Feed The Future India Triangular Training (FTF-ITT)

International Training Program on

Agroforestry Research and Development to Improve Livelihood, Nutritional and Environmental Security: Policy, Practice and Impact

10 to 24 October, 2019

Training Lecture Notes

World Agroforestry (ICRAF)
South Asia Regional Program
NASC Complex, Dev Prakash Shastri Marg,
Pusa Campus, New Delhi, India
http://worldagroforestry.org/

World Agroforestry (ICRAF)

The World Agroforestry (ICRAF- www.worldagroforestry.org) is a centre of scientific excellence that harnesses the benefits of trees for people and the environment. Leveraging the world's largest repository of agroforestry science and information, ICRAF develops knowledge practices, for farmers' fields to the global sphere, to ensure food security and environmental sustainability. ICRAF is the only institution that does globally significant agroforestry research for all of the developing tropics. Knowledge produced by ICRAF enables governments, development agencies, practitioners and farmers to utilize the power of trees to make farming and livelihoods more environmentally, socially and economically sustainable at scales. ICRAF is a member of the CGIAR (Consultative Group on International Agricultural Research) consortium. ICRAF's headquarters are based in Nairobi, Kenya, with six regional and several sub-regional and country offices located across Africa, Asia, and Latin America.

ICAR-Central Agroforestry Research Institute (CAFRI)

The Central Agroforestry Research Institute, (CAFRI- http://cafri.res.in) a national institute is the only dedicated research institution of India in the field of agroforestry under the umbrella of the Indian Council of Agricultural Research (ICAR). It works and promotes improving quality of life of rural people through integration of perennials on agricultural landscape through economic, environmental and social benefits. The institute coordinates the All India Coordinated Research Project (AICRP) on Agroforestry which has 37 centres located in different agro-climates of the country. CAFRI and ICRAF work in close partnership since 1985 on various aspects of agroforestry through an umbrella agreement between ICAR and ICRAF, and by a jointly developed work plan.

Forest College and Research Institute (FC&RI)

The Forest College and Research Institute (FC & RI) located at Mettupalayam is under Tamil Nadu Agricultural University (TNAU), Coimbatore (www.tnau.ac.in/fcri). The mandate of FC & RI is education, research and extension. It imparts education in forestry and agroforestry to students and produce able forest administrators and self-sustaining entrepreneurs. FC & RI undertakes research on basic and applied aspects of forestry and agroforestry to evolve technologies to enhance productivity. The institute imparts training and offers consultancy to tree farmers', non-government organizations and departmental functionaries. FC&RI and ICRAF have agreed to work together on the proposed training, and to collaborate on a larger agenda.

Consultative Group on International Agricultural Research (CGIAR)

CGIAR (Consultative Group on International Agricultural Research), as the world's largest global agricultural innovation network, brings evidence to policy makers, innovation to partners, and new tools to harness the economic, environmental and nutritional power of agriculture. CGIAR integrates and coordinates the research of its 15 member-centers in producing new knowledge and technology that is needed to meet the Sustainable Development Goals (SDGs).

MANAGE

MANAGE was established in 1987, as the National Centre for Management of Agricultural Extension at Hyderabad, by the Ministry of Agriculture & Farmers Welfare, Government of India as an autonomous Institute, from which its acronym 'MANAGE' is derived. In recognition of its importance and expansion of activities all over the country, its status was elevated to that of a National Institute in 1992 and re-christened to its present name i.e., National Institute of Agricultural Extension Management.

MANAGE is the Indian response to challenges of agricultural extension in a rapidly growing and diverse agriculture sector. The policies of liberalization and globalization of the economy and the level of agricultural technology becoming more sophisticated and complex, called for major initiatives towards reorientation and modernization of the agricultural extension system. Effective ways of managing the extension system needed to be evolved and extension organizations enabled to transform the existing set up through professional guidance and training of critical manpower. MANAGE is the response to this imperative need. MANAGE offers its services in the following five streams viz., Management Training, Consultancy, Management Education, Research, and Information Services.

The vision of the MANAGE is "to be counted among the most pioneering, innovative, farmer focused and self-supporting Agricultural Management Institutes in the World". The following mandates of the MANAGE also emphasize on MANAGE linkage with Global Institutions for mutual learning.

- Developing linkages between prominent states, regional, national and international institutions concerned with agricultural extension management.
- Forging collaborative linkages with national and international institutions for sharing faculty resource.
- Serving as an international documentation centre for collecting, storing, processing and disseminating information on subjects related to agricultural management.

Feed The Future India Triangular Training (FTF-ITT) Program

A new agriculture partnership between US and India to achieve Ever Green Revolution to address Global Food Security was announced during the State visit of the then US President Mr. Barack Obama to India in November 2010. The effort included Triangular Cooperation adapting technological advances and innovative solutions to address Food Security Challenges in Africa. Besides, it also includes areas such as health, energy, women empowerment and sanitation under the statement of guiding principles on triangular cooperation for global development. The objective of training is 'to address human and institutional capacity gaps in food & nutritional security, in select African and Asian countries'.

MANAGE is representing Government of India and USAID-India is representing USA for implementation of Feed The Future India Triangular Training (FTF ITT) during 2016-20. Forty Four international training programs are to be organised involving Indian missions and respective governments of 20 FTF partner countries (Asia: Afghanistan, Bangladesh, Vietnam, Cambodia, Lao PDR, Mongolia, Myanmar, Nepal and Sri Lanka; Africa: Botswana, Democratic Republic of Congo, Ghana, Kenya, Liberia, Malawi, Mozambique, Rwanda, Sudan, Tanzania and Uganda. Between, October 2016 to July 2017, MANAGE has organized 37 International Training Programs (including two programs in Afghanistan and Uganda) benefitting 968 executives on different training themes.

Training courses of 15 days duration at selected Indian institutions are organised in on identified different themes. Each course module focuses on themes or subsectors in which Indian institutions are reputed or have demonstrated comparative advantage to offer such trainings and ensure that it effectively responds to the target countries' capacity gaps.

A participatory approach in program design and implementation is offered by each participating institution and more focus is given on practical exposures and field visits. Back at Work Plan (BAWP) is one of the endeavours towards ensuring the sustainability of the FTF ITT program. BAWP chosen by the participants address some practical problem(s) in their area. The project emanating from their BAWP runs for a minimum of 6 months after the completion of the training program.

Training Lecture on Agroforestry Research and Development to improve livelihood, nutritional and environmental security: Policy, Practice and Impact

Coordination and Compilation

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Message from Director General, MANAGE

Smt. V. Usha Rani, IAS
Director General,
MANAGE

Feed The Future India Triangular Training (FTF ITT) is a collaborative program of United States of America represented by USAID, India and Government of India represented by National Institute of Agricultural Extension Management (MANAGE). FTF ITT aims at building the capacity of Public and Private Functionaries in Agriculture and Allied sectors of 20 Partner Asian and African Countries in emerging areas of Agriculture Development relevant to their respective countries with an objective to eradicate hunger and poverty by addressing food insecurity and nutritional issues. MANAGE, Hyderabad is the lead institute to implement FTF ITT program in collaboration with reputed national and International organizations in India and abroad through 44 International Training programs identified and prioritized based on Demand Analysis carried out by MANAGE.

Sustainable agriculture, tree cover in developing countries is getting more attention at the global level as a result of the Nationally Determined Contributions (NDCs) for post-2020 climate actions committed by the countries under the Paris Agreement of the United Nations Framework Convention on Climate Change (UNFCCC). Each country through its climate plan as reflected in their NDC has set an ambition for reducing emissions, taking into account its domestic circumstances and capabilities. In achieving the NDC targets, agroforestry is one of the major thrust areas in mitigation and adaptation for climate change while ensuring food, nutritional and income security.

India has made tremendous advancement in mainstreaming agroforestry in its national development agenda, as a result of National Agroforestry Policy (NAP)- 2014 and Sub-Mission on Agroforestry (SMAF) with an objective to address global food security challenges under changing climate.“Feed The Future India Triangular Training (FTF ITT) Program” has announced an International Training in “Agroforestry Research and Development to improve livelihood, nutritional and environmental security: Policy, Practice and Impact” during 10-24 October, 2019.

The World Agroforestry (ICRAF) has the global as well as national expertise in organising such training-cum-educational trip as a result of its strong association with agroforestry policy development and implementation in India and other Asian countries through technological advancements, scientific research and innovations along with its national partners.

MANAGE, trusts that this training material notes on Agroforestry: Policy, Practice and Impact will enhance the awareness and strengthen the capacity of middle level policy makers who directly provide leadership role in implementation of agroforestry projects/ programs in their respective countries. I congratulate PMU team at MANAGE and ICRAF World Agroforestry Centre for their concerted efforts in making this program happen. I wish success to the training and its adoption by the policy makers.

V. Usha Rani

Message from Regional Director, ICRAF

Javed Rizvi, Ph.D.
Regional Director,
South Asia Regional Porgram (SARP),
World Agrforestry (ICRAF), New Delhi, India

Introduction of compatible trees in the agricultural landscape (on the field boundaries, inter cropping with crops, and on community lands) is globally recognised to provide additional and diverse food with less inputs leading to increased income and climate security. The science of agroforestry has evolved and expanded from an initial focus on agricultural productivity to its current multifunctional and transformational approach. This involves sustainable production systems & landscape encompassing and restoration and optimizing hydrological parameters to make agriculture climate smart.

