10.2 %), other (8.7 %), and building materials (6.3 %). Seven species occurred commonly in ComHgs (more than 70 %) even in home gardens where species numbers per garden were not high: *Musa sapientum*, *Lansium domesticum*, *Bacaurea ramiflora*, *Alpinia siamense*, *Mangifera indica*, *Hibiscus rosa-sinensis* and *Solanum barbisetum*. Five species occurred commonly in SufHgs (more than 70 %) even in home gardens where species numbers per garden were not high: *Mangifera indica*, *Musa sapientum*, *Bauhinia variegata*, *Erythralium scandens* and *Ocimum tenuiflorum*. Most of soils in both groups of home gardens were sandy to sandy clay loam. Both surface and subsurface soils were slightly acidic and rich in nutrient contents. The cation exchange sites of the soils were saturated with exchangeable bases, predominated by Ca, resulting in the value of base saturation to exceed 100%. In comparison with other land uses, both groups of home gardens could be characterized by high contents of nutrients throughout soil profile. It is suggested that higher soil fertility down to subsoils could allow diverse plants with different rooting depths to coexist within a relatively small area of home gardens in northern Thailand.

Keywords: *sufficiency economy, commercial economy, home gardens, northern Thailand*

AD5.3.5. Variation studies in *Ulmus villosa* Brandis: a suitable tree species for agroforestry

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The present investigation entitled “Variation studies in *Ulmus villosa* Brandis” was carried out at the experimental field of Department of Tree Improvement & Genetic Resources, College of Forestry, Dr. Y. S. Parmar University of Horticulture & Forestry, Nauni-Solan during 2010-12. Seeds were collected from five mother trees each at six seed sources and progenies were raised to study the extent and pattern of variation with respect to growth and biomass characters. However, the wood samples were collected from selected trees for studying wood characters. Site S₄ (Jagoti/District Shimla) exhibited outstanding performance for the growth and biomass characters of progenies followed by S₁ (Jadh/District Mandi) and S₅ (Katouch/District Shimla), whereas S₃ (Jhidi/District Mandi) showed the lowest values for these characters. Site S₆ (Andhra/ District Shimla) trees exhibited outstanding performance for wood characters followed by S₄ (Jagoti/District Shimla) trees. High heritability with moderate genetic gain was observed for collar diameter followed by plant height and petiole length among growth and biomass characters and high heritability with moderate genetic gain was recorded in wood density among wood characters. Highly significant and positive genotypic and significant phenotypic correlation were observed for height and diameter, fresh shoot weight and fresh root weight and dry shoot weight and dry root weight. Molecular diversity study was conducted on 23 promising progenies of *U. villosa* using ten RAPD primers. A total of 57 markers were generated, which exhibited 100% polymorphism. Such a high level of polymorphism reflects the outcrossing nature of the species. UPGMA dendrogram based on RAPD markers resolved into four major clusters and the similarity coefficient among 23 progenies of *U. villosa* ranged from 0.04 to 0.70 indicating a broad genetic base of *U. villosa* progenies. Maximum similarity (70%) was observed between Jag-T₂ (Jagoti/District Shimla) and Jag-T₃ (Jagoti/District Shimla). However, the minimum values were

observed between Ka-T₄ (Katouch/District Shimla) and Jag-T₂ (Jagoti/District Shimla) (0.04). RAPD analysis proved helpful for estimating the magnitude of genetic diversity at molecular level.

Keywords: biomass characters, *Ulmus villosa*, progenies, genetic diversity

AD5.3.6. Endangered biodiversity of Hadoti region especially in Kota district of eastern Rajasthan

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Biodiversity, colorful diversity of earth's ecosystems, species and their genes, is being increasingly valued because it sustains life itself. But it is under serious threat globally; several hundred's species are becoming extinct every day with habitat destruction, unsustainable ways of living and competition for space between people and wild species. India is one of the 12 mega biodiversity countries in the world. The country is divided into 10 biogeographic regions. The diverse physical features and climatic situations have formed ecological habitats like forests, grasslands, wetlands, coastal and marine ecosystems and desert ecosystems, which harbor and sustain immense biodiversity. The Rajasthan region is one such region. Biogeographically, *Hadoti* region is situated close to the borders of Madhya Pradesh and having fertile agricultural region for plentiful yields in grain and pulses. Chambal River makes its lush green. Many forest plants, wild trees and wild animals are found in natural habitats. It is rich in its biodiversity and in last decade, this biodiversity has been shrunk in the region. This includes wild plant species such as *Butea monosperma*, *Azadirachta indica*, *Pithecellobium dulce*, *Ficus religiosa*, *f. bengalensis*, *Acacia catechu*, *Syzygium cumini*, *Foenix wild*, *Acacia nilotica* etc. The populations of wild animals such as wild boar, blue bull, jackals, wolf, leopard, wild dogs, hedge hog, and many more have decreased many times. Poaching and killing for meat, fur skin and other animal parts is reducing the number of wild animals. There is a need to save the biodiversity of this region by making people aware of the flora and fauna and taking drastic steps for poaching and killing wild animals and illegal felling of trees in order to make money.

Keywords: biodiversity, habitat, wild plants

5.4 Agroforestry in dry and degraded lands

AD5.4.1. Establishment of *Jatropha curcas* in alkali land with bio-inoculants and various fertilizer doses

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India has about 17.69 million hectares of degraded land due to salinity, alkalinity or other issues. The reclamation of degraded land is useful for the production of fuel, fodder and food with increase in demand. The four mycorrhizal species used in the experiment were isolated from the alkali land. The AM fungi and other fertilizer doses were used for reclamation of alkali wasteland with

Jatropha curcas. The AM fungi played an important role in plant establishment, growth, branch formation and collar diameter when inoculated with urea, SSP, FYM and vermicompost. The *Acaulospora laevis* inoculated with urea + SSP + vermicompost to *Jatropha* plants showed maximum plant height. The minimum plant height of *Jatropha* plants was recorded in *Gigaspora margarita* inoculated plants with dung. The AM fungi, *Glomus constrictum* inoculated *Jatropha* plants showed maximum number of branching when supplemented with urea + SSP and vermicompost while the minimum number of branching per plant was recorded in *Jatropha* plants inoculated with *Glomus fasciculatum* and dung. The maximum number of collar diameter was recorded in *Jatropha* plants inoculated with *Glomus constrictum* + urea + SSP + FYM + vermicompost and minimum number of collar diameter was recorded in *Acaulospora laevis* and dung inoculated plants. Vermicompost increased soil porosity, organic matter and beneficial microorganisms in the plant root environment, urea provides nitrogen and SSP provides phosphorus which was made available to plants through AM fungi. The soil pH was reduced considerably after eighteen months and nutrition levels of soil also increased and became suitable for cultivation of low salt tolerant crops. The data were recorded quarterly from experimental field and found highly significant statistically.

Keywords: *Jatropha curcas*, AM fungi, alkali land reclamation, bio-inoculants, fertilizers

AD5.4.2. Effects of controlled grazing management on soil carbon stocks in a dry savannah ecosystem in Ethiopia

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Controlled grazing management has been recognized as one of the strategies to enhance soil carbon sequestration and preservation, but empirical evidences have been lacking. We investigated the effectiveness of long-term (14-36 years old) livestock exclosures in changing soil carbon in the semi-arid savanna of southern Ethiopia. Our objectives were to assess differences between exclosures vs. adjacent open-grazed rangelands, age of exclosures and soil depths on soil carbon. We selected four replicates of three age categories of range exclosures, i.e. <20, 20-30 and >30 years old, each paired with adjacent open grazed lands as control. Accordingly, soil samples were collected from each age category (both in exclosures vs. adjacent open-grazed) at two soil depths (0-20 cm and 20-50 cm). We found no significant ($P > 0.05$) differences between exclosures and open-grazed rangelands in all the three age categories, as well as between both soil depths (the top 0-20 cm and sub-soils 20-50 cm). The age chronosequence further suggested no significant ($P > 0.05$) changes in soil carbon content with increasing duration of exclosures.

We suggest that the effects of grazing managements on soil carbon stocks and managing livestock exclosures on the basis of their specific ecologies should be the foremost goal, while carbon sequestration being an ancillary benefit. Therefore, projects targeting at mitigating climate change by sequestering more carbon in the soils through livestock exclosure management in dry savanna ecosystems should be carefully designed and which could be considered as a co-benefit.

Keywords: ecosystem services, exclosure, land degradation, soil carbon

AD5.4.2.3. Mapping and assessment of desertification using LANDSAT data on a regional scale

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Desertification is a serious threat to the ecological environment and social economy in our world and there is a pressing need to develop a reasonable and reproducible method to assess it at different scales. In this paper, the Hognu Khaan protected area in Mongolia was selected as the research region and a quantitative method for desertification assessment was developed by using Landsat TM/ETM+ data on a regional scale. In this method, NDVI, GSI (Topsoil grain size index) and land surface albedo were selected as assessment indicators of desertification to represent land surface conditions from vegetation biomass, landscape pattern and micrometeorology. Based on considering the effects of vegetation type and time of images acquired on assessment indicators, assessing rule sets were built and a decision tree approach was used to assess desertification of Hognu Khaan protected area in 1990, 2002 and 2011.

Keywords: *desertification, sand, assessment, correlation, top soil grain size index*

6.0 Applying science to the future of agroforestry: policy innovation and global issues

6.1 Policy, governance and international frameworks

AD6.1.1. Transforming innovation platforms into viable farmer institutions for sustainable land management in Uganda

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Innovation platforms (IPs) are institutional arrangements composed of a wide range of stakeholders (including farmers, researchers, private sector, extension staff and policy makers) who are key in diagnosing, planning, implementing, evaluating, providing feedback and re-planning sustainable land management activities as well as accessing relatively cheap and affordable financial services. Supporting sustainable land management (SLM) with cheap and affordable financial services is critical and has been identified as a challenge by IP members. This requires financial services which are not readily available with the actors of the IPs. The government of Uganda has initiated financial support through Uganda Cooperative Savings and Credit Union (UCSCU) which would bridge the gap between innovation platform members to access credit to support SLM activities. Focus group discussions and key informant interviews involving 65 participants (35 male and 30 female) were conducted with the stakeholders to understand the current status of the IPs and the overall environment in which they are operating (strength, opportunities, strategies and challenges) for transforming IPs into viable local institutions. Results indicate that there exist government institutions and partners that are willing to support IPs with cheaper financial services at an interest rate of 2% compared to the 13% of other lending institutions on condition that they have business plans. Savings and credit management, weak rules and regulations, coupled with poor enforcement mechanisms were cited as major challenges facing innovation platforms. It was

concluded that mobilization, sensitization and training of all actors in innovation platform approach in savings and credits can support sustainable land management. Strengthening of the IP rules and regulations involving local leadership are recommended as key to accessing affordable credit.