Agroforestry is increasingly mainstreamed in the national development agendas, which is evident from the fact that agroforestry is recognized as a priority for mitigation by 23 countries, and for adaptation by 29 countries. This recognition for agroforestry as a solution to burning issues has been possible due to the innovative research and development endeavours of researcher world over where ICRAF has been playing a pivotal role for the last 40 years. The forty years of research backed by undisputable data resulted in our participation in the development and launch of National Agroforestry Policy of India in 2014 during the 3rd World Agroforestry Congress in New Delhi, which was jointly organised by the Indian Council of Agriculture Research (ICAR) and ICRAF. This was the first national policy internationally exclusively dealing with agroforestry. Subsequently, ICRAF extended technical support to Nepal which approved and launched its own National Agroforestry Policy during July, 2019. ICRAF also worked with policy makers of ASEAN to develop ASEAN Agroforestry Strategy. We are technical partners of India and Nepal for the implementation of the agroforestry policies.

World Agroforestry (ICRAF), is celebrating its 40th Anniversary rejoicing our strong partnership with more than 70 countries without which it was impossible for us to take the agroforestry agenda to its current level. I strongly feel, organizing the training on “Agroforestry Research and Development to improve livelihood, nutritional and environmental security: Policy, Practice and Impact” for our Asian and African partners is a glowing tribute to our thriving partnership. It is expected that the training will enhance the efforts of Government of India to promote collaboration with India and other partner countries through its “South-South Cooperation”.

It is our privilege to co-organize this international training for Asian and African partners in close collaboration with National Institute of Agricultural Extension Management (MANAGE), ICAR; ICAR- Central Agroforestry Research Institute (CAFRI), Jhansi; and Forest Collage & Research Institute (FCRI), Mettupalayam, Tamil Nadu. We at ICRAF look forward to organize this training for the policymakers who in turn would be Ambassadors of Agroforestry, and would catalyse mainstreaming agroforestry in the research for development agenda in their respective countries.

I extend a warm welcome to the Executives from partner countries attending the training, & wish a great success to the members of the organizing team. My sincere thanks goes to ICAR, USAID, MANAGE, ICAR-CAFRI, FC & RI and to all the Resource persons for an exemplary cooperation.

J Rizvi

Preface

Role of trees or tree cover is well recognized to significantly reduce the risk of climate change, and make the environment more conducive to humans, livestock, and to agriculture. Trees contribute over 10% of the US $3.1 trillion worth of GDP created by the agricultural sector (Annual Report 2016-2017: Harnessing the multiple benefits of trees on farms. World Agroforestry Centre). Agroforestry, that is trees integrated into agriculturally productive landscapes, is one of the ways to protect and compensate the loss of forest cover; provide the benefits that otherwise will be obtained from already over-exploited forests; increase environmental sustainability; enhance the production of food, fodder, fuelwood, and timber; reduce soil erosion and degradation; assist rehabilitation of degraded lands; enhance soil organic matter; remove atmospheric carbon through sequestration; support biodiversity and provide many other social, religious, and aesthetic benefits.

Agroforestry is recognized as the ultimate tool to enhance the resilience to climate change and reduce the carbon footprint of the developmental activities. To achieve the Intended Nationally Determined Contributions (INDCs), 23 countries have recognized agroforestry as a priority for mitigation, and 29 countries for adaptation (https://ccafs.cgiar.org/agricultures-prominence-indcs-data-and-maps#.Wfa1uohx200). Introduction of compatible trees in the agricultural landscape (on the field boundaries, inter cropping with crops, and on community lands), provide additional and diverse food with limited inputs. As annual crops are more susceptible to climate extremes as compared to trees, intercropping of multipurpose trees with crops, reduces farmers' risks to face hunger due to crop failure, besides increasing the green cover. A tree can be sold to arrange anytime cash during any emergency in the form of fuelwood or timber, thus serving as a 'biological ATM'.

During 2014, India took lead in formulation and implementation of the world's first National Agroforestry Policy, and South Asia Regional Program (SARP) of ICRAF played important role as a technical partner in its development and now in implementation of the same (http://agricoop.gov.in/sites/default/files/National_agroforestry_policy_2014.pdf and https://www.worldagroforestry.org/publication/national-agroforestry-policy-india-experiential-learning-development-and-delivery-phases).

Tremendous success of India's agroforestry policy in increasing awareness about the benefit and potential of agroforestry; removal of legal hurdles in planting, felling and transporting agroforestry products (mainly timber and wood); and in channelizing huge resources to mainstream agroforestry in the national agenda has exhibited ripple effect in the South Asia region and beyond. ICRAF is currently working with the Governments of Bangladesh and Nepal (http://kathmandupost.ekantipur.com/news/2017-11-05/nepal-gearing-up-to-draft-agroforestry-policy.html), and with some South East Asian countries (ASEAN AF Strategy, http://www.worldagroforestry.org/region/sea/publications/detail?pubID=4392) to develop their respective agroforestry policies/ strategies/guidelines.

One of the most important successes of agroforestry in India, is the fact that the country fulfils about 70% of its timber needs through agroforestry (Soujanya Shrivastava and Ajay Kumar Saxena 2017). To realize the full potential and benefits of agroforestry, there is an urgent need and demand to sensitize the policy makers, and strengthen their capacities for mainstreaming agroforestry in their country's development agenda.

ICRAF's South Asia Research Program based at New Delhi, in collaboration with CAFRI and FC & RI, would be thus organizing an international hands-on training-cum-study visits on the Agroforestry Research and Development to improve livelihood, nutritional and environmental security: Policy, Practice and Impact.

Acknowldegements

The World Agroforestry, South Asia Regional Program, ICRAF, New Delhi acknowledges partial financial support received from US Government represented through USAID, India and Indian Government represented through National Institute of Agricultural Extension Management (MANAGE) under the Feed The Future India Triangular Training to organize the training, "Agroforestry Research and Development to improve livelihood, nutritional and environmental security: Policy, Practice and Impact".

The training is jointly organized by the World Agroforestry, South Asia Regional Program, ICRAF, New Delhi with ICAR-Central Agroforestry Research Institute (CAFRI), Jhansi, Uttar Pradesh and Forest College and Research Institute (FC & RI), Mettupalayam, Tamil Nadu. We at ICRAF sincerely thank the Director, CAFRI & Dean, FC & RI for extending all the support and cooperation.

We acknowledge following individuals and organizations for their valuable contribution in organizing this training:

Mrs. V. Usha Rani, IAS, Director General, Dr Mahantesh Shirur Program Director, Dr Goldi Tewari Program Manager and the Program Management Unit (PMU), MANAGE,

Dr T Mohapatra, Secretary, DARE & Director General ICAR; Mr. Sushil Kumar, Secretary ICAR; Dr K Alagusundaram Deputy Director General (NRM) ICAR; Dr S Bhaskar, Assistant Director General (AAFCC), ICAR; Dr S K Chaudhari, Assistant Director General (SWM), ICAR; Dr Anil Kumar Director, CAFRI & Project Coordinator, AICRP on Agroforestry; Dr Inder Dev, Principal Scientist, CAFRI,

Prof N Kumar Vice Chancellor, Dr K K Suresh Dean, Dr K T Parthiban Forest College and Research Institute (FCRI) Mettupalayam, Tamil Nadu; and Dr A Dalwai, IAS, CEO, NRAA, MoAFW, New Delhi,

Dr Tony Simon Director General World Agroforestry-ICRAF, Dr Ravi Prabhu Deputy Director General (Research) ICRAF; Dr Anja Gassner, Head, Research Methods Unit, ICRAF, and communication team of ICRAF and ICRAF Coordinators from the regions,

Keith E. Simmons, Mission Director, USAID/India and India representatives of USAID,

SARP-, CAFRI- and FC & RI- teams,

All the resource persons who have immensely contributed in providing the lecture notes and consented to deliver the lecture,

The Participants/Executives from Bangladesh, Botswana, Cambodia, Kenya, Liberia, Malawi, Nepal, Myanmar, Sri Lanka, Tanzania and Uganda and respective Governments of nominating the Executives, and

Point of Contacts (POCs) of Partner Countries.

Introduction

Agroforestry Research and Development to Improve Livelihood, Nutritional and Environmental Security: Policy, Practice and Impact

Training Date: 10 to 24th October 2019

Training Venue: ICRAF, New Delhi; CAFRI, Jhansi; and FCRI, Mettupalayam, India

Training Duration: 15 days

Course Director: Dr Javed Rizvi, Regional Director, World Agroforestry

Training Objectives

1. To sensitize the policy makers to bring agroforestry in the mainstream development agenda of the country
2. To train in developing and implementing scientifically designed agroforestry systems
3. To provide an interactive platform for understanding challenges, potential, and learning from experience sharing from policy to practice at watershed, experiment, demos and farmers field level
4. To develop robust planning skills for successful adoption, removal of impediments for practicing agroforestry, especially in arid and semi-arid rain fed ecologies, and capacity to measure the impact.