Keywords: *regulations, savings and credit cooperative union, institutional arrangements, business plans*

6.4 Landscape approaches

AD6.4.1. Land cover and tree biomass dynamics in the agricultural landscape of Uluguru Mountains, Tanzania

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Uluguru Mountains are renowned for their high biodiversity richness, endemism and presence of threatened species of flora and fauna. Like many other areas in the Eastern Arc Mountains, Uluguru Mountains face challenges of deforestation and forest degradation. Historically, land use change for various reasons has accelerated clearing of the forest vegetation from the highland to the lowlands on these mountains. This study attempted to assess the trends of land cover as a result of land use change at a temporal and spatial scale in the study site. Landsat imageries acquired with less cloud cover were used for land cover and land use change assessment using remote sensing and GIS techniques. Tree plots were sampled from three major land uses of forest patches, fallow and active farm for wood biomass assessment. Tree inventory data were analyzed for plot level biomass estimation which was then incorporated with satellite imageries to produce landscape-level tree biomass maps to reflect its dynamics for the last three decades. Results indicated that forest cover has declined to the lower level categories, and farmland was increasing over time. This trend signifies the expansion of agricultural frontiers and conversion of forest to other land uses. High regeneration was observed in the fallows indicating the potential for restoration if land conditions are favourable. Forest patches have relatively remained intact with less degree of wood extraction, indicating that farmers extract wood more on active farms and fallows. Generally, the tree biomass has been declining over the years, thus corresponding to forest cover changes. Modes of crop farming which includes shifting cultivation and, repeated and continuous use of fire during annual farm preparation were responsible for discouraging tree regeneration on active farms. As shown in fallows, tree regeneration can also be exercised in repeated crop farming with agroforestry interventions to enable tree retention and enrichment at a spatial arrangement for easy farm preparation and management to realize improved tree cover and biomass.

Keywords: *biodiversity, shifting cultivation, tree cover transition, trees on farm*

AD6.4.2. Long term observation of land use change and its impacts on livelihoods in the Nicaragua Honduras Sentinel Landscape

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The CGIAR research program Forests, Trees and Agroforestry has established a sentinel landscapes (SL) network (eight in total), including a site in Nicaragua Honduras. These SLs were set up to facilitate long term research and comparative analysis, using multiscale approaches and indicators in forested landscapes.

The Nicaragua Honduras sentinel landscape (N-H SL) covers an area of 67 992 km². It incorporates three biosphere reserves in Honduras and one in Nicaragua (the heart of the Central American Biological Corridor). Key land uses include closed primary as well as secondary forests, traditional agroforestry (coffee, cacao) and silvopastoral systems, and annual crop production. The N-H SL exemplifies the dynamics of severe deforestation due to expansion of the agricultural frontier, in particular extensive livestock production, and the ineffectiveness of incentives and policy enforcement to protect conservation areas.

Base line data (soil status, forest resources and socio economic conditions) has been collected in four selected sites to understand the relationship between livelihoods and land health, and develop indicators to monitor temporal changes in the landscape. Local organizations identify sentinel landscapes as a unique opportunity to obtain reliable information and foster capacity building supporting better management of their resources. Key research questions are: i. what social, economic and political conditions underlie current trends of forest degradation and different models of tree cover recovery? ii. What are the impacts of community forest management and different models of tree cover recovery on livelihoods and ecosystem services? The creation of open access data bases (e.g., structure, coding, common methodologies and variables, access procedures, intellectual property rights and recognition), including existing information from public and private sectors, local, national and international R&D organizations, that will permit comparative analysis between two countries, is a major challenge.

Keywords: forest transitions, long term research and monitoring, Mesoamerica, sentinel landscape

AD6.4.3. Assessing land health constraints across West African cocoa landscapes

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A number of studies have demonstrated the role of cocoa farming in the degradation of lands in humid areas of West and Central Africa, which account for two-thirds of the world's cocoa production. However, its magnitude and the impact on soil health are poorly documented. The objective of the present study was to assess major soil health constraints associated with sun-grown cocoa farming. The study sites are cocoa landscapes in Ghana, Nigeria and Cameroon where the Land Degradation Surveillance Framework (LSDf), a nested hierarchical spatial sampling design, was used. The sampling unit is a landscape of 100 km² stratified into 16 clusters and 160 plots. Soil parameters were

analyzed using MIR spectroscopy calibrated against reference analyses on 10% of the samples. Generally the percent area under cultivation across landscapes is similar and ranges from 48.7% (Cameroon) to 49.0% (Ghana and Nigeria) with median values of cultivated/managed areas of 2220 ha; 6390 ha; 7780 ha per 100 km² in Cameroon, Nigeria and Ghana, respectively. Root depth restriction is likely the major constraint, which affected 46% plots in Cameroon, 77% in Nigeria and 45% in Ghana covering 1990 ha; 3540 ha and 3980 ha. The degradation risk occurred at 67% in Cameroon, 27% in Nigeria and 8% in Ghana and covered 6270 ha, 2590 ha and 700 ha. In topsoil, organic carbon values were higher in Nigeria (35.5 g kg⁻¹) relative to Ghana (20.8 g kg⁻¹), but both values were within the medium range for tropical soils. A reverse trend was found for total N, which values are considered low in general. Soil pH in Nigeria is below the critical limit of 5.5, indicating strong soil acidity, while Ghana displayed a median value of 6.12. The exchangeable aluminum values in the topsoil (0-20 cm) are below 800 mg kg⁻¹ with higher values in the subsoil (20-50 cm). The contribution of the results towards sustainable cocoa farming in Africa is discussed.

Keywords: land degradation, cocoa farmings, land health, landscapes

6.5 Agroforestry, water quality and nutrient export

AD6.5.1. Ecology of *Eupetorium adenophorum* (Kalabansa) in restoring for ecology of agro-ecosystem in Uttarakhand

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Eupetorium adenophorum, *sprengel* (Kalabansa), a fast growing fuel wood plant species finds a tremendous potential in restoring the highly sensitive and fragile Himalayan ecology by way of its high regeneration capacity, good soil-water-nutrient conservation value thus provide protecting shield to highly eroded and degraded sloping lands. The results on compatibility studies with *Robinia pseudoacacia*, *Gravia optiva*, *Celtis australis*, *Pennisatum cladestimum*, *Coix lachrymal*, *Desmodium teleaifolium* and Hybrid nappier were recorded good compatibility. It has also found to improve the organic matter status, water stable aggregates in soil. The volume of runoff water and losses of soil, organic carbon and nutrient in runoff water were markedly influenced by rainfall, slope of land as well as vegetative cover of *Eupetorium adenophorum*. It effectively lowered down the runoff volume by 72.5 to 82.6, soil loss by 55.3 to 73.7 and organic carbon by 61.0 to 77.2%, respectively. It also reduced the amounts of total soluble salts (TSS), Ca⁺², Mg⁺², K⁺ and Na⁺ by 11.3, 20.9, 24.7, 22.9 and 25.8% NO₃⁻, PO₄⁻³, SO₄⁻², Cl⁻, HCO₃⁻ and CO₃⁻² by 29.3, 26.3, 15.7, 14.2, 15.0, 16.3% respectively in runoff water from sloping lands.

Contribution of individual ion concentration in runoff water indicated that HCO₃⁻ and CO₃⁻² constituted 68%, Ca⁺² and Mg⁺² 17.1%, K⁺ and Na⁺ 5.3% and NO₃⁻, PO₄⁻³, SO₄⁻² and Cl⁻ constituted 9.4% of total ion concentration in water. Order of dominance of different cation was Ca⁺² > Mg⁺² > Na⁺ > K⁺ and of anions HCO₃⁻ > CO₃⁻² > Cl⁻ > NO₃⁻ > SO₄⁻² > PO₄⁻³.

Keywords: *Eupetorium adenophorum*, Himalayan ecology, runoff volume, soil and nutrient losses

6.6 Successful and scalable business models for agroforestry with quantified mitigation and adaptation co-benefits

AD6.6.1. Economic evaluation of carbon capture in the APA -Serra de Baturité, Brazil, 2012

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Forest carbon capture is a mechanism to reduce greenhouse gases. Trees, through the process of photosynthesis, absorb carbon dioxide, CO₂, from the atmosphere and store it as biomass. The Environmental Protection Area (APA) was the motivation to develop this study. Quantifying and assessing the financial viability of the generation of carbon credits were the main objectives. The quantification of CO₂ storage was estimated by the non-destructive method (based on forest inventory estimates) and the economic criteria used to evaluate was the Net Present Value (VPL), the equivalent annual value (EAV) and the Internal Rate of Return (IRR). The results show that the rainforest of the APA Serra de Baturité on average captured 84.63 tCO₂ h⁻¹, and according to market prices and costs in 2012, forestry projects for carbon capture is non-viable if sold in the market of Clean Development Mechanism. In contrast, the projects are viable if sold in the New Zealand Emission Trading Scheme (TIR = 135) and in the Over the Counter (TIR=74). To summarize, the carbon forest project in the APA Serra de Baturité is economically viable. Moreover, this study provides a suitable methodological guideline for economic evaluation of carbon capture projects. Above all, it is important to highlight that the challenge in sustainability is to keep standing forests not just for environment, but also because such protected areas generate higher economic benefits if compared with other extractive uses.

Keywords: *cash flow, rainforest, transaction costs*

AD6.6.2. Managing renewable natural resources sustainably from the green economy perspective through agroforestry techniques

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Renewable natural resources (RNR) are an important source of livelihood means that provide sustenance for many rural inhabitants including those that are not domiciled in those places referred to as rural. This importance has led to efforts strategically aimed at sustainable ways of generating and utilising these RNR. One such way is the use of agroforestry techniques in realising this objective. Agroforestry techniques combine many land-use practices on a single piece of land such that agronomic and non-agronomic plants and animals are brought together for management purposes on a single land unit. Series of researches/studies have been carried out in this regard before and particularly since around 1987 when 'Our Common Future' or the 'Brundtland Report' was published. This publication dwelled more on issues concerning sustainable development, defined as development that meets the needs of the present without compromising the ability of future generations to meet their own needs. Recently, the concept of 'green economy', an offshoot of the broader sustainable development concept, has also been well publicised. Although there may be no single agreed definition, set of indicators or financial measurements for what exactly the 'green economy' consists of, literature shows that

agroforestry can be efficiently used in realising part of the concept. Thus, for the positive and beneficial parts of this and other types of concepts to be successfully implemented and gained from, particularly in the developing regions, (most especially those concepts externally conceived), then the support of all stakeholders will be necessary. In line with this, this presentation has been conceived to highlight some of the definitions/descriptions including some current operational methods of 'greening an economy', how some agroforestry techniques fit in and how these can be used in the sustainable management of RNR for the present and future generations.