Key focus areas

1. Policy, strategy and guidelines to mainstream agroforestry which will include why these are important, what problems will be solved through these instruments, how these are formulated & implemented at national and sub-national level,
2. Importance and needs of scientifically designed agroforestry systems; how to develop and implement these systems; ways to encourage farmers/ development practitioners to accelerate the adoption of proven agroforestry systems,
3. Interactions with policy makers, senior researchers, practitioners, NGOs, CBOs involved in agroforestry - from policy to practice level; understanding of challenges and potential in country/ regional perspective,
4. Ensuring accelerated adoption of agroforestry practices by farmers in rural communities under various kinds of climatic conditions,
5. Ensuring moisture conservation , especially in dry and rainfed areas for successful mainstreaming of agroforestry in the national agenda,
6. Potential of other NRM practices to enhance the impact of agroforestry,
7. How to measure the impact of agroforestry interventions on increased resilience to climate change; improved food, nutrition, fodder & energy security; capability to provide extensive ecosystem services; potential to rehabilitate and improve degraded lands; increased green cover,
8. Continued networking to increase the sustainability of the study visit/ training.

Learning outcomes

The hands-on training-cum-study visits on "Agroforestry Research and Development to improve livelihood, nutritional and environmental security: Policy, Practice and Impact" will enhance much needed awareness, understanding and knowledge of middle-level policy makers about agroforestry research and development, country level existing agroforestry policies & efforts on developing agroforestry policies/ strategies in different countries. It will also cover broad spectra of topics, such as: traditional and transformed agroforestry systems; new instruments and tools for mainstreaming agroforestry, like MIR based soil analytical technology; use of Geo-informatics based applications for qualitative and quantitative mapping of agroforestry; and smart phone based applications to provide extension services to practitioners. Further, some of the very unique outcomes of the proposed training will be exposing the policy makers to "agroforestry in action" sites showcasing agroforestry based watershed sites, maintenance of in-vivo gene bank, business incubator, small, medium and commercial level agroforestry based industries.

Teaching Methodology

The hands-on training-cum-study visit will be imparted through lectures, discussions, field interactions, case studies and practical sessions. The participants will be given hands-on experience using highly participatory approach, and by visiting the experiment farms, labs, agriculture demonstration units, watershed sites, and agroforestry business incubator. Subject Matter Specialist (SMS), policy makers, development agents, and farmers will directly interact and share their experiences with the participants. Each Executives will be expected to contribute ideas and take part in group discussions and provide feedback. The executives will be exposed to 70 per cent practical / field activities and hands- on experience, and 30 per cent will be through interactive and participatory discussions/ presentations.

Lecture Notes Structure

The training comprises of 26 class room lecturers and 8 case studies & field visits. The notes are arranged in five sections:

1. AF 1 — Agroforestry: Research and Development, and Policies
2. AF 2 — Agroforestry Practice for Livelihood, Nutritional and Environmental Security, and Impact
3. AF 3 — Agroforestry: Commercial & Value Chain Aspects
4. AF 4 — Case Studies and Field Visits
5. AF 5 — A Glimpse of History and Culture of India

AF 1 -- Agroforestry: Research and Development, and Policies

Agroforestry: Definition, Products and Services

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Abstract
Due to alarming decline in forest and tree cover, the demands of the population in respect of their requirement of timber, firewood, etc. are not met. As a result, soil and water base for food production is being degraded. Agroforestry, a deliberate association of trees and shrubs with herbaceous crops/ livestock or other components of agricultural production systems holds a great promise for contributing to sustainable land use. The most significant contribution of trees in agroforestry is their favourable influence on soil fertility. Adoption of agroforestry practices can relieve pressures on remaining natural forests by meeting local needs through farm and community tree resources. Although agroforestry systems have existed for centuries, new innovations are required to improve existing practices. Developing suitable agroforestry technologies is of paramount importance to make the system more productive and sustainable.

Keywords: Trees on farm, agricultural production system, adoption, benefits

Introduction
Area under forest is declining everyday due to tremendous demographic pressure and infrastructure growth needs while agricultural area is almost stable. In spite of multiple benefit from agroforestry practices, majority of farmers have been hesitant to adopt these systems on large scale primarily because of certain apprehensions about the tree component such as long rotation, reduction in gross area and complicated legal procedures involved in tree farming trade and market fluctuations. As a result tree component on farm lands has often been restricted which is evident from the Global Report on Assessment of Tree Cover on Agricultural Land which reports 10% tree cover in just 48% of agricultural land. In the recent times, agroforestry has received more attention due to diversified outputs, sustained agricultural productivity, diverse incomes, moderation in climate aberrations and technological interventions lead by research institutions and private organizations. One of the major concerns in large scale adoption of agroforestry in spite of huge potential is lack of well-defined set of regulations and guidelines related to harvesting, transportation and marketing of agroforestry produce.

Agroforestry has high potential for simultaneously satisfying three important objectives viz., protecting and stabilizing the ecosystems; producing a high level of output of economic goods; and improving income and basic materials to rural population. Besides, agroforestry is capable of conserving natural resources through various ways under different agro-climatic regions. The livelihood security through agroforestry and its potential in meeting basic needs are presented hereunder.

The rate of return of investment in research on tree crops has been shown to be quite high (88%). But enterprise development and enhancement of tree product marketing have to be given emphasis Tree domestication, and the commercial processing and marketing of tree products and services is a new frontier for agroforestry research for development. A major role is also emerging in the domain of environmental services, particularly the development of mechanisms to reward the rural poor for the watershed protection, biodiversity conservation and carbon sequestration that they provide to society.

In the present scenario Agroforestry is going to play an important role in providing livelihood security particularly to the small and marginal farmers. Agroforestry will help in reducing the risk factor due to potential of perennial woody material to face the challenges of climate change. These woody perennials provide many opportunities to the local farmers for increasing their income and provide employment opportunities. There are many areas through which agroforestry empowers the local farmers economically and socially through diversified products.

Agroforestry for Livelihood Security and Employment opportunities

Agroforestry systems due to diverse options and products provide opportunities for employment generation in rural areas. Increased supply of wood in the market has triggered a substantial increase in the number of small-scale industries dealing with wood and wood based products in the nearby areas. Such industries have promoted agroforestry and contributed significantly to increasing area under farm forestry. Recognizing agroforestry as a viable venture, many business corporations in India such as ITC, WIMCO, West Coast Paper Mills Ltd., Hindustan paper Mills Ltd., institutes such as IFFCO have entered into the business and initiated agroforestry activities in collaboration with farmers on a large scale.

Agroforestry for food security

The country's food production has increased five folds in the past five decades, but recent improvements in food supply have been insufficient to fulfill the nutritional needs of the average person in a population that has grown from less than 350 million in 1947 to 1.36 billion today. Wheat and rice have shown the greatest increase in yields, while production of coarse grains and pulses has changed only marginally. Increasing the production and consumption of protein-dense foods, pulses in particular, will be necessary if the country is to meet its protein needs. Agroforestry with appropriate tree- crop/ legume combination is one option in this regard. By virtue of diversity of the components of the agroforestry, nutritional security to the communities could be ensured. Fodder cultivation under agroforestry land use will ensure production of milk, meat and animal products. Wide range of foods crops, pulses and oil seeds can meet diverse needs of society. The estimated demand for food by 2025 will be around 320 million tons and food crops grown under agroforestry alone are likely to contribute about 25 million t/annum

Agroforestry for Livestock production

Promotion of silvipasture contributes in two forms namely additional fodder supply that ensures proper rearing of livestock and environmental protection. Small ruminant farming based on goats and sheep is most ideal under agroforestry. The average net income from rearing of small ruminants in one ha of developed silvipasture is very encouraging and farming system based agro forestry is need of the dryland regions in the Country.

Arresting Land Degradation

This has to be considered as a public policy issue, as this is important for overall economic growth as well as for equity considerations. Finally, future generations have rights to a viable soil resource and governments, as 'custodians' of the land (and, indeed, as owners of much of it), have an obligation to arrest degradation. The major reason of land degradation is failure to adopt NRM technologies primarily due to lack of recognition of a natural resource problem, lack of importance of the natural resource or its problem, lack of willingness to invest in the resource, lack of capacity to invest in the resource, lack of economic and other incentives to invest in the resource or lack of information and support services that are necessary to implement investment.

There are some causes of land degradation that are either not possible to prevent or are too costly to prevent at farm or landscape scales. These include climatic as major storms that bring forth massive rain and wind erosion, environmentally induced droughts, fires, major pests or diseases that destroy vegetative cover, and human-induced or perpetuated degradation such as massive health calamities or wars. But many other types of degradation can be prevented or at least mitigated through land management, where agroforestry is one of the most effective options.

Other benefits of Agroforestry

While modifying natural vegetation for their productive use, farmers develop and maintain agroforestry systems that make substantial contributions to biodiversity in multi-functional landscapes. The increased uptake of agroforestry in multi-functional landscapes can reduce pressure on forests and protected conservation areas. Agroforestry can create habitat for wild species in landscape matrices surrounding forest conservation areas. Agroforestry can improve both terrestrial and aquatic habitat. Extensive agricultural activities often lead to a reduction in the amount or quality of wildlife habitat. Agroforestry offers a unique opportunity for improving habitat in agricultural landscapes. Populations of many wildlife species often increase with the addition of trees such and shrubs into agricultural areas. This increase provides opportunities for both hunting and recreational uses, as bird watching. Agroforestry development can be implemented in a way that reduces the risk of alien invasive species to acceptable levels, if adequate precautions are taken.