Keywords: *agroforestry techniques, green economy, renewable resources, sustainable development*

AD6.6.3. Role of Agro-forestry in mitigating the Climate Change: Case studies of Karnataka state

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A case study of five farmers was done in Karnataka state district in 2013 to know the opinion of farmers concerning the impact of different agroforestry systems in mitigating the climate change. The first farmer cultivating fruits crops + plantation crops + flower crops + agricultural crops +forestry (teak, silver oak, pongamia, rosewood) opined that, the forestry trees serve as wind break, as a fence which avoids spread of pests and diseases, prevents stray and grazing animals from outside. It prevents soil erosion, improves soil fertility, keeps the micro climate cool reducing irrigation requirement and fetches additional income. The second farmer practicing agriculture + vegetable crops + flower crops +forestry (Teak and silver oak) opined that, up to 5-6 years of planting of forestry species, the yield of vegetable and flower crops was better. But afterwards, it extended its root system and absorbed moisture and nutrients which are applied to the main crops. The third farmer practicing agriculture + vegetable crops + forestry (Teak and silver oak) expressed that he is getting low yield due to shade effect, powdery mildew and thrips incidence. Further, he opined that during rainy season, the heavy leaf drippings break the growing tips of the crops, causes lodging hence, reduced yields. The fourth farmer practicing grapes + forestry (teak, silver oak) opined that, the trees absorbs moisture and nutrients applied to the grapes causes powdery mildew and pests incidence resulting in reduced fruit quality.

Keywords: *agroforestry, climate change, climate change mitigation, agroforestry systems*

Annex 1: List of posters presented

1. Poplar (*Populus deltoides*) based agroforestry system: a case study of Southern Haryana: **AK Deswal**, VPS Yadav, Rajender Kumar, RB Gupta
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3. Agro-forestry based crop diversification for income and environmental services on reclaimed ravine lands: a case study: **VC Pande**, RS Kurothe, HB Singh, SP Tiwari
4. Transformation of Fruit Tree Orchard into Multistoried Agroforestry System: A Way for Higher Production and Income: **Giashuddin Miah**, Abiar Rahman, Mahbub Islam
5. Assessment of growing stock of Bamboo under agroforestry systems in central India: **Inder Dev**, SK Dhyani, KB Sridhar, SP Ahlawat, Ram Newaj, RK Tewari, RV Kumar, Ramesh Singh, RS Yadav, A Venkatesh, RP. Dwivedi, DR Palsaniya
6. Performance of gum yielding trees based agroforestry models from Central India: **Rajendra Prasad**, SK Dhyani, B Alam, Ajit, AK Handa, Ramesh Singh, VD Tripathi
7. Opportunities and challenges of high value cash crop large cardamom-based agroforestry in the Eastern Himalayas: **Ghanashyam Sharma**
8. Economic viability of Andrographis in Agroforestry: **Anne Madhavi Lata**
9. Evaluation of agri-horti-silvicultural agroforestry systems in rainfed uplands of coastal Odisha, India: **Alok Kumar Patra**, Ashok Kumar Mohapatra
10. Identification of elite genotypes of fruit trees for arid zone agroforestry: **Purkha Ram Meghwal**, Akath Singh
11. Performance of Potato varieties and their time of sowing under Poplar plantation: Ankurdeep Preety, **Rishi Indra Singh Gill**, Baljit Singh
12. Pinus gerardiana for agro forestry systems: An opportunity for rural development: **Raj Kumar**, GS Shamet, OP Chaturvedi, Harsh Mehta, Rajesh Kaushal, Ayub Dar
13. Tree-crop association for livelihood security of small and marginal farmers of coastal Odisha: **Ashok Mohapatra**, Prasanjit Mishra, Alok Kumar Patra
14. Influence of Climatic Factors on Lac Cultivation on Flemingia macrophylla in understored plantations of Dalbergia sissoo: **Baragur Neelappa Divakara**
15. Trees on Farmland: composition, abundance and role of trees on farmland in rural communities: **Lila Puri**, Henrik Meilby
16. Development of Agroforestry models for semi-arid tropics of Andhra Pradesh : **Murugharajendra Bheemappa Honnuri**, Gillela Ravishankar Reddy
17. Abelmoschus esculentus a potential intercrop under Grewia based agroforestry system of mid hill of Himachal Pradesh: **Kashmir Pant** , Aalok Gulabrao Yewale, Rajesh Kaushal, Prem Prakash, Chandrashekhar S Sanwal
18. Critical Issues in Poplar Based Different Agroforestry System in India: **Avtar Singh**, Ashok Kumar
19. Response of selected indigenous dryland agroforestry tree species to salinity and their implication to soil fertility management: Hadia Seid, Fassil Kebede, **Emiru Birhane**, Kiros Meles Hadgu, Jermias Gasper Mowo
20. Agroforestry and Energy security: Corporate, NGO and Academic collaborative initiatives: **Varunkumar SV**, Manjunath L, Ramakrishna Hegde, Rachappaswamy R
21. Soil improvement by organic inputs of an agroforestry system in arid zone of India: Arun Kumar

Sharma, **DK Painuli**, SP Seth, H Singh

22. Anna Pratha and Agroforestry Development in Bundelkhand and Diara land of Indo-Gangetic plains of India: **R K Tewari**., Asha Ram, CK Bajpai, Shishupal Singh Yadav, Kumar Dhyani
23. Biochar derived from crop and tree residues can revitalize drylands in India: **G Venkatesh**, JVNS Prasad, G Rajeshwar Rao, KA Gopinath, B Venkateswarlu, PV Ramesh Babu
24. Soil moisture dynamics and nutrient depletion pattern in agrisilvicultural systems: **Prasannajit Mishra**, Bibhuti Bhusan Behera, Alok Kumar Patra, Ashok Kumar Mohapatra
25. Traditional Agroforestry is Basis of Sustainability in Arid Zone: Examples from Western Rajasthan: **Moola Ram**, LN Harsh
26. Response of Pruning and nutrient application on fruit and fodder yields of *Ziziphus mauritiana* Lamk in hot arid India. **Birbal Meel**, Vijay Singh Rathore, narayan singh nathawat, seema Bhardwa, narendra dev yadava
27. Enhancing Forage Production through Silvipastoral System in Arid Regions: **Mavji Patidar**, PR Meghwal, AK Patel, Tanvi Maheshwari
28. Potential of bio diesel plantations in drylands of South India : Experiences: **GR Rao**, KV Rao, B. Venkateswarlu
29. Agro-forestry for sustaining rural livelihoods in hot arid areas in India: **VP Tewari**
30. Soil Quality Under *Grewia Optiva* Based Agroforestry System in Doon Valley of Western Himalayas: **Rajesh Kaushal**, Archana Verma, Debashis Mandal, Harsh Mehta, Jagmohan Tomar, Om Parkash Chaturvedi, Jayaprakash Jagadees, Raj kumar, Avinash Rathore
31. Carbon storage potential of Tea agroforestry system in Barak Valley, Assam, North East India: **Rinku Moni Kalita**, Ashesh kumar Das, Arun Jyoti Nath
32. Carbon sequestration potential of agroforestry practices in the mid hills of central Himalaya: **Ram Prakash Yadav**, Jaideep Kumar Bisht
33. Carbon sequestration potential of teak plantations of different agro-climatic zones and age-gradations of Southern India: **Chiranjeeva Reddy Milkuri**
34. Atmospheric CO₂ capture and photochemical efficiency determined adaptive potential of *Pongamia pinnata* to Climate Change: **Badre Alam**, Arun Kumar Handa, Ram Newaj, Shiv Kumar Dhyania
35. Biomass and carbon stock in trees grown in agroforestry under semi-arid regions of Central India: **Ram Newaj**
36. Agroforestry based watershed approach for livelihood security and climate change resilience in degraded agro ecosystems **DR Palsaniya**, Ramesh Singh, RK Tewari, SK Dhyani, S Yadav,RP Dwivedi
37. C-sequestration and its predictive model for Poplar (*Populus deltoides*) based agrisilvicultural system in north India: **Sumit Chaturvedi**, Salil Tewari, Rajesh Kaushal
38. Carbon sequestration, storage rate and biomass estimation of multipurpose agroforestry tree species: **Bolla Joseph**, racharla shankar Shankar, K B sunitha devi
39. Woody biomass and carbon sequestration potential in agri-horti-silvi systems in arid region of north-western Rajasthan: **Bilas Singh**
40. Vegetation composition and socio-economic significance of homegardens in Aizawl district of Mizoram, North-East India Leishangthem **Jeecelee**, Soibam Lanabir Singh, Uttam Kumar Sahoo
41. Studies on structural and functional diversity in the urban and peri-urban homegardens of Kerala, India: **Kunhamu TK**, Niyas P, Jothisna C, Aneesh CR, Neelesh Kumar, Sukanya S
42. Asian homegardens between time and space : lessons from India and Thailand: **Sylvie Guillerme**, Bérénice Bellina, Jean-Marc Dubost

43. Anthropological differential management of fodder trees and shrubs”: **Devashree Nayak**
44. Impact of *Hardwickia binnata* based silvipastoral system on runoff in Central India: **Ramesh Singh, RK Tewari, SK dhyani RK Singh, R Singh, Asha Ram**
45. Variation in proximate and mineral content in fruit and leaf of 12 provenances of Gamari (*Gmelina arborea* Linn Roxb: **Amarendra Nath Dey, Nagendra Prasad Todaria**
46. Study on exploring tree fodder as livestock feed in silvipasture system: **Kathirvelan Chinnadurai**
47. Effect of mineral mixture supplementation on reproductive performance of anestrus heifers fed on oak leaves: Akash Chandrakar, **Biswanath Sahoo**, J Raju, AK Garg, K Narayanan, P Thirumurgan, K Sharma
48. In vitro evaluation of mixing five high tanniniferous tree leaves with *Grewia optiva* leaves for feeding ruminants: **Alagarsamy Kannan, TK Bhat**
49. Evaluation of feeding value of some lesser known tree leaves/shrubs as replacement of wheat straw by in vitro trials: **Alagarsamy Kannan**
50. Heterosis in intra-specific hybrids of *Grewia optiva* : genotypes using line X Tester mating design: **Saresh NV**, NB Singh, Archana Verma, M S Sankanur, JP Sharma, SM Raghavendra , VP Khanduri, CS Dhanai
51. Effect of condensed tannin on growth performance and gastrointestinal nematode load of goats fed oak leaves diet in hill: J Raju, **Biswanath Sahoo**, A Chandrakar, AK Garg, M Sankar, AK Sharma.
52. Evaluating domestication potential of *Pentaclethra macrophylla* Benth in view of increasing its contribution to food production: **Alain Calice Tsobeng**, Honore Tabuna, Ebenezer Asaah, Zac Tchoundjeu, Patrick Van Damme
53. Phenotypic variations in fruits and seed traits of *Chrysophyllum albidum* in three agroecological zones in Nigeria: **Chioma Jasmine Okwu**, Ebenezer Asaah, Sierra Leone Joseph Amanze, Alain Tsobeng, Zac Tchoundjeu
54. The Wave Project – two years of a space and time experiment: **Ciro Abbud Righi**
55. Canopy modification of *Eucalyptus camaldulensis* sprouts due to shade: **Ciro Abbud Righi**, Vincent Couderc, Carlos Rodrigues Pereira, Hilton Thadeu Zararte Couto
56. Cassava production in an agroforestry system with eucalyptus: **Ciro Abbud Righi**, Damien Joubert, João Luis Ferreira Batista
57. Short rotation trees in agroforestry: a tool for enhancing income through industry linkage: **Maheswarappa Veerapur**
58. Addressing constraints in propagation of *Allanblackia* spp. through seed sectioning and air layering: **Daniel A. Ofori**, Joseph M Asomaning, Theresa Peprah, Zac Tchoundjeu, Jeremias G Mowo, Ramni Jamnadass
59. Correlation and path analysis studies in teak for stem volume production: a suitable tree species for agroforestry: **Dipika purushottam Ayate**
60. Do propagation methods affect tree growth and fruiting in African plum (*Dacryodes edulis*)?: **Ebenezer Asaah**, Mabel B Atone, Alain Tsobeng, Zac Tchoundjeu, Frederick Numbisi
61. Wheat Performance and Soil Properties under High Density Plant Geometry of Fast Growing Tree Species in North-Indian Plains: **Manish Kumar**, OPS Bana, Rajesh Kaushal, Sumit Chaturvedi, Salil Tewari, CP Nath, Somnath Sitaram
62. Effect of moisture conservation and nutrient management on growth of *Eucalyptus Pellita* plantation: **Shivaputra Bammanahalli**, GV Dasar, Mahantappa Sankanur, YS Parmar, Manish Kumar, YS Parmar
63. Hybrids of *Eucalyptus torelliana* Hook. and *Eucalyptus citriodora*: FV Muell, **Parveen Velmi**