Agroforestry for Carbon Trading

Agroforestry has importance as a carbon sequestration strategy because of carbon storage potential in its multiple plant species and soil as well as its applicability in agricultural lands and in reforestation. Agroforestry can also have an indirect benefit on carbon sequestration when it helps to decrease pressure on natural forests, which are the largest sinks of terrestrial carbon. Another indirect avenue of carbon sequestration is through the use of agroforestry technologies for soil conservation, which could enhance carbon storage in trees and soils. The current and projected trends of Green House Gases (GHG) emission from India indicates that the rate of emission grew at the rate of 4 per cent per annum during 1990 and 2000 period and projected to grow further to meet the national developmental needs. India's CO_2 equivalent emission form all energy, industrial processes, agricultural activities, land use, land use changes and forestry (LUC&F) and waste management practices for the base year 1994 were 1228.54 million tones per year. If the area under agroforestry, afforestation and reforestation programme is optimized, then this land use will have maximum potential of carbon sequestration for next 25 years. The area under plantation including agroforestry is expected to be 94.7 million ha. Out of that the area under forest is 69.70 million ha and in agroforestry 25 million ha. Thus the total carbon sequestration potential of these areas would be 118.37 million tones carbon ha^{-1} yr^{-1} in next 25 years. Looking to the present and future rate of CO_2 equivalent emission in next 25 years would be 1227.68 million tones carbon yr^{-1}. The forestry and agroforestry would sequester 9.3% atmospheric carbon dioxide into tree biomass. The steps proposed for terrestrial carbon management strategies and potential land use. For carbon sequestration: afforestation, reforestation and restoration of degraded and wastelands;

improved tree management practices to increase growth rates; implementation of agroforestry practices/ systems on agriculture and pasture lands. For carbon conservation, conservation of biomass and soil carbon in existing sinks, improved lopping and harvesting practices, Improved efficiency of wood processing; fire protection and more effective use of burning in both forest and agricultural systems; and for C-substitution (substitution of fossil fuels): Increased use of biofuels, increased conversion of wood biomass into durable wood products for use in place of energy-intensive materials. Agroforestry practices such as agri-silviculture or agri-horti-silviculture systems for food and wood/fruit production; boundary and contour planting for wind and soil protection; silvi-pasture system for fodder production as well as soil and water conservation; complex agroforestry systems, viz. multistrata tree gardens, home gardens, agri-silvi-horticulture and horti-silvi-pasture systems for food, fruits and fodder especially in hill and mountain regions and coastal areas and biofuel plantations are suitable for sequestering atmospheric carbon.

Enhance Productivity

Farm productivity and product quality can be increased substantially when agroforestry practices are utilized. Windbreaks protect crops, livestock, and soil and water resources. In cold weather, livestock protected by trees exhibit improved weight gains of as much as 10 percent and require up to 50 percent less feed. In dry climates tree windbreaks can increase row-crop productivity by 10 to 25 percent. This is due to their ability to moderate the effects of hot, drying winds which increase evaporation and plant transpiration by crops.

Improve Soil Quality

Sediment eroded from crop fields and construction sites carries unwanted pesticides and excess nutrients into ditches, streams, and water supply reservoirs. Eroded soils are less productive due to loss of organic matter, nutrients, and soil structure. Trees, shrubs, and other permanent vegetation in the landscape create stable areas that reduce or eliminate wind and water soil erosion. Windbreaks or cropping systems placed on contours within a field limit the movement of water downhill, thereby reducing its velocity and erosive power. When these practices are placed perpendicular to erosive winds, the reduced wind energy results in less erosion.

Biofuel and Bioenergy

Biofuels are renewable liquid fuels coming from biological raw materials and has proven to be good substitute for oil in the transportation sector as such biofuels are gaining worldwide acceptance as a solution for problems of environmental degradation, energy security, restricting imports, rural employment and agricultural economy. The potential tree borne oilseeds holding promise for biofuel are *Jatropha curcas*, *Pongamia pinnata*, Simarouba, *Azadiracta indica*, *Madhuca spp.*, etc.

The main biomass energy sources in rural areas which are being used in the households include wood from forest, croplands and homesteads, cow dung and crop biomass. *Prosopis juliflora* is the major source of fuel for the boilers of the power generation plants in Andhra Pradesh (the other materials are rice husk, cotton stalks, other wood etc.). About Rs.700-1300/t is the price offered for *P.juliflora* wood at factory gate depending on the season and moisture. The *Prosopis juliflora* distribution and use was studied in Chittoor and Prakasam districts of Andhra Pradesh, Kutch-Bhuj district of Gujarat and Raichur & Bellary districts of Karnataka. The estimates made by the Forest Development Corporation, Gujarat has an area 170972 ha of *Prosopis juliflora* in three districts of Gujarat viz. Bhuj, Patan and Surendranagar in the year 2005, with a potential of 152600 t of charcoal production and employment generation of 1.86 million mandays per rotation.

Bio-diversity Conservation

India is an important centre of biodiversity, housing over 45,000 plant species and 810,000 animal species representing 7% of the world's flora and 6.5 % of the world's fauna. The UN Convention on Biological Diversity calls for conservation of the biological diversity, sustainable use of its components and fair and equitable sharing of benefits arising out of the utilization of genetic resources. Agroforestry innovations contribute to bio-diversity conservation through integrated conservation-development approach. Forest degradation has caused immense losses to the bio-diversity which can be conserved through Agroforestry by adopting a strategy of conservation through use. The bio-diversity thus conserved shall help in the development or improvement of new varieties or populations and provide new agroforestry options.

Based on the Indian experience in the research and development of agroforestry in a scientific manner with policy support, the participant countries can develop suitable agroforestry technologies for creating livelihood opportunities and natural resource conservation for environmental security. The most important issue to identify the requirements of the farmers and link the production system with the wood based industry and marketing infrastructure. Most of the countries are lacking experienced manpower in the subject of agroforestry. To overcome this critical issue there is need to identify suitable organizations and institutions in each country which can impart training to the interested professional willing to work in the field of agroforestry. This can be further strengthened through suitable policies for promoting agroforestry in the respective countries.

Way Forward

Agroforestry if promoted in a suitable way can go a long way in improving the productivity, income, employment and livelihood opportunities of rural households especially of the smallholder farmers. Proper growth of agroforestry would help in meeting the ever increasing demand of timber, food, fuel, fodder, fertilizer, fibre and other agroforestry products. There is need to have a strong field database on agroforestry as in case of agriculture crops. Information like number of trees on the farm, species grown, survival rate, number of trees planted / harvested, quantity of wood and wood products produced or available etc. needs to be recorded in a database system at village level The agriculture sector has the facilities of insurance and credit from the financial institutions and an organized marketing structure. But, the farmers practising tree-based farming are devoid of any such facilities and this is a major hurdle in boosting agroforestry among resource-poor farmers. There has been some tree insurance initiatives taken in the country by States like Tamil Nadu, Kerala and few other states through Insurance Companies. However, such efforts are needed at country level to encourage involvement of farmers in expanding the area under agroforestry. Besides for large scale adoption, it is essential to provide credit and market facilities to farmers adopting tree-based farming. This needs urgent attention at the Union as well as State level to take initiatives farther and create momentum.

Historical Development of Agroforestry and Overview of Global Agroforestry Systems

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Abstract
Agroforestry is an age old concept which now encompasses a diverse set of integrated land use practices employed for variety of purposes. Agroforestry presently is one of the ways to protect and compensate the loss of forest cover; provide the benefits that otherwise will be obtained from already over-exploited forests; increase environmental sustainability; enhance the production of food, fodder, fuelwood, and timber; reduce soil erosion and degradation; assist rehabilitation of degraded lands; enhance soil organic matter; remove atmospheric carbon through sequestration; support biodiversity and provide many other social, religious, and aesthetic benefits. The paper presents historical development of agroforestry and an overview of agroforestry systems in Asia and Africa.

Keywords: Nationally Determined Contributions (NDCs), resilience, shifting cultivation, taungya system

Introduction
Agroforestry is an age old concept that has now been renewed and invigorated by the ingress of technology. Farmers, especially those in the tropics, have a long tradition of raising food crops, trees and animals together as well as exploiting a multiple range of production from natural woodlots. A brief account of agroforestry history and its present institutional arrangement is outlined here.

Agroforestry from ancient time to present day: brief outline
- Cultivating trees and crops together is an ancient practice used by farmer’s world over.
- There are enumerable examples from different parts of the world where trees were grown with agricultural crops on the same field which is now known as agroforestry.
- Trees were an integral part of these farming systems where trees were retained to support agriculture.
- Shifting cultivation in Asia where certain trees were retained to provide seeds and shade became common later on.
- In Africa the situation was different where crops and vegetables were grown together under a cover of trees.
- By the end of 19th century taungya system emerged as a practice to establish plantations. From Asia it was introduced in South Africa.
- By 1970s agroforestry got acceptance for farm and forest due to various development and research and development in agriculture.
- Agroforestry institutionalized in 1978 with establishment of the International Centre for Research in Agroforestry, ICRAF), an international institute headquartered in Nairobi, Kenya, founded as "International Council for Research in Agroforestry".
- In 2002, the ICRAF acquired the World Agroforestry Centre name and now it is World Agroforestry but International Centre for Research in Agroforestry (ICRAF) is still the brand name.

The background for the establishment was an International Development Research Centre (IDRC) of Canada Project Report in July 1975, which recommended the establishment of an international organization, which would support, plan, and coordinate, on a world-wide basis, research combining the land-management systems of agriculture and forestry. This proposal was resulted in establishment of World Agroforestry Centre. The Centre specializes in the sustainable management, protection and regulation of tropical rainforest and natural reserves. It is one of 15 agricultural research centres which makes up the global network known as the CGIAR. ICRAF conducts research in agroforestry, in partnership with National Agricultural Research Systems with a view to developing more sustainable and productive land use. The focus of its research is countries/regions in the developing world, particular in the tropics of Central and South America, Southeast Asia, South Asia, West Africa, Eastern Africa and parts of central Africa.

Agroforestry systems

Agroforestry systems include both traditional and modern land-use *systems* where trees are managed together with crops and/or animal production *systems* in agricultural settings. The agroforestry systems are grouped as,

- Aagrisilviculture (crops - including tree/shrub crops - and trees),
- Silvopastoral (pasture/animals + trees), and
- Agrosilvopastoral (crops + pasture/animals + trees).
- Specialized AF systems such as apiculture with trees, aquaculture in mangrove areas, multipurpose tree lots, and so on,

Major types of agroforestry systems in the tropics for different ecological region are-

Humid Lowlands

- Shifting cultivation
- *Taungya*
- Plantation-crop combinations
- Multilayer tree gardens
- Intercropping systems

Semiarid Lowlands

- Silvopastoral systems
- Windbreaks and shelterbelts
- Multipurpose trees for fuel and fodder
- Mutlipurpose trees on farmlands

Highlands

- Soil conservation hedges
- Silvopastoral combinations
- Plantation-crop combinations

The common agroforestry systems in Asia and Africa are summarized in Table 1.

The information as presented above indicates that the term 'agroforestry' encompasses a diverse set of integrated land use practices employed for variety of purposes. The aim is to achieve synergy between the components, which leads to net improvements in one or more of a range of characteristics, such as productivity and sustainability.

Agroforestry Research & Education

The main focus of agroforestry research in most of the countries was on diagnostic survey and appraisal of existing farming system and agroforestry practices including farmers' preferences, collection and evaluation of germplasm for fuel, fodder and small timber, economical relation and management practices of agroforestry systems and role of agroforestry in environment protection, post-harvest technology and value addition.

Presently in various African countries agroforestry research is on: domesticating trees for high-quality germplasm to produce fruit, energy and fodder; Improving on-farm tree management; restoring cocoa orchards; managing tree-crop interactions to optimize parkland performance; developing tree-based land restoration; developing value chain and public private partnerships, analysing the current regulations and supporting the development of conducive environment for the promotion of trees and agroforestry.

Agroforestry is now taught as a part of forestry- and agriculture-degree in different countries.

Intended Nationally Determined Contributions (INDCs) and Agroforestry

Agroforestry is recognized as the ultimate tool to enhance the resilience to climate change and reduce the carbon footprint of the developmental activities. To achieve the Intended Nationally Determined Contributions (INDCs), 23 countries have recognized agroforestry as a priority for mitigation, and 29 countries for adaptation (https://ccafs.cgiar.org/agricultures-prominence-indcs-data-and-maps#.Wfa1uohx200).

A study presented by the World Agroforestry Centre (ICRAF) at the UN Climate Change Conference shows that agroforestry covers about one billion ha of land worldwide, with experts estimating that the carbon storage potential in these agroforestry systems can offset an equivalent of 20 years of emissions from deforestation. Further evidence shows that agroforestry contributes to microclimate and water regulation, supports biodiversity conservation, improves soil fertility, and helps diversify nutrition, significantly contributing to food security. This potential role of agroforestry is set out in more detail in a recent ICRAF study titled, How Agroforestry Propels Achievement of Nationally Determined Contributions, available at http://www.asb.cgiar.org/Publications%202017/Policy%20Brief-%20How%20Agroforestry%20Propels%20Achievement%20of%20Nationally%20Determined%20Contributions-%2013112017.pdf

Role of trees or tree cover is well recognized to significantly reduce the risk of climate change, and make the environment more conducive to humans, livestock, and to agriculture. Trees contribute over 10% of the US $3.1 trillion worth of GDP created by the agricultural sector (Annual Report 2016-2017: Harnessing the multiple benefits of trees on farms. World Agroforestry Centre). Agroforestry is one of the ways to protect and compensate the loss of forest cover; provide the benefits that otherwise will be obtained from already over-exploited forests; increase environmental sustainability; enhance the production of food, fodder, fuelwood, and timber; reduce soil erosion and degradation; assist rehabilitation of degraded lands; enhance soil organic matter; remove atmospheric carbon through sequestration; support biodiversity and provide many other social, religious, and aesthetic benefits. On the basis of research conducted so far, agroforestry practices applicable to different suitable sites for sequestering atmospheric carbon in wood biomass as well as soils can be selected as below;

i. Agri-silviculture or agri-horticulture systems for food and wood/fruit production
ii. Boundary and contour planting for wind and soil protection

iii. Silvi-pasture system for fodder production as well as soil and water conservation
iv. Complex agroforestry systems, viz. multistrata tree gardens, home gardens, agri-silvi-horticulture and horti-silvi-pasture systems for food, fruits and fodder especially in hill and mountain regions
v. Non-timber tree farms for rubber, tannins, medicines, bamboo, rattan, etc.
vi. Bio fuel plantations
vii. Taungya system which is applied in tandem with forest management
viii. Hedgerow intercropping
ix. Improved fallows
x. Sloping agricultural land technologies (SALT) for fodder, fuelwood, soil conservation, environment protection. Integration of soil conservation and food production strategies on steep slopes; alternate strips of timber and firewood trees with cereals (corn, upland rice, etc.) and legumes (soybean, mung bean, peanut, etc.); provides the farmers returns throughout the year.

Policies and strategies

Introduction of compatible trees in the agricultural landscape (on the field boundaries, inter cropping with crops, and on community lands), provide additional and diverse food with limited inputs. As annual crops are more susceptible to climate extremes as compared to trees, intercropping of multipurpose trees with crops, reduces farmers' risks to face hunger due to crop failure, besides increasing the green cover.

During 2014, India took lead in formulation and implementation of the world's first National Agroforestry Policy, and South Asia Regional Program (SARP) of ICRAF played important role as a technical partner in its development and now in implementation of the same (http://www.indiaenvironmentportal.org.in/files/file/Agroforestry%20policy%202014.pdf and https://www.worldagroforestry.org/publication/national-agroforestry-policy-india-experiential-learning-development-and-delivery-phases).

Tremendous success of India's agroforestry policy in increasing awareness about the benefit and potential of agroforestry; removal of legal hurdles in planting, felling and transporting agroforestry products; and in channelizing huge resources to mainstream agroforestry in the national agenda has exhibited ripple effect in the South Asia and beyond. ICRAF recently worked with the Governments of Bangladesh and Nepal (http://kathmandupost.ekantipur.com/news/2017-11-05/nepal-gearing-up-to-draft-agroforestry-policy.html), and with some South East Asian countries (ASEAN AF Strategy, http://www.worldagroforestry.org/region/sea/ publications/detail?pubID=4392) to develop their respective agroforestry policies/ strategies/guidelines. Nepal, working with ICRAF became the second country globally to launch its own national agroforestry policy on 3rd July, 2019.

One of the most important successes of agroforestry in India, is the fact that the country fulfils about 70% of its timber needs through agroforestry. To realize the full potential and benefits of agroforestry, there is an urgent need and demand to sensitize the policy makers, and strengthen their capacities for mainstreaming agroforestry in their country's development agenda.

Agroforestry and employment generation

Agroforestry systems offer great potential to create new jobs in the rural areas, and thus, to a certain extent, reverse the process of transmigration to urban areas. That is, the great diversity of products from agroforests provides opportunities for development of small-scale rural industries and for creating off-farm employment and marketing opportunities. Quite apart from providing food products and industrial raw materials, agroforestry tree products constitute a source of biofuels for the rural households and can offset industrial/automobile fossil energy consumption (Kumar et al., 2012). For rehabilitation of degraded lands, agroforestry in one of the promising option. Rehabilitation of saline, alkaline, and water-logged soils through bio-drainage by planting *Eucalyptus* at specified intervals also has been successfully demonstrated in India.

Way forward

Agroforestry is the best option for the restoration of the degraded environment and meeting day to day needs of the people, besides mitigating the climate change effects and providing a great opportunity for the rural development. Agroforestry systems (AFS) as models have been developed and evaluated for the varying agro-climatic situation in both the region. Agri-silvipasture, agri-horticulture, silvipastoral, agri-horti- silvi-pastoral, horti-pastoral, agri-silvipastoral, AFS with sericulture, apiculture and fisheries with trees, and other systems have been developed for different altitudinal ranges, slopes and soil depths.