64. Socioeconomic and household's contribution of African conophor nut, a neglected livelihoods products full of promise: **Jiofack Tafokou Rene Bernadin**, Guedje Nicole Marie, Tchoundjeu Zacharie, Jejoly Jean, Avana Marie Louise, Mate Mweru Jean Pierre
65. Causes of disappearing of *Acacia nilotica* from the farmer's fields of Northern India: A review: **Rama Kant**
66. Complementarities of Intercropping in Casuarina junghuhniana pulp wood production system in Tamil Nadu, India **Jamaludheen V**, Divya MP, Parthiban KT
67. Assessment of growth characters of bamboo spc under rainfed condition in humid tropics: **Vijay Vishnu Dalvi**, Balasaheb Sawant, Prakash Ramchandra Pawar
68. The Role of Short Rotation Coppice Technology in Fuelwood Supply in Rungwe District, Tanzania: **Anthony Kimaro**, Mathew Mpanda, Abdalla Liingilie, Martha Swamila, L L Lulandala, George Karwani
69. Developing Populus ilicifolia as a bioenergy agroforestry tree species and genomic research tool for adaptive evolution: **Alice Muchugi**, Sammy Muraguri, Robert Kariba, Ramni Jamnadass, Sammy Carsan
70. Effects of Arbuscular mycorrhizal inoculations and cotyledons removal on early seedling growth of *Pongamia pinnata* (L.): **JKLA**, Anil Kumar, Anuradha Jha, Madhvi Kamalvanshi, Neha Chakravarty, Shiv Kumar Dhyani
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72. Performance of *Ocimum* species under *Pongamia pinnata* based silvi-medicinal agroforestry systems in South Gujarat: AH Suvera, **NS Thakur**, SK Jha, RS Chauhan
73. Perception and willingness of farmers to adopt agro-forestry for charcoal feedstock supply in dry lands of Mutomo, Kenya: **Geoffrey Ndegwa**, Miyuki Iiyama, Johanes Hamhaber, Dieter Ahnuf
74. *Pongamia pinnata* value chain of biofuels as a economic venture in agroforestry system: **Balakrishna Gowda**, Haleshi C, Pavithra HR, Vijayakumar GC, Prasanna KT
75. Biofuel trees species in agroforestry system – a source for agribusiness: **Balakrishna Gowda**, Prasanna KT, Rajeshkumar Kodi, Girish AC, Chandrika K
76. Bio-processing of lignocellulosic poplar (*Populus deltoides* Bartr.) wood for biofuel production: Rekha Rawat, **Lakshmi Tewari**, Rajkumar Pandey, Disha Sharma, Salil Tewari,
77. Retrospective on the hype: bottlenecks for jatropha bioenergy value chain development in Africa: **Miyuki Iiyama**, Navin Sharma, Violet Moraa, Jeremias Mowo, Ramni Jamnadass
78. Karanja (*Pongamia pinnata* L.) based agri-silviculture system under rainfed conditions: **Naresh Kaushik**, Suman Malik, Kumari
79. Fueling the future: poplar and willow as renewable bioenergy crops in Canada: **Raju Yaranna Soolanayakanahally**, William R. Schroeder, Chris Stefner, Hamid Naeem, Ron Gares
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82. Vegetative propagation by stem cuttings of 12 fodder woody species indigenous to West African Sahel: **Catherine Ky-Dembele**, Jules Bayala, Antoine Kalinganire, Fatoumata Tata Traoré, Brehima Koné, Alain Olivier
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84. Diversity and nutrient contents of mango varieties along an altitudinal and a latitude gradient in Malawi: Shem Kuyah, Simon Mngomba, John Saka, **Katja Kehlenbeck**
85. Morphological and Biochemical Characterization in the Germplasms of Terminalia chebula Retz: an important tree species **Mahantappa Sankanur**, N B Singh, Sanjeev Thakur, Sapna Thakur, N V Suresh, Archana Verma
86. Provenance variation for pod and seed germination parameters of Cassia fistula L. in agro-climatic zones of N. Karnataka: **Holalgouda Y Patil**, Renuka Nayak, Shivanna H, Surendra P
87. Effect of different pre-sowing treatments on seed germination parameters of Cassia fistula L.: **Holalgouda Y Patil**, Renuka Nayak, Shivanna H, Surendra P
88. Agroforestry and the role of tree fruits for diversifying diets and improving nutrition: **Stepha McMullin**, Gudrun Keding, Katja Kehlenbeck
89. Lac cultivation: Livelihood security for Bundelkhand farmers of Central India: Sridhar KB, Sudhir Kumar, Rajendra Prasad, Rajendra Singh, S Ghoshal, Mohammed Monobraullah, A venkates
90. Priority Indigenous Fruit Trees in the Drylands of East Africa: Examples from Kenya, Tanzania and Uganda: **Clement Akais Okia**, Benard Muok, Lawrence Mbwambo, Oscar Eyog-Matig
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94. Hunger and undernourishment in forest areas: Positioning wild edible plants into food security and nutrition debates: **Precillia Ijang Tata**
95. Incentives and constraints of clove based agroforestry in the uplands of Java, Indonesia: **Shigekazu Kawashima**, Shintaro Kobayashi, Shigeki Yokoyama
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127. Gender roles, responsibilities and spaces: Implications for agroforestry research and development in Africa: **Evelyn Kiptot**
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299. Capacity Building for Natural Resources and Agro-forestry in agricultural Education: **Dennis Mandizvid Chipare**
300. Factor analysis to assess impact of silvipasture and grassland ecosystem under arid conditions: **Sharmila Roy**, Nav Ratan Panwar, Prakash Mal
301. Food System Pathway Modeling and Homegarden Agroforestry for Combating Urban Food Deserts: Gregory Toth, **Tom Reynolds**, PKR Nair
302. Influence of a silvopastoral system in the Brazilian savanna on soil physical parameters: **Regina Maria Quintao Lana**, Angela Maria Quintao Lana, Guilherme Lanna Reis, Rodrigo Martins Alves de Mendonca, Iran Borges
303. A case study analysis of Agricultural Extension Services (AES) provided by public department and marketing behavior (MB): **Gangadharappa RN**, Gangappagouda Shivanagouda Biradar
304. Vulnerability of coconut based agroforestry systems in Sri Lanka to climate change: **Sanathanie Ranasinghe** , Nihal Premasiri, Chandana Pradeep
305. Fodder Production From Woody Perennials in Mountains of Uttarakhand through management practices: **Sujeet Kumar Lavania**, Virendra Singh, Vinod Kumar Sah
306. Barriers to integrating forestry into agricultural system: Analysis of forest legislation and policy in Nepal: **Bishnu Hari Pandit**, Hemant Ojha, Krishna Shrestha
307. Bioreclamation of salt affected soil through Terminalia arjuna and Dendrocalamus strictus plantation model: **Talevar Singh Rahi**, Lal Bahadur, Anil Kumar Goe, Shri Krishan Tewari, Chandra Shekhar Nautiyal
308. Coffee and tree root systems in sub-optimal soil and climatic conditions in unshaded and shaded coffee compared: **Maria da Penha Padovan**, Anna Catherine Deffner, Ledis Fernando Navarrete Vallencillo, Elvin Dani Navarrete Palacios, Mirna Barrios Aguirrez, Sergio Vilchez Mendoza, Aureliano Nogueira Costa, Carolina Vega Jarquin, Bruno Rapidel
309. Integrating agroforestry and sheep feeding for increased food security in Mali: Alain Olivier, **Jean Bonneville**., Hamidou Nantoumé, Alassane Sanogo, Jules Bayala, Sidiki Gabriel Dembélé
310. Terrestrial carbon sequestration in Poplar based agroforestry systems in North-Western states of India: **Parveen Kumar**
311. Quantification of forest carbon degradation in Nicaragua using RapidEye remote sensing data: **Fredy Nelson Argoty**, Miguel Cifuentes, Pablo Imbach, Fernando Casanoves, Lee Vierling, Muhammad Ibrahim
312. Importance of remnant forests and native shade trees in coffee agro-forests for coffee pollination and fruit-set: **Smitha Krishnan**, Jaboury Ghazoul, Kushalappa G Cheppudira, Uma Shaanker R
313. Productivity and financial viability of potential agroforestry systems in North-Western India: **Navneet Kaur**, R.I.S Gill, Baljit Singh
314. Intensive forage production under rainfed silvipostoral system in semi-arid regions of India: **Susheela Raavipati**, Shanti Madaraju