For large-scale adoption of agroforestry, the prerequisites are: improving the marketing and processing of agroforestry products involving public-private partnerships; product diversification and value addition; development and promotion of substitutes and/or supplements for costly, imported external inputs (e.g., fodder trees, fertilizer trees); creating an enabling environment and exploring new avenues for dissemination of agroforestry related technologies; training and capacity building in agroforestry among all major stakeholders including policy makers highlighting the benefits of agroforestry and the constraints impeding its adoption; and partnering with a broad range of actors. Therefore, disseminating science-based evidence and otherwise demonstrating the effectiveness of agroforestry systems at scale to encourage the uptake of these systems; developing ecological services through agroforestry systems is to be prioritized by the countries in Asia and Africa. For fully realizing the benefits of agroforestry, there is an urgent need and demand to sensitize and strengthen the capacity of the stakeholders, disseminate the successful agroforestry systems as models as part of the implementation of agroforestry programs in various countries.

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***Table 1. Common agroforestry systems* in Asia and Africa (modified from Nair, 1989).**

***Agroforestry systems* and practices**	**South Asia**	**South East Asia**	**East & Central Africa**	**West Africa**
		Agri-silvicultural		
Improved fallow (in shifting cultivation areas)	Subsistence food production system, improvements to shifting cultivation; several	Forest villages of Thailand; various fruit trees and plantation crops used	Improvements to shifting cultivation e.g.	*Acioa barterii, Anthonontha macrophyta, Gliricidia*

	approaches e.g. in the north-eastern areas of India	as fallow species in Indonesia	gum gardens of the Sudan	*sepium* etc., tried as fallow species
Taungya system	Originated in Burma and spread to different parts of the world. Field crops grown in the interspaces of forest crops during the early stages. Trees: *Shorea robusta*, *Teak, shisham*, *Acacia catechu*, *Eucalyptus* etc.	Widely practiced; forest villages of Thailand an improved f	The Shamba system	Several forms, several names
Tree gardens	Dominated by fruit trees in all ecological regions	Dominated by fruit trees		
Hedgerow intercropping (alley cropping)	Practiced by the smallholder farmers. MPTS and/or field crops grown in association with commercial tree crops. Many experimental approaches e.g. conservation farming in Sri Lanka. Nitrogen fixing trees are preferred.	Extensive use of *Sesbania grandiflora, Leucaena leucocephala* and *Calliandra calolhyrsus*	The corridor system of Zaire	Experimental systems on alley cropping with Leucaena and other woody perennial species
Multipurpose trees and shrubs on farmlands	Several forms in lowlands and highlands, e.g. Khejri-based system in dry parts of India, hill farming in Nepal	Dominated by fruit trees: also *Acacia mearna* cropping system, Indonesia	Various forms e.g. the Chagga system in Tanzania hills, Nyabisindu system in Rwanda	*Faiderbida (Acacia) albida* based systems in dry areas; *Butyrospermum* and *Parkia* systems 'Parc arboree'
Plantation crop combinations	Tea, coffee, cacao, spices like clove, nutmeg, black pepper, betel vine etc. requiring varying shade for optimum growth and production are grown under shade trees in plantations; other crop mixtures including various spice trees also common	Plantation crops and multipurpose trees; smallholder crops combinations with plantation crops; plantation crops with spice trees	Integrated production; shade trees in commercial plantations; mixed systems in the highlands	Plantation crop mixtures; smallholder production systems
Agroforestry fuelwood production	Short rotation intensive cultural systems involving fast growing tree species, e.g., eucalyptus, acacia, teak etc. Various forms, including social forestry systems	Several examples in different ecological regions	Various forms	Common in the dry regions
Shelterbelts, windbreak; soil conservation hedges	Practised in many parts in which fast growing trees are planted at close intervals (e.g., block planting of *Casuarina* and *Acacia mangium* in the coastal areas.	Terrace stabilization on steep slopes	Nyabisindu system in Rwanda	Various forms
SILVOPASTORAL SYSTEMS				

Protein bank (cut-and-carry) fodder production	Adapted tree + grass combinations contributing to forage production. *Acacia leucophloea* + *Cenchrus setigerus* silvipasture system in the Kangeyam tract of Tamil Nadu; over 400 year old system. Multipurpose fodder trees on or around farmlands, especially in highlands	Very common, especially in highlands	Very common	Very common
Live-fences of fodder trees and hedges	*Sesbania, Euphorbia, Syzigium*, etc. common	*Leucaena, Calliandra* etc. used extensively	Very common in all ecological regions	
Trees and shrubs on pasture	Several tree species being used very widely	Grazing under coconut and other plantation crops	The *Acacia* dominated system in the arid parts of Kenya, Somalia and Ethiopia	Cattle under oil palm; cattle and sheep under coconut
AGROSILVO-PASTORAL SYSTEMS				
Woody hedges for browse, mulch, green manure, soil conservation etc.	Various forms, especially in lowlands	Various forms,	Common; variants of the Shamba system	Very common
Home-gardens (involving a large number of herbaceous and woody plants and/or livestock)	Kerala and Kandyan homegardens are prominent. Common in all ecological regions; often involving fruit trees	Very common; Java home-gardens good examples; involving several fruit trees	Various forms the Chagga homegardens; the Nyabisindu system	Compounds farms in humid lowlands
OTHER SYSTEMS				
Agrosilvo fishery (aquaforestry)	Silviculture in mangrove areas; trees on bunds of fish-breeding ponds. Common in coastal tracts of India, Bangladesh, Sri Lanka, and Maldives.	Silviculture in mangrove areas; trees on bunds of fish-breeding ponds		
Various forms of shifting cultivation	Very common; various names	Swidden farming and other forms	Very common	Very common in lowlands
Apiculture with trees	Apiculture, lac culture, and sericulture. Sericulture based agroforestry systems quite remunerative	Common	Common	Common

Agroforestry: Traditions, Transformations and Prospects Focus on Asia and Africa

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Abstract
The South and Southeast Asian region is often described as the cradle of agroforestry in recognition of its long history of the practice of an array of systems under diverse agroecological conditions. Similarly in African continent trees and shrubs play an important role in protecting the environment. The multitude of systems that have evolved in both regions over centuries reflect the accrued wisdom and adaptation strategies of millions of smallholder farmers to meet their basic needs of food, fuelwood, fodder, plant-derived medicines, and cash income in the wake of increasing demographic pressure and decreasing land availability in South and Southeast Asia and degradation of the environment in Africa. Prominent examples of agroforestry in Asia and Africa include multifunctional homegardens, which promote food security and diversity; woody perennial-based systems furthering employment avenues and rural industrialization; fodder trees and silvipatoral systems favoring resource conservation; and tree-dominated habitats, which sustain agrobiodiversity and promote climate change mitigation.

Keywords: Agroforestry systems, Chagga gardens, Homegardens, Parkland system, Shifting cultivation

Introduction

South Asia is often described as the cradle of agroforestry in view of its long history of the practice of tree based farming systems under diverse agro-ecological conditions. Important South Asian ecologies where tree-based production systems are very common include the hilly and mountainous areas, tropical plains, arid and semiarid regions, and the coastal humid zones (Kumar et al., 2012). Traditional agroforestry systems including homegardens were common since ancient time. Many of these traditional agroforestry systems, however, have evolved and adapted to the changing climate and demography.

In Africa, trees and shrubs play an important role in protecting the environment. Trees inside and outside forests contribute to food security in Africa in the face of climate variability and change. They also provide environmental and social benefits as part of farming livelihoods. Varied ecological and socio-economic conditions have given rise to specific forms of agroforestry in different parts of Africa.

Farmers in South Asia and Africa have been domesticating fruit trees and other agricultural crops around their homestead since long primarily to meet their subsistence needs. The best example of this is the tropical homegardens in Asia, which are essentially a complex integration of diverse trees with understorey crops. Fruits plants including *Aegle marmelos*, *Buchanania lanzan*, *Phyllanthus emblica* (Indian gooseberry), *Mangifera indica* (mango), *Ficus* sp. (fig), *Madhuca* sp. (mahua), and *Ziziphus* sp. (ber) were planted by the dwellers. In West and Central Africa fruit tree domestication became closely linked to processing and marketing of tree products, rural resource centres and marketing arrangements and the fruit plants such as

Annacardium occidentale (Cashew nut), *Artocarpus communis* (jackfruit), *Carica papaya* (papaya), *Citrus* sp., *Cocos nucifera* (cocnut), *Dialium guineense, Mangifera indica* (mango) and *Psidium gujava* (guava) were common species.

Prominent agroforestry systems in Asia and Africa

Prominent agroforestry systems such as parkland, agrisilviculture with poplar (*Populus deltoides*), *Eucalyptus* spp., multi-storied systems with plantation crops viz. coffee (*Coffea* spp.), tea (*Camellia sinensis*), cacao (*Theobroma cacao*) and spices (e.g., black pepper, cardamom) in association with a variety of trees, betel vine (*Piper betel*) + areca palm (*Areca catechu*), intercropping systems with coconut, para rubber (*Hevea brasiliensis*), and other trees, and commercial crop production under the shade of trees in natural forests (e.g., cardamom) are common in South and South-East Asia. The homestead agroforestry in Bangladesh, Kandy homegardens in Sri Lanka, Kerala homegardens in India, and alder-cardamom systems in Nepal and north-eastern India are some of the examples of the classical homegardens from this region.

In other Southeast Asian countries farmers use a rich variety of agroforestry practices. These include high-diversity home gardens, improved fallow (e.g. with naturalized *Leucaena* spp. in the Philippines), commodity-based agroforestry systems (Indonesia), agroforests such the damar agroforests and "jungle rubber" of Sumatra, taungya and tumpangsari in teak or pine plantations in Indonesia and Thailand, trees planted at wide spacing in open-field agriculture (e.g. forest–rice terrace systems in the southern and northern Philippines), SALT (Sloping Agricultural Land Technologies; e.g. hedgerow planting and alley cropping) and NVS (natural vegetative strips) on sloping land in Indonesia, the Philippines and Viet Nam, and boundary planting around farms and fields (e.g. of fodder trees in Indonesia and the Philippines).

Deliberate growing of trees on field bunds (risers) and in agricultural fields as scattered trees, the practice to utilize the open interspaces in the newly planted orchards and forests for cultivating field crops are also widespread here. Multifunctional homegardens, which promote food security and diversity; woody perennial-based systems furthering employment avenues and rural industrialization; fertilizer trees and integrated tree-grass/crop production systems favouring resource conservation; and tree-dominated habitats, which sustain agrobiodiversity and promote climate change mitigation are also popular in the subcontinent.

From African continent, agroforestry systems such as silvipastoral, agri-silvi-pastoral, agri-silvicultural and Parkland in arid and semi-arid ecozones; bush-fallow-food-crop rotation, Shamba (taungya) in Kenya; compound farms of south-eastern Nigeria; alley cropping in humid and sub-humid; and Chagga homegardens in tropical highlands are some of the examples.

In East and Southern Africa, agroforestry systems include cereal-based systems with indigenous and introduced tree species for timber (*Grevillea robusta*, *Eucalyptus* spp.), fruits (e.g. mango (*Mangifera indica*), avocado (*Persea americana*), charcoal (*Acacia* spp.), fodder (*Calliandra* spp.) and soil-fertility improvement (*Faidherbia albida*). Traditional "parkland" systems – which are mixed crop–tree–shrub–livestock components are the main sources of food, income and environmental services across the Sahelian zone of West Africa.

In the humid tropics of West and Central Africa, prevalent agroforestry practices include homegardens, perennial crop-based systems (cocoa, coffee, oil palm, rubber), slash-and-burn agriculture where high-value timber and non-timber forest product species are retained, and improved fallows (e.g. with red calliandra (*Calliandra calothyrsus)*, leucaena (*Leucaena leucocephala)*, gliricidia (*Gliricidia sepium*), ice-cream bean (*Inga edulis*), mangium (*Acacia mangium)* and *Acacia auriculiformis, Sesbania sesban*; boundary planting (mostly in hilly areas) and small woodlots with *Eucalyptus* spp., red stinkwood (*Prunus africana*) and silver oak (*Grevillea robusta*).

Multifunctionality is a characteristic feature of agroforestry practices in South Asia, as in Africa. Most agroforestry systems have the intrinsic potential to provide food, fuel, fodder, green manure, plant derived medicines, and timber resources. The choice of species and planting techniques adopted in such systems also reflect the accrued wisdom and insights of the traditional people who interacted with the environment for long. Of late, economic incentives to the land managers have acted as a major driver of agroforestry in certain parts of South Asia. Poplar (*Populus* spp.)-based agroforestry in northern India, is a case in point. Consequent to the ban on timber cutting in the state forests of India, and the widening gap between demand and supply, woodlots of other fast growing trees such as *Eucalyptus* spp., *Leucaena leucocephala*, *Casuarina equisetifolia*, *Acacia mangium*, *A. auriculiformis, Ailanthus triphysa*, and *Melia dubia* have also became popular among the farmers in several parts of South Asia.

Agroforestry research in South Asia and Africa

Although agroforestry as a practice was very ancient in South Asia, the science of agroforestry is relatively new. Organized research on agroforestry started in India with the establishment of the All India Coordinated Research Project on Agroforestry in 1983 (ICAR 1981). The research initiatives gained further momentum with the commencement of forestry education programs in the State Agricultural Universities of India during 1985/1986 and the founding of the National Research Centre for Agroforestry (NRCAF) at Jhansi, UP, in 1988. The main focus of research was on Diagnostic survey and appraisal of existing farming system and agroforestry practices including farmers' preferences, Collection and evaluation of germplasm for fuel, fodder and small timber, economical relation and management practices of agroforestry systems and role of agroforestry in environment protection, post-harvest technology and value addition (Handa et al. 2015). Other countries in the region such as Nepal, Sri Lanka, Pakistan, and Bangladesh also followed a similar strategy, and agroforestry came of age in those countries too (Kumar et al, 2012).

The World Agroforestry, International Centre for Research in Agroforestry (ICRAF) through its Agroforestry Research Network of Africa (AFRENA) and in collaboration with national research systems identified a number of agroforestry practices from various countries. ICRAF initiated research programs in Malawi, Zambia, Tanzania, Cameroon, Uganda, Rwanda, Kenya and Brundi to generate location specific technologies (Singh, 1997).

The main focus of the agroforestry research in various African countries is presently on: domesticating trees for high-quality germplasm to produce fruit, energy and fodder; Improving on-farm tree management; restoring cocoa orchards; managing tree-crop interactions to optimize parkland performance; developing tree-based land restoration; developing value chain and public private partnerships, analysing the current regulations and supporting the development of conducive environment for the promotion of trees and agroforestry. In addition disseminating science-based evidence and otherwise demonstrating the effectiveness of agroforestry systems at scale to encourage the uptake of these systems; developing ecological services through agroforestry systems.

Agroforestry in present perspective

Although tree-based systems were evolved world over in the past, much has changed in respect of the attitudes of people towards environment and natural resource conservation. High demographic pressure has led to over-exploitation of the natural resources, especially forest resources.

Many of these smallholder family farms, e.g., the tropical homegarden systems, are indeed woody perennial-based mixed species production units with multiple production and service functions. Multipurpose and fertilizer trees are integral components of such systems. Carbon sequestration for climate change mitigation is a low-hanging fruit of agroforestry. Fortunately, a paradigm shift on matters relating to environmental protection and sustainable land use has occurred in the recent past. Agroforestry, evergreen agriculture, and smallholder production systems have attracted considerable attention around the world, of late, and tree-based production systems are being promoted, the world-over.

The potential of agroforestry to contribute to sustainable development has been recognized in many international policy declarations also. For example, the United Nations Framework Convention on Climate Change (UNFCCC) and the Intergovernmental Panel on Climate Change (IPCC) acknowledged it as a component of climate-smart agriculture and is frequently mentioned as having a strong potential for climate change adaptation and mitigation. The United Nations Convention to Combat Desertification (UNCCD) acknowledges agroforestry's potential to control desertification and rehabilitation. It is also seen as an important element in the ecosystem approach promoted by the Convention on Biological Diversity (CBD) for agrobiodiversity conservation.

Agroforestry is recognized as the ultimate tool to enhance the resilience to climate change and reduce the carbon footprint of the developmental activities. To achieve the Intended Nationally Determined Contributions (INDCs), 23 countries have recognized agroforestry as a priority for mitigation, and 29 countries for adaptation (https://ccafs.cgiar.org/agricultures-prominence-indcs-data-and-maps#.Wfa1uohx200).

Introduction of compatible trees in the agricultural landscape (on the field boundaries, inter cropping with crops, and on community lands), provide additional and diverse food with limited inputs. As annual crops are more susceptible to climate extremes as compared to trees, intercropping of multipurpose trees with crops, reduces farmers' risks to face hunger due to crop failure, besides increasing the green cover.

During 2014, India formulated and implemented National Agroforestry Policy. South Asia Regional Program (SARP) of ICRAF played important role as a technical partner in its development and now in implementation of the same. Tremendous success of India's agroforestry policy in increasing awareness about the benefit and potential of agroforestry; removal of legal hurdles in planting, felling and transporting agroforestry products (mainly timber and wood); and in channelizing huge resources to mainstream agroforestry in the national agenda has exhibited ripple effect in the South Asia region and beyond. ICRAF recently worked with the Governments of Bangladesh and Nepal (http://kathmandupost.ekantipur.com/news/2017-11-05/nepal-gearing-up-to-draft-agroforestry-policy.html), and with some South East Asian countries (ASEAN AF Strategy, http://www.worldagroforestry.org/region/sea/publications/detail?pubID=4392) and Republic of Rwanda to develop their respective agroforestry policies/ strategies/guidelines. Nepal, working with ICRAF became the second country globally to launch its own national agroforestry policy on 3rd July, 2019.