315. Effect of shade and nitrogen levels on production and quality of bajra napier hybrids: **Shanti Madaraju**
316. Salt-affected lands- threats, opportunities and technologies for production of biomass and bioenergy: **Surinder Kumar Sharma**, Gurbachan Singh, Jagdish Chandar Dagar
317. Carbon storage and carbon sequestration of tree Species influenced by Planting Geometry under Farm Forestry: **Dinkar J Jiotode**, Vijay Mahadeo Ilorkar
318. Fodder tree technology: Extension and adoption challenges in Northern Malawi: **Colm P Duffy**, Greg Toth
319. Value chain development of agroforestry species for ensuring sustainable livelihood in India: **Narayan G Hegde**
320. Agroforestry option for smallholder farmers in Northwest Vietnam – Late fruiting longan with grass strips and short term: **Tuan V Vu**, Phong V. Tan, Lua T. Hoang
321. Development potential of Agroforestry systems with son tra (*Docynia indica*) in the Northwest Vietnam: **Lua Hoang Thi**, Thuong H Pham, Delia Catacutan, Toan D Vu
322. Variability, heritability and association studies among different clones of *Eucalyptus tereticornis* planted at two sites: **Rakesh Kumar**, KS Bangarwa
323. Carbon augmentation of farmlands of Bohol through development of oil palm based agroforestry: **Florencia B. Pulhin**, Rodel D. Lasco
324. Biofuel trees species in agroforestry system – a source for agribusiness: **Balakrishna Gowda**, Prasanna KT, Rajeshkumar Kodi, Girish AC, Chandrika K
325. Agroforestry domestication potential of a native tree species in Vanuatu: **Geoff Smith**, Doland Nichols, Kevin Glencross, Graeme Palmer, John Grant, Raxon Vira
326. Integrated use of organics and inorganics in different intercrops in Pongamia Based on Agri-Silvi culture system in sem: **Khan A. Mohammad Abdul**, Reddy Prathap Kumar, Ambapurkar Krishna, P.Rajesh
327. Necessity of agroforestry system to sustain the use and conservation of *Mimusops andongensis* Hiern in Benin: **Gisèle Koupamba Sinasson Sanni**, Charlie M. Shackleton, Brice A. Sinsin
328. Effect of different level of Indol Butyric Acid (IBA) on rooting and sprouting of semi hard wood cutting of Olive (*Olea Bharat*) M. Nandre, Ramesh Shakhela, Surendra Kumar, R.K.Sharma
329. Use of Information, Communication technologies for promotion of agroforestry in the Pacific: **Vinesh Prasad**
330. Adopting Agroforestry models for Improved Soil Health for better farm returns: **Vinesh Prasad**
331. Evaluation of *Dalbergia sissoo* Roxb. progenies at field stage under semi-arid regions of Punjab: **Avtar Singh**, Gurvinder Pal S Dhillon
332. Experience in the use of agroforestry practice to enhance land productivity: Esohe G. Oboho, Ekeoba **M Isikhuemen**
333. Establishment of *Jatropha curcas* in alkali land with bio-inoculants and various fertilizers doses: **Preetesh Kumari**, Kaushal P Singh
334. Selection and performance of Mulberry Provinces (*Morus indica* L.) – a promising agroforestry tree species of India: **RS Loushambam**, Chaman L Thakur, DR Bhardwaj
335. Decentralised capacity building of rural communities in agroforestry: an efficient means of reforestation and the fight against climate change: **Koffi Koudouvo**
336. *Ailanthus excelsa* Roxb: A potential tree species for short rotation agroforestry in Semi-arid Tropics: **Vijay M Ilorkar**

337. Effect of row spacing and mulching on production potential of maize (*Zea mays* L.) in guava (*Psidium guajava* L.) based agrihorti system under rainfed condition: Nitya Nand Shukla, Bhalendra Singh Rajput and **Avijit Sen**

Annex 2: Congress Committees

Executive Committee

Tony Simmons, Director General, World Agroforestry Centre

S Ayappan, Director General, Indian Council of Agricultural Research

Congress Organizing Group

August Temu, World Agroforestry Centre, Nairobi, Kenya

A K Sikka, Indian Council of Agricultural Research

B Mohan Kumar, Indian Council of Agricultural Research

V P Singh, World Agroforestry Centre, New Delhi, India

Sanjay Tomar, World Agroforestry Centre, New Delhi, India

Cathy Watson, World Agroforestry Centre, Nairobi, Kenya

S K Dhyani, National Research Centre for Agroforestry, India

Paul Stapleton, World Agroforestry Centre, Nairobi, Kenya

Gulshan Borah, World Agroforestry Centre, New Delhi, India

Tony Gourley, Global Initiative

Science and Programmes Committee

Co-chairs Science and Programme Committee

Mohan Kumar, Indian Council of Agricultural Research

Ravi Prabhu, World Agroforestry Centre, Nairobi, Kenya

Session Leaders

Session Number	Session Leader(s)	Session Title
Agroforestry systems, income and environmental benefits		
1.1	<ul style="list-style-type: none"> J S Samra, National Rainfed Area Authority, India K B Thampi, National Rainfed Area Authority, India 	Policy on agroforestry and tree based farming
1.2	<ul style="list-style-type: none"> B M Kumar, Indian Council of Agricultural Research A K Singh, Central Arid Zone Research Institute, India 	Agroforestry for rural employment and income generation
1.3	<ul style="list-style-type: none"> Gurbachan Singh, Central Soil Salinity Research Institute (CSSRI), Haryana, India J C Dagar, Central Soil Salinity Research Institute (CSSRI), Haryana, India 	Land Reclamation: Bio-drainage and salinity control
1.4	<ul style="list-style-type: none"> V N Sharda, Central Arid Zone Research 	Drylands and agroforestry

	Institute, Jodhpur, India <ul style="list-style-type: none"> B Venkateswarlu, Central Arid Zone Research Institute, Jodhpur, India 	
Climate change, multifunctionality, livestock and fish systems		
2.1	<ul style="list-style-type: none"> B M S Rathore, Ministry of Environment & Forests, New Delhi, India 	Agroforestry for Climate change mitigation and adaptation
2.2	<ul style="list-style-type: none"> P K R Nair, University of Florida, USA 	Tropical homegardens: Multi functionality and benefits
2.3	<ul style="list-style-type: none"> P S Pathak, Pitambara Agri Sciences P Ltd, Uttar Pradesh, India P Singh, Banaras Hindu University, Uttar Pradesh, India 	Tree fodder and animal nutrition
The business of agroforestry: applying science		
3.1	<ul style="list-style-type: none"> Z Tchoundjeu, World Agroforestry Centre, Yaounde, Cameroon 	The viability of trees as crops: agroforestry, pulp and wood-based enterprises, cocoa, coffee
3.2	<ul style="list-style-type: none"> N Sharma, World Agroforestry Centre, New Delhi, India 	Biofuels: using trees as a sustainable energy resource
3.3	<ul style="list-style-type: none"> R Jamnadas, World Agroforestry Centre, Nairobi, Kenya S Bhagawat, The Open University, UK 	Improving nutrition through agroforestry: the business case
3.4	<ul style="list-style-type: none"> R Prasad, Independent consultant, Natural Resource Management K D Singh, Academy of forest and environmental services, New Delhi, India 	Building livelihoods on tree products
3.5	<ul style="list-style-type: none"> P Worms, World Agroforestry Centre, Brussels, Belgium 	Public-private partnerships: adding value to develop markets for producers
3.6	<ul style="list-style-type: none"> M Van Noordwijk, World Agroforestry Centre, Bogor, Indonesia Beria Leimona, World Agroforestry Centre, Bogor, Indonesia Terry Sunderland, 	Valuing the environmental services of trees on the landscape
Sustaining development through agroforestry		
4.1	<ul style="list-style-type: none"> DN Tewari, Utthan: Centre for sustainable development and poverty alleviation, Uttar Pradesh, India KG Saxena, Jawaharlal Nehru University, New Delhi, India 	Meeting development challenges with agroforestry
4.2	<ul style="list-style-type: none"> D Catacutan, World Agroforestry Centre, Hanoi, Vietnam 	The gender dimensions of applying agroforestry innovation
4.3	<ul style="list-style-type: none"> C Mbow, World Agroforestry Centre, Nairobi, Kenya T S Rosenstock, World Agroforestry Centre, Nairobi, Kenya 	Adapting to climate change
4.4	<ul style="list-style-type: none"> D Callo-Concha, Center for Development Research (ZEF), University of Bonn, Germany A Schwachula, Center for Development Research (ZEF), University of Bonn, Germany 	Bridging science and development
4.5	<ul style="list-style-type: none"> F Sinclair, World Agroforestry Centre, Nairobi, Kenya 	Increasing food production through trees on farms
4.6	<ul style="list-style-type: none"> M Hassan, World Agroforestry Centre, Nairobi, Kenya A Yaye, African network for agriculture, agroforestry and natural resources education (ANAFE), Nairobi, Kenya 	Building development abilities through education and capacity development
Applying science to the future of agroforestry: breakthroughs and innovations		
5.1	<ul style="list-style-type: none"> E Somarriba, CATIE, Turrialba, Costa Rica P Vaast, World Agroforestry Centre and 	Humid multi-strata systems

	CIRAD, Nairobi, Kenya	
5.2	<ul style="list-style-type: none"> T Vagen, World Agroforestry Centre, Nairobi, Kenya 	New tools and paradigms
5.3	<ul style="list-style-type: none"> E Barrios, World Agroforestry Centre, Nairobi, Kenya 	Biodiversity and agroforested habitats
5.4	<ul style="list-style-type: none"> J deLeeuw, World Agroforestry Centre, Nairobi, Kenya K S Rao, GB Pant Institute of Himalayan Environment and Development CR Babu, Centre for Environmental Management of Degraded Ecosystems, University of Delhi, Delhi, India 	Agroforestry in dry and degraded lands
5.5	<ul style="list-style-type: none"> Jose Shibu, University of Missouri, USA 	Temperate agroforestry
5.6	<ul style="list-style-type: none"> C Padoch, Centre for International Forestry Research (CIFOR), Bogor, Indonesia U Pradhan, World Agroforestry Centre, Bogor, Indonesia 	The social science of agroforestry
Applying science to the future of agroforestry: policy innovation and global issues		
6.1	<ul style="list-style-type: none"> A Wardell, Centre for International Forestry Research (CIFOR), Bogor, Indonesia F Place, International Food Policy Research Institute, Washington DC 	Policy, governance and international frameworks
6.2	<ul style="list-style-type: none"> George Cadisch, University of Hohenheim, Germany J Xu, World Agroforestry Centre, Kunming, China 	Ecology and economics of rubber-based agroforestry
6.3	<ul style="list-style-type: none"> S Franzel, World Agroforestry Centre, Nairobi, Kenya 	The science of scaling up and the trajectory beyond subsistence
6.4	<ul style="list-style-type: none"> P Minang, World Agroforestry Centre, Nairobi, Kenya 	Landscape approaches
6.5	<ul style="list-style-type: none"> M R Mosquera Losada, Universidade de Santiago de Compostela, Spain V Nair, University of Florida, USA 	Agroforestry, water quality and nutrient export
6.6	<ul style="list-style-type: none"> H Neufeldt, World agroforestry Centre, Nairobi, Kenya 	Successful and scalable business models for agroforestry with quantified mitigation and adaptation co-benefits

Annex 3: Congress Agenda

Monday, 10 February 2014

0800–0900

Buses transport participants to Vigyan Bhawan

South Asia Day

Vigyan Bhawan, Maulana Azad Road, New Delhi

Inauguration

0900–1030

Registration at Vigyan Bhawan Annex

1030–1100

Coffee and tea served at Vigyan Bhawan Annex, courtesy of the Indian Tourist Development Corporation

1100–1115

All participants seated in Vigyan Bhawan Plenary Hall

1130–1300

Opening ceremony (*see separate programme for further details*)