Way forward

In the face of increasing population and demand for food production with high nutritive values, the prime need is to develop appropriate production systems having ability to continue with the current increasing trend of land productivity, producing high nutritional food to fight the rampant malnutrition, and combat the impacts of climatic changes and extreme events. This will need to shift focus from agricultural fields to the agricultural landscape approach. With land holdings getting smaller, degradation of the soil fertility and natural resources increasing, changing climate and increasing sudden extreme events; it is important to make the agricultural landscape more robust and sustainable to ensure enhanced livelihood including food and nutritional securities of the smallholder farmers through promotion of tree-crop systems in agricultural lands which can be produced even under unfavorable environmental condition. The woody species not only provide the climate resilient backbone of the system, but they also offer high-value products and ecosystem services. The above review clearly indicates that agriculture with trees enhances livelihood and supports food and nutritional security through:

(1) the direct provision of tree foods such as fruits and leafy vegetables and by supporting staple crop production;
(2) by raising farmers' incomes through the sale of wood, timber, and other tree products and surplus staples;
(3) by providing fuelwood for energy;
(4) by providing green fodder to the livestock, especially during natural calamity; and
(5) by supporting various ecosystem services.

While challenges for such a system in supporting food and nutritional security include policy and market constraints and underinvestment in research, strong opportunities exist to promote multifunctional, climate-smart agricultural methods involving trees. To better support food and nutritional security, reforms in existing relevant policies, and/or development of new agroforestry policy are urgently required to reform tree and land tenure for the benefit of small-scale farmers. Examples from India, Nepal, Bangladesh and other Asian countries and Rwanda from Africa are given above. Policy reforms are also needed to ensure quality supply of agroforestry planting material (seed and seedlings), credit and insurance, recognizing agroforestry products as agriculture products, and removing currently imposed restrictions on felling and transporting wood and timber. Therefore, investments are needed at policy & advocacy, research and development, and out scaling of proven agroforestry systems according to respective agro-climates and needs of local communities.

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CAFRI: A Journey of Agroforestry Research and Development in India

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Abstract
The Indian Council of Agricultural Research (ICAR) initiated a network project for organized research in agroforestry in 1983. To strengthen and coordinate the agroforestry research the National Research Centre (NRC) for Agroforestry was established on 8th May, 1988 at Jhansi (Uttar Pradesh) which was upgraded on 1st December, 2014 as ICAR- Central Agroforestry Research Institute (ICAR-CAFRI). The paper discusses the agroforestry research and development by the Institute during last more than three decades.

Key words: Agroforestry research and development, Carbon dioxide sequestration, watershed approach

Introduction

Agroforestry is practiced by millions of farmers worldwide, and has been a feature of agriculture for millennia. With the science and technology ingress, agroforestry encompasses a wide range of trees that are grown on farms and in rural landscapes, and includes the generation of science-based tree enterprise opportunities that can be important in the future.

ICAR-Central Agroforestry Research Institute

The Indian Council of Agricultural Research (ICAR) has initiated a network project for organized research in agroforestry in 1983. To strengthen and coordinate the agroforestry research the National Research Centre for Agroforestry was established on 8th May, 1988 at Jhansi (U.P.). After 26 years of successful research and development activities on agroforestry, from 1st December, 2014, ICAR elevated the status of the National Research Institute for Agroforestry (NRCAF) to ICAR- Central Agroforestry Research Institute (ICAR-CAFRI).

Institute is actively involved in designing and conducting research and development programmes on agroforestry models suitable for different edapho-climatic conditions of India through its research institute at Jhansi and 37 AICRPAF Institutes throughout India representing different agro-climatic conditions. Initially, the activities have broadly been grouped as Agrisilviculture, Agrihorticulture & Silvipasture, Tree Improvement & Silviculture and Human Resource Development & On Farm Research. Looking to the importance of the agroforestry research programmes have been reoriented under System Research, Natural Resource & Environment Management, Tree Improvement, Post-Harvest & Value Addition and HRD, Technology Transfer & Refinement.

Institute in its national agroforestry mandate, has spent more than thirty years to systematize the science of agroforestry and has developed tools and methods to conduct agroforestry research. India has developed robust agroforestry science, innovations and practices that are attracting global interest. The basic, applied and strategic research in different spheres of agroforestry are targeted through institutional and externally funded ad-hoc and network projects.

MISSION
To improve quality of life of rural people through integration of perennials on agriculture landscape for economic, environmental and social benefits.

VISION
Integration of woody perennials in the farming system to improve land productivity through conservation of soils, nutrients and biodiversity to augment natural resource conservation, restoration of ecological balance, alleviation of poverty and to mitigate risks of weather vagaries.

MANDATE

- Develop sustainable agroforestry practices for farms, marginal land and wastelands in different agro-climatic zones of India.
- Coordinate network research for identifying agroforestry technologies for inter-region.
- Training in agroforestry research for ecosystem analysis.
- Transfer of agroforestry technology in various agro climatic zones.

Agroforestry Research & Development Initiatives of ICAR-CAFR
Some of the most significant research initiatives and achievements of ICAR-CAFRI are detailed hereunder:

Carbon dioxide sequestration potential of agroforestry systems under irrigated and rainfed conditions
Carbon sequestration potential of agroforestry system was higher under irrigated condition than rainfed condition. However, carbon sequestration potential of the system depends on nature of tree species, tree density, crop grown and agronomic inputs given to the intercrops. Estimation of carbon stock available under agroforestry practices on farm lands under different agro-climatic regions needs to be done through predictive models and remote sensing. *Albizia procera* being a fast growing tree species had accumulated 0.96 t biomass tree^{-1} at the age of 30-years and *Hardwickia binata* and *Dalbergia sissoo* could accumulate only 0.62 and 0.38 t biomass tree^{-1}, respectively at the same age. *Albizia procera* based agroforestry had sequestered 635.68 t CO_2 ha^{-1} at age of 30-years but other systems like *Dalbergia sissoo* and *Hardwickia binata* based agroforestry systems could sequester 79.43 and 268.93 t CO_2 ha^{-1} respectively. Simalarly aonla based sytem had sequestered only 67.56 t CO_2 ha^{-1} at 25-year age.

The simulation of biomass, soil carbon and carbon sequestration potential of agroforestry practices was done by using CO2FIX model on regional basis and Jhansi districts was chosen for the study. The total biomass (tree +crop), soil carbon and carbon sequestered and CO_2 equivalent carbon sequestered in baseline was 11.15, 9.44, 20.60 and 75.53 t C ha^{-1}, respectively and corresponding values of these parameters would be 19.53, 16.21, 35.74 and 131.06 t C ha^{-1}, respectively over simulated period of 21 years. The water use efficiency was calculated on the basis of total water consumed by individual tree of aonla and anjan from July 1, 2010 to April, 2011 and biomass accumulated by these trees during same period. Aonla is producing 0.82g biomass in one liter of water and anjan is producing 0.32 g biomass in one liter of water. Selection of suitable tree species/varieties and agroforestry system may one of the strategies to mitigate the problems related to abiotic stresses like drought, heat, low temperature/cold/frost, salinity and alkalinity, floods, hailstorms/high winds.

Assessment of carbon sequestration potential of agroforestry systems
The institute is working on three aspects under National Initiative on Climate Resilient

Agriculture (NICRA) project *viz*., assessment of carbon sequestration potential of agroforestry systems existing on farmers' fields in different agro-climatic regions through simulation model (CO_2Fix model), mapping of agroforestry area using GIS and Remote Sensing technique and study on thermotolerance. The assessment of carbon sequestration potential (CSP) has been completed in 48 districts covering 16 states (U.P., Gujarat, Bihar, West Bengal, Rajasthan, Punjab, Haryana, Himachal Pradesh, Maharashtra, Tamil Nadu, Andhra Pradesh, Orissa, Chattisgarh and Telangana). The number of trees on farmers' field varied from 4.02 to 111.82 trees per hectare in these states. The net carbon sequestered in agroforestry systems existing on farmers' fields under different states is 10.18 t C ha^{-1} from baseline over simulated period of 30-years. The carbon sequestration potential (CSP) of agroforestry systems in these states is 0.33 t C ha^{-1} yr^{-1}. The soil organic carbon (SOC) in agroforestry systems existing on farmers' fields in different states (Rajasthan, Madhya Pradesh, Maharashtra, Andhra Pradesh, Karnataka and Telangana) was higher than pure crop. The SOC in agroforestry systems under these states varied from 53.47 to 100.13 t C ha^{-1} in 0-90 cm soil depth.

Agroforestry Models/Systems Developed

1. *Eucalyptus based agroforestry system*

Four clones of *Eucalyptus tereticornis* namely C-3, C-7, C-6 and C-10 obtained from ITC, Bhadrachalam were planted as agrisilviculture, Block Plantation and Boundary Plantation. Wheat and Blackgram were grown in the interspaces during *rabi* and *kharif* seasons, respectively. After the age of seven years, the Eucalyptus trees were harvested and thereafter the coppice shoots were harvested at the age of 4 years in 2014. Before harvesting of the trees, the data related to tree growth and biomass for different systems was recorded. Sixteen trees each were destructively harvested from agrisilviculture, boundary plantation as well as from compact block plantations for observations on above and below ground biomass components. The average dbh (diameter at breast height) of the harvested trees was 19.32 cm and the mean height value was 21.01 m. The average total dry biomass (including above and below ground both) was recorded as 164.66 kg/tree.

2. *Albizia procera based agroforestry system*

A field study was done on tree-crop interaction in *Albizia procera* based agroforestry system in relation to soil moisture, light and nutrients. The growth of *Albizia procera* during initial two years was slow and picked up in third year. The growth performance of trees in tree-crop system was significantly