Inaugural address by Shri Pranab Mukherjee, Honourable President of India

Panel of dignitaries

Shri Sharad Pawar, Honourable Minister of Agriculture and Food Processing Industries
Dr M. Veerappa Moily, Honourable Minister of Environment and Forest

Shri Ashish Bahuguna, Secretary of Agriculture
Dr S Ayyappan, Secretary of the Department of Agricultural Research and Education and the Director General of the Indian Council of Agricultural Research

Dr Anthony J. Simons, Director General of the World Agroforestry Centre

Krishikarman award ceremony

Honouring farmers from Andhra Pradesh, Arunachal Pradesh, Assam, Bihar, Chhattisgarh, Haryana, Jharkhand, Madhya Pradesh, Maharashtra, Manipur, Meghalaya, Mizoram, Odisha, Punjab, Tripura, Uttar Pradesh, West Bengal

Youth awards

1305–1400

Lunch – courtesy of the Indian Tourist Development Corporation

Plenary 1

Venue: Vigyan Bhawan Plenary Hall

1400–1405

ICAR song

1405–1410

Introduction of keynote speaker and panelists
Dr S Ayyappan, Secretary of the Department of Agricultural Research and Education and the Director General of the Indian Council of Agricultural Research

1415–1445

Keynote address

Dr M S Swaminathan, Emeritus Chairman and Chief Mentor of the MS Swaminathan Research Foundation

1445–1505

Panel discussions

Dr Dina Nath Tiwari, Founder and Head of Utthan, Centre for Sustainable Development and Poverty Alleviation, India

Dr R S Paroda, Chairman, Trust for Advancement of Agricultural Sciences and Executive Secretary, Asia Pacific Association of Agricultural Research Institutes

Prof. H P M Gunasena, Chairman, Coconut Research Institute, Sri Lanka

Dr Rita Sharma, Secretary, National Advisory Council, Government of India

1505–1515

National Agroforestry Policy: a brief overview

1515–1520

Wrap up

Dr M S Swaminathan, Emeritus Chairman and Chief Mentor of the MS Swaminathan Research Foundation

1520–1650

Breakout session 1

Theme: **Agroforestry systems, income and environmental benefits**

Theme leader: **P K R Nair**

1.1 Policy on agroforestry and tree-based farming systems

Venue: Plenary Hall

Chairs: **J S Samra** and **K B Thampi**

- Agroforestry research in Indonesia: where to go for the next two decades

Dede Rohadi

- Mediating factors of agroforestry changes in Vietnam: implications for agroforestry development

Hoa Thi Nguyen

- The role of agroforestry in newly allotted forest lands in tribal Odisha

Kamla Khanal

- CAFNET – first effort in India to value ecosystem services from coffee-based agroforestry systems

Cheppudira Kushalappa

- Agroforestry systems in China - a proposed classification for Chinese tropical agroforestry

Xiao Guo

- Trees on private lands: a regulatory impact analysis in select states in India

Chetan Agarwal

1.2 Agroforestry for rural employment and income generation

Venue: Hall 4

Chairs: **A K Singh** and **B Mohan Kumar**

- Tree-borne oil seed crops – a step towards building energy security in rural India

Balakrishna Gowda

- *Santalum yasi Seem.* a vital agroforestry species for rural employment and livelihoods development in Fiji

Saurindra Narayan Goswami

- Implementation of agroforestry for poverty alleviation and livelihood improvement in the state of Tripura, India

Avinash M Kanfode

- Role of agroforestry in poverty alleviation at Ghatail Upazilla of the Tangail District, Bangladesh

Md. Wasiul Islam

- Ensuring integrated timber and non-timber forest product marketing for improving rural livelihoods: lessons learnt from Indonesia

Muktasam Abdurrahman

- Yamunanagar – a model of a symbiotic relationship between farmers and wood-based industries

Raj Kumar Sapra

1.3 Land reclamation: biodrainage and salinity control

Venue: Hall 5

Chairs: **Gurbachan Singh** and **J C Dagar**

- Biodrainage: an ecofriendly agroforestry technique for controlling waterlogging, livelihood security and carbon sequestration
Jagdish Dagar
- Rehabilitation of degraded sodic land through agroforestry and monoculture plantations
Kripal Singh
- Biodrainage as successful models for combating water logging in canal command: some case studies
Rajbir Singh
- Cultivation of intercrops inside biodrainage (*Eucalyptus camaldulensis*) vegetation under a waterlogged ecosystem in Odisha
Somnath Roy Chowdhury
- Biodrainage for salinity control: myth or reality for the Indian monsoonal climate
P S Minhas
- Potential of tree plantations for wastewater disposal: Long term use in Eucalyptus
R K Yadav

1.4 Drylands and agroforestry

Venue: Hall 6

Chairs: V N Sharda and B Venkateswarlu

- Design and development of agroforestry systems in low rainfall regions of India for combating climate change
Murari Mohan Roy
- Improving productivity of common grazing resources in hot arid region of India through participatory pasture development
Arun Misra
- Livelihood diversification through agroforestry in semi-arid regions of India
Prasad JVNS
- Cultivating resilient landscapes - opportunities for restoring degraded and vulnerable lands with agroforestry systems
Matilda Palm
- Bamboo-based agroforestry for livelihood security and environmental protection in semi-arid regions of India
Sudhir P Ahlawat
- Beyond the project cycle: ex-post assessment of agroforestry adoption and management in semi-arid Karnataka
James Brockington

1650–1720

Tea/coffee break – Book release: details in daily announcement

1720–1850

Breakout session 2

Theme: **Climate change, multifunctionality, livestock and fish systems**

Theme leader: Giashudin Miah

2.1 Agroforestry for climate change mitigation and adaptation

Venue: Plenary Hall Chair:

B M S Rathore

- Below-ground carbon stocks of 21-year-old *Grevillea robusta* stands in the humid tropics of Kerala
Samritika Thakur
- Climate change and agroforestry management in Sri Lanka: adverse impacts, adaptation strategies and policy implications
Mangala Premakumara De Zoysa
- Yield, carbon density and climate change impact on bagras (*Eucalyptus deglupta* Blume) in corn-based hedgerow intercropping
Richmund Palma
- CO₂ sequestration estimation for the litsea-cassava agroforestry model in the Central Highlands of Vietnam
Bao Huy
- Assessment of carbon stocks and fractions under agroforestry plantation in the hilly ecosystems of northeast India
Ramesh Thangavel
- Greenhouse gas mitigation in a landscape perspective - a case study from semi-arid regions of India
Prasad V N S Jasti

2.2 Tropical home gardens: multifunctionality and benefits

Venue: Hall 4

Chair: P K R Nair

- Carbon stock and tree diversity of dry-zone homegardens in southern Sri Lanka
Eskil Mattsson
- The multiple drivers of homegarden decline in Kerala, India
Thomas Arcadius Fox
- Floral and avifaunal composition, richness and diversity of traditional agroforestry homegardens on the Konkan coast of Maharashtra
Kumarsukhadeo Prakash Gadekar
- The potential of palms in Southeast Asian agroforestry systems and homegardens
Anders Sánchez Barfod

- REDD+ benefits to encourage good practices outside forest lands: a case study in Vietnam

Hoan Trong Do

- Homegarden agroforestry for socioeconomic, ecological and environmental sustainability in Sri Lanka
DKNG Pushpakumara
- Quest for an appropriate bamboo species in tropical homegardens - can *Dendrocalamus stocksii* (Munro) fit the bill?
Syam Viswanath

2.2 Tree fodder and animal nutrition

Venue: Hall 5

Chairs: Punjab Singh and P S Pathak

- Sustainable fodder production strategy through utilization of wastelands in hills
Jaideep Kumar Bisht
- Nutritional value and mineral profile of forest foliages in the temperate SubHimalayas
Biswanath Sahoo
- Fodder production through agroforestry: a boon for profitable sheep and goat farming
Bandeswaran Chinnaondi
- Development of suitable silvipasture models for meeting fodder requirements in Tamil Nadu
Divya M P
- Growth and yield of agricultural crops intercropped under three multipurpose trees in Mizoram, northeast India
P C Vanlalhlun

Traditional agroforestry systems for the rural development in the hills of Garhwal Himalaya India

Arvind Bijalwan

Evening programme

1850–1900

Buses depart from Vigyan Bhawan to Ashok Hotel

1900–1945

Cultural programme, Ashok Hotel

1945–2130

Cocktail followed by Inaugural Dinner, Ashok Hotel

2130

Buses depart from Ashok Hotel to various hotels

0700–0900

Buses transport participants from hotels to venue Kempinski Ambience, Shahdara

Plenary 2: The role of business in accelerating the impacts of agroforestry

Venue: Plenary Hall

0900–0910

Welcome remarks and introduction of Chair, keynote speaker and panelists

Tony Simons, Director General, World Agroforestry Centre

0910–0930

Keynote address

Howard Shapiro, Chief Agricultural Officer, Mars Inc.

0930–1025

Plenary keynotes and panel discussion

The role of business in accelerating the impacts of agroforestry

RK Pachauri, Panel Chair (TBC)

Shri Krishna Byre Gowda, Minister of Agriculture, Karnataka (TBC)

Howard Shapiro, Chief Agricultural Officer, Mars Inc.

Michael Hailu, Director, Technical Centre for Agricultural and Rural Cooperation

Bernard Giraud, President, Livelihoods Venture, Danone

Tristan Lecomte, Founder and Chief Executive Officer, Pur Project and Ashoka Fellow (TBC)

1025–1030

Wrap up

Tony Simons, Director General, World Agroforestry Centre

1030–1100

Tea/coffee break – Book release: details in daily announcement

Breakout sessions

1100–1230

Breakout session 3

The business of agroforestry: applying science

Theme leader: Roger Leakey

3.1 The viability of trees as crops: agroforestry, pulp and wood-based enterprises, cocoa and coffee

Venue: see daily announcement

Chair: Zac Tchoundjeu

- Agroforestry for food and wood security: an industry experience in India
H D Kulkarni
- Highest wood production by poplar (*Populus deltoides*) clones under agroforestry systems in Punjab State, India - a case study
Mohammed Haque
- Small farm diversification strategies by coffee farmers around Mount Kenya in Kenya
Sammy Carsan
- Cocoa agroforestry system - improving productivity and profitability of smallholder cacao in Sulawesi
Janudianto
- Cocoa agroforestry systems vs. monocultures under conventional and organic management - results from tropical Bolivia
Christian Andres

3.2 Biofuels: using trees as a sustainable energy resource

Venue: see daily announcement

Chair: Navin Sharma

- A tool for more sustainable fuel use? Carbon finance for cookstoves in India
Olivia Freeman
- Alley coppice: an innovative agroforestry system that combines timber and energy wood production
C Dupraz
- A novel model for mangrove agroforestry to provide livelihoods and biofuel feedstock
Koteswara Rao Karanam
- Trees as a global source of energy: from fuelwood and charcoal to pyrolysis-driven electricity generation and biofuels
Philip Dobie

3.3 Improving nutrition through agroforestry: the business case

Venue: see daily announcement

Chairs: Ramni Jamnadas and Shonil Bhagwat

- Potential of fruit trees in the drylands of Sub-Saharan Africa for food and nutrition security and income generation
Katja Kehlenbeck
- Indigenous trees incubators in agroecological zones in Kenya for the commercialization of nutritional foods
Anja Oussoren
- Wildlife, a forgotten resource of agroforestry and shifting cultivation landscapes
Robert Nasi
- The effect of tree cover on child nutrition in Indonesia: examining the relationship between tree cover consumption of micronutrient-rich foods
Amy Ickowitz
- Moringa - a vegetable tree for improved nutrition, health and income of smallholder farmers
A W Ebert

3.4 Building livelihoods on tree products

Venue: see daily announcement

Chairs: Ram Prasad and K D Singh

- Short-rotation coppice agroforestry for charcoal small business in Papua New Guinea
Ian Nuberg
- Can farmers actually DO business? A proposition on building smallholder-level livelihoods using a business approach
Aulia Perdana
- Timber production and poverty: management strategy of smallholder timber farmers in West Java, Indonesia
Mohamad Siarudin
- Agroforestry option for improving livelihood and environment: case study from eastern Indonesia
Suyanto
- Promotion of teak under an agroforestry system for enhancing rural livelihood
Pramod Shukla
- Socioeconomic factors influencing position of women in fruits and vegetables value chains in the Coast region, Tanzania
Martha Swamila

3.5 Public-private partnerships: adding value to develop markets for producers

Chair: Patrick Worms

- Public-private partnerships on tree domestication for sustainable agroforestry and business innovations: Allanblackia spp.
Daniel A. Ofori
- Conservation and sustainable agriculture project in Bajo Mira and Fronterra territory, Colombia
Karla Kanavan
- Cooperation or capture? The politics of private partnerships for sustainable coffee agroforestry
Arshiya Bose
- How agroindustries influence cocoa growers' cropping practices in Cameroon?
Sarah Langrand
- The business of agroforestry: opportunities and challenges for commercial investment in agroforestry-based ventures
Sagun Saxena

3.6 Valuing the environmental services of trees in the landscape

Venue: see daily announcement

Chairs: Meine Van Noordwijk, Beria Leimona and Terry Sunderland

- Valuing the environmental services of trees in the landscape: an introduction
Beria Leimona
- Synergies and trade-offs amongst multiple functions of trees in agricultural landscapes
Shem Kuyah
- Quantification and valuation of ecosystem services of temperate tree-based intercropping systems in Quebec, Canada
Alain Olivier
- The French green and blue corridors implementation process: challenges for agroforestry
Sylvie Guillerme
- Can payments for ecosystem services steer sustainable management of forest patches in an agricultural landscape?
Nasta Babirye
- Forest conservation policy and motivational crowding: experimental evidence from Tanzania
Brent Swallow

1230–1400

Lunch - **Launch of the World Agroforestry Centre book 'Trees for Life'**

1400–1530

Breakout session 4

Theme: **Sustaining development through agroforestry**

Theme leader: **Fergus Sinclair**

4.1 Meeting development challenges with integrated approaches

Venue: see daily announcement

Chairs: **D N Tewari** and **K G Saxena**

- Inclusive green economy, sustainable development and agroforestry with special reference to the south
Maharaj Krishen Muthoo
- Agroforestry research in India: experience of 100 years with a focus on an organized national programme
Shiv Kumar Dhyani
- Sustainable access to energy: charcoal for the poor to save biodiversity in the eastern Congo (RDC)
Isabelle Vertriest
- Assessing aboveground biomass carbon stock of miombo woodlands and (its) controlling factors in southern Africa
Lulseged Tamene
- Participatory agroforestry development and sloping land user group in DPR Korea
Jun He
- Spice market value chains and implications for development in the east Usambaras, Tanzania
Renee Bullock

4.2 The gender dimensions of applying agroforestry innovation

Venue: see daily announcement

Chair: **Delia Catacutan**

- Gender matters in agroforestry in dry and degraded lands? An analysis from tribal India
Purabi Bose
- Gender, sheep and trees in Zan Coulibaly, Mali: methodological approaches
Jean Bonneville
- From rubber agroforestry to oil palm plantations in Sumatra, Indonesia: shifting gender roles
Ratna Akiefnawati

- Gender equity in payments for environmental services: analysis of pilot projects in Asia and Africa
Mamta Vardhan

- Agricultural (in)justices: investigating feminization of agriculture and its implications to food security in Nepal
Sujata Tamang

- Mother Earth: women's role in cacao agroforestry decision process in coastal Ecuador
Trent Duane Blare

4.3 Adapting to climate change

Venue: see daily announcement

Chairs: **Cheikh Mbow** and **Todd Rosenstock**

- Choosing suitable agroforestry species, varieties and seed sources for future climates with ensemble approaches
Roeland Kindt
- In search of dynamic linkages between agroforestry and ecosystem-based adaptation: a case study of the Mid Hills of Nepal
Racchya Shah
- Climate change adaptation: strategies of smallholder upland farmers in the Philippines
Leila Landicho
- Livelihood improvement of farming communities vulnerable to land degradation and climate change
Sarath Premalal Nissanka
- Agroforestry, a viable strategy for climate change mitigation and livelihood
Sumit Chakravarty
- Carbon sequestration and emission reduction through tree- and energy-based interventions for mitigating climate change
Dibakar Mahanta
- Agroforestry interventions through carbon finance – a viable option in mitigation of climate change
Amol Vasishth

4.4 Bridging science and development

Venue: see daily announcement

Chairs: Daniel Callo-Concha and Anna Schwachula

- ZEF experience in bridging science and development: examples from agroforestry research
Christian Borgemeister
- Scaling-up the science to create an EverGreen Agriculture in African countries
Joerg Lohmann
- Agroforestry systems as components of agroecological transition processes in eastern Amazonia and associated public policy - emphasis on the state of Pará, Brazil
Tatiana Deane de Abreu Sá
- Exploring the incentives for on-farm adoption of agroforestry in degraded cropping areas in Uzbekistan
Asia Khamzina
- Farmer to farmer interpersonal communication in agroforestry innovation dissemination in Sulawesi, Indonesia
Endri Martini
- Conservation and livelihood impacts of an agroforestry system: a case study of the Kavrepalanchok district of Nepal
Bishnu Hari Pandit

4.5 Increasing food production through trees on farms

Venue: see daily announcement

Chair: Fergus Sinclair

- Farmer motivations and participatory trial design for enhancing food security through developing farm tree resources in Ethiopia
Abayneh Derero
- Introducing trees on sloping land to improve livelihoods in northwest Vietnam
Lua Hoang
- Edible, multi-purpose Australian acacias for agroforestry farming systems in Africa's drylands
Peter Cunningham
- Revitalizing African agriculture from the ground up: a case study of soil fertility, fertilizer subsidy and agroforestry
Viola Glenn

- The value of local knowledge about tree management in designing agroforestry interventions to improve food security **Anne Kuria**
- Prospects for integrating trees in crop fields: a synthesis across India
David Harris

4.6. Building development abilities through education and capacity development

Venue: see daily announcement
Chairs: Mehmood Hassan and A Yaye

- The master tree grower and peer group mentoring programmes: building farmer and community capacity
Rowan Reid
- Integrating knowledge management and ICT4D in capacity building for agroforestry and natural resource management **Kiringai Kamau**
- Two decades of agroforestry training, education and research at Université Laval, Québec, Canada
Damase Khasa
- Reforming curricula for agribusiness education and training in Africa: the ANAFE focus for the incoming years
Sebastian Chakeredza
- Experiential learning practices in Nigerian's tertiary agricultural education institutions **Marie Louise Tientcheu Avana**

1530–1600

Tea/coffee break – Book release: details in daily announcement

1600–1700

Poster session

Venue: see daily announcement

All posters covering breakout sessions 1, 2 and 3 will be displayed. Poster presenters will stand by their posters, present a brief description of their work and respond to questions.

Concurrent event

Private Sector Marketplace and Buzz

Groups Venue: Kempinski Gardens

1715

Buses leave Kempinski Hotel to other hotels

Wednesday, 12 February, 2014

0700–0900

Buses transport participants from hotels to Kempinski Ambience, Shahdara

Plenary 3: Scientific breakthroughs and innovations

Venue: Plenary Hall

0900–0905

Welcome remarks and introduction of keynote speaker and panelists

Dr Ben Chikamai, Director of Kenya Forest Research Institute

Keynote addresses

0905–0920

Innovations in agroforestry research to meet wide challenges: the cases of climate change and food sovereignty

Dr Tatiana Deane de Abreu Sá, agrometeorologist and plant ecophysiologicalist, Embrapa

0920–0935

Title: TBC

Dr Kate Schreckenberg, Centre for Underutilised Crops, University of Southampton, UK

0935–1000

Panel discussion

P K R Nair, Distinguished Professor and Director of Center for Subtropical Agroforestry

Eduardo Somarriba, Distinguished Scientist at CATIE

Eduardo Rojas, Assistant Director General Forestry, UN Food and Agriculture Organization, Italy

Kate Schreckenberg, University of Southampton, UK H A J Gunathilake, Director, Coconut Research Institute, Sri Lanka

1000–1020

Plenary comments

1020–1030

Wrap up

Dr Jules Pretty and Dr Tatiana Deane de Abreu Sá

1030–1100

Tea/coffee break – Book release: details in daily announcement

Breakout sessions

1100–1230

Breakout session 5

Theme: **Applying science to the future of agroforestry**

Theme leader: Eduardo Somarriba

5.1 Humid multi-strata systems

Venue: see daily announcement

Chairs: Eduardo Somarriba and P Vaast

- Strong spatial variability of light use efficiency in a coffee agroforestry system, highlighted by 3D light and gas exchange model

Fabien Charbonnier

- Invent a new model for cocoa smallholders: agroforestry, a credible alternative to face an uncertain future

Bruno Rapidel

- Linking local ecological knowledge to plant functional traits in coffee and cocoa agroforestry systems in Costa Rica

Jenny Ordonez

- Understanding farmers: using role-playing games to explore futures of landscape management in the Western Ghats, India

Claude Garcia

- Impacts of a coffee agroforestry system on socioeconomic performance of the upper Sekampung watershed in Sumatra, Indonesia **Bustanul Arifin**

- Coffee and climate change: the importance of systems thinking

Laurence Jassogne

5.2 New tools and paradigms

Venue: see daily announcement

Chair: Tor Gunnar Vagen

- New technologies to old problems: online role-playing games, farmers and coffee agroforestry in the Western Ghats

Jenu Kalla

- Agroforestry systems risk/revenue balance: an investor's point of view.

Clement Chenost

- The end of the sun/shade dichotomy in agroforestry systems: mapping of plant light budgets in multistrata heterogeneous plots **Fabien Charbonnier**

- Using ground-penetrating radar in agroforestry systems: quantification of tree root distribution and biomass

Kira A Borden

Wednesday, 12 February, 2014 (continue)

- The talking toolkit for facilitating farmer groups on the role of trees for adaptation
Elisabeth Simelton
- Combining a numerical model with farmer participation for the design of sustainable and practical agroforestry systems
Bruno Rapidel

5.3 Biodiversity and agroforested habitats

Venue: see daily announcement

Chairs: Edmundo Barrios and

Fabrice DeClerck

- Tree-soil interactions and the provision of soil-mediated ecosystem services
Edmundo Barrios
- Shade, litter, nematodes, earthworms, termites and companion trees in coffee agroforestry in relation to climate resilience
Kurniatun Hairiah
- Impact of rubber tree plantations on soil functional biodiversity and soil organic carbon
Alain Daniel Brauman
- The role of coffee agroforestry in the conservation of forest tree diversity and community composition

Vivian Valencia

- Effects of local and landscape conditions on insect pollinators in a forest-agricultural landscape of West Java, Indonesia

Dendi Muhamad

- The effects of shade, altitude and landscape composition on coffee pests in East Africa
Mattias Jonsson

5.4 Agroforestry of dry and degraded lands

Venue: see daily announcement

Chairs: C R Babu, K S Rao and Jan De Leeuw

- The Spinal: a sustainable productive alternative for the interior dryland development of the Chilean Central Mediterranean area?
Alejandro Lucero
- Trees and resilience in dryland agroforestry systems in eastern African
Jan De Leeuw
- Agroforestry for rehabilitation of degraded lands and poor quality waters: livelihood security and mitigating climate change
Jagdish Chander Dagar

- Using species distribution models to select climate change-resistant species for ecological restoration of bowé in West Africa
Elie Antoine Padonou
- Arbuscular mycorrhizal association and growth response of *Faidherbia albida* (Del.) A. Chev. as influenced by land use type
Mengisteab Hailemariam
- Physiological response of switchgrass for bioenergy alley cropping in soils of varying depths in central Missouri
Sougata Bardhan

5.5 Temperate agroforestry

Venue: see daily announcement

Chairs: Shibu Jose, S Raju, A Mason and Paul Burgess

- Temperate agroforestry in the 21st century: a North American perspective
Shibu Jose
- Evaluating nitrogen transfer from the Caragana shelterbelt and its effects on yield and nutrition of forage crops
Anthony Kimaro
- Effects of silvopastoral practices on intensively managed quality timber plantations in Spain
Gerardo Moreno
- Environmental and biological interactions on productivity of silvopastoral system with *Pinus contorta* Dougl. ex. Loud.
Alvaro Sotomayor
- Introducing AGFORWARD – a project to advance agroforestry in Europe
Paul J. Burgess

5.6 The social science of agroforestry

Venue: see daily announcement

Chairs: Christine Padoch and Ujjwal Pradhan

- Rural livelihoods, HIV/AIDS and agroforestry interventions: social science methods for addressing complex problems
Joleen Timko
- The role of informal social networks in agroforestry adoption and management
Marney E Isaac
- Transforming land and livelihoods: analysis of agricultural land abandonment in the Mid Hills of Nepal
Krishna Prasad Paudel

- Migrants and land markets in Jambi, Indonesia: the prospect of agroforestry development in peatland
Gamma Galudra
- Management of Ghana's modified taungya system: challenges and strategies for improvement
Emmanuel Acheampong
- Understanding diversity of smallholder agroforestry and forestry systems in hilly and mountainous landscapes: regional comparisons in Asia
Kiran Asher
- Decentralization and forest restoration governance: a comparative study in upland communities of southwest China
Jun He

1230–1400

Lunch – book launch: see daily announcement

1400–1530

Breakout sessions 6

Theme: **Sustaining development through agroforestry**

Theme leader: Frank Place

6.1 Policy, governance and international frameworks

Venue: see daily announcement

Chairs: Andrew Wardell and Frank Place

- Revisiting debates on the role of gender in the governance of trees and forests in the context of climate change
Bimbika Sijapati Basnett
- Why has community forestry made a limited contribution to agroforestry in Nepal?
Dil Bahadur Khatri
- Engagement of private sector in REDD+: issues, opportunities and challenges
Isilda Nhantumbo
- Security beyond the political forest: regulation, formalization and timber production in northern Central Java
James Thomas Erbaugh

6.2 Ecology and economics of rubber-based agroforestry

Venue: see daily announcement

Chairs: Georg Cadisch and Jianchu Xu

- Factors influencing the adoption of improved rubber agroforestry system by rubber smallholder farmers in Indonesia
Dudi Iskandar
- Ecosystem services trade-offs and synergies of rubber agroforestry under uncertainty
Grace Ballesfin Villamor
- Rapidly increasing demand for rubber drives plantations into ecological margins and threatens biodiversity
Antje Ahrends
- The planter's bet. Can family-own rubber farms match global challenges?
Philippe Thaler
- Measuring the impact of rubber agroforestry: an integrative ecosystem service assessment framework
Marc Cotter
- Small-scale rubber farming and income risk in Xishuangbanna, China
Hermann Waibel
- Rubber monoculture or rubber agroforestry: are there implementable policy supports based on results from spatially explicit models?
Zhuangfang Yi

6.3 The science of scaling up and the trajectory beyond subsistence

Venue: see daily announcement

Chair: Steve Franzel

- Determinants of farm households' agroforestry technology adoption in Ethiopia: empirical evidence from selected district
Abebe Beyene
- Farmer-to-farmer extension: a viable option to enhance agricultural dissemination? Evidence from Cameroon
Ann Degrande
- Why volunteer? Insights from farmer to farmer extension in Kenya and Uganda
Evelyn Kiptot
- Taking tree-based ecosystem approaches to scale: impacts, drivers and mechanisms
Steve Franzel

- What is the influence of extension methods and approaches on adoption of agroforestry practices in Zambia?
Gillian Kabwe

- Agricultural research for development: implications for policy, practice and investment
Philip Dobie

6.4 Landscape approaches

Venue: see daily announcement

Chair: Peter Minang

- Landscape approaches, from concept to action: insights from 191 landscape initiatives in Africa and Latin America
Philip Dobie
- Environmental services as binding pillars to synergize climate change mitigation and adaptation in rural landscapes
Lalisa A Duguma
- Are innovation platforms possible institutions for integrated natural resource management practices at the landscape level?
Verrah Akinyi Otiende
- Freeing the land of the tea legacy - the case of Wild Flower Holdings
Kamal Melvani
- The Model Forest landscape approach: innovative territorial governance
Jean-Claude Njomkap
- Is agroforestry feasible towards conservation in protected areas? An ongoing case study in rural Mexico
Victor Avila-Akerberg

6.5 Agroforestry, water quality and nutrient export

Venue: see daily announcement

Chairs: M R Mosquera Losada and Vimala Nair

- Innovative technology for water quality protection in agroforestry systems
Vimala Nair
- Shade level and tree species composition affect water dynamics in coffee agroforestry systems of the Western Ghats, India
Philippe Vaast
- Modelling the effects of adopting agroforestry on basin-scale surface runoff and sediment yield in the Philippines
David Wilson

- Chemical attributes of a silviopastoral system with a legume tree and signal grass in the Brazilian savanna

- Performance of herbal medicinal crops under a sapota-jatropha-based three-tier agroforestry system
Rodrigo Martins Alves de Mendonca
- Restoring riparian vegetation – a promising means to ensure clean water
Vishnu K. Solanki
- Restoring riparian vegetation – a promising means to ensure clean water
Kamal Melvani

6.6 Successful and scalable business models for agroforestry with quantified mitigation and adaptation co-benefits

Venue: see daily announcement

Chair: Henry Neufeldt

- Agri-businesses reducing climate, water and community risks: landscape approaches in agroforestry systems
Gabrielle Kissinger
- Potential role of exotic poplar in increasing tree cover as an alternative to forest restoration in India
Kulvir Singh Bangarwa
- Oil palm and agroforestry systems: coupling yields with environmental services, an experiment in the Brazilian Amazon
Andrew Miccolis
- From a demonstration plot to an integrated resource and agricultural tourism centre. The case of MIFACIG, Belo, Cameroon
Kuh Emmanuel Loah

1530–1600

Tea/coffee break - Book release: details in daily announcement

1600–1700

Poster session

Venue: see daily announcement

All posters covering breakout sessions 4, 5 and 6 will be displayed. Poster presenters are required to stand by their posters, present their work and respond to participants' questions.

1715

Buses leave Kempinski Hotel to other hotels

0700–0900

Buses transport participants from hotels to Kempinski Ambience, Shahdara

Plenary 4:

The integration of science, business and development

Venue: Plenary Hall

0900–0905

Welcome remarks and introduction of keynote speaker and panelists

0905–0935

Keynote address

Agroforestry and the Sustainable Development Goals

Dr Dennis Garrity, UNCCD Drylands Ambassador and Former Director General of ICRAF

0935–1000

Panel discussion

Hans Friedrich, Director General, International Network for Bamboo and Rattan

Shantanu Mathur, International Fund for Agricultural Development

James Myers, International Institute for Environment and Development (TBC)

Charlotte Streck, Director, Climate Focus

Ranjit Barthakur, Senior Advisor, Tata Consulting Services, Chairman, GMS and Secretary General, Club of Rome India (TBC)

1000–1025

Plenary comments

1025–1030

Wrap up

Dr Dennis Garrity, UNCCD Drylands Ambassador and Former Director General of ICRAF

1030–1100

Tea/coffee break - Book release: details in daily announcement

Closing session: Synthesis

1100–1105

Summary of outcomes and the way forward

Tony Simons, Director General, World Agroforestry Centre

1105–1145

Syntheses and lessons learned on business, science and development

Meine van Noordwijk and **Ravi Prabhu**, World Agroforestry Centre

1145–1200

Discussions

1200–1205

Valedictory

Welcome to the Honourable Minister for External Affairs

Dr S Ayyappan, Secretary of the Department of Agricultural Research and Education and the Director General of the Indian Council of Agricultural Research

1210–1235

Presentation and discussion of Congress resolutions

1235–1245

Address by the Honourable Minister for External Affairs Shri Salman Khurshid

1245–1300

Vote of thanks

Ravi Prabhu, World Agroforestry Centre

Congress ends

1300–1400

Lunch

Side events

14:00–15:30

International Union of Agroforestry (ICRAF and ICAR)

Venue: Sapphire

Agroforestry for biofuels (Navin Sharma, ICRAF)

Venue: Jade

Capacity development and partnership (Mehmood Hassan and Margaret Kroma, ICRAF)

Venue: Coral

Poplar agroforestry (International Poplar Commission)

Venue: Turquoise

20 years of ASB (Peter Minang, ICRAF)

Venue: Emerald

15:30–17:00

Transforming cocoa production (Christophe Kouame, ICRAF)

Venue: Jade

Scenarios of change for agroforestry landscapes: The Western Ghats Sentinel Landscape Initiative (Sanjay Tomar, ATREE etc.)

Venue: Coral

EverGreen Agriculture Network meeting

Venue: Turquoise

17:15

Transport of participants from Kempinski to their hotels



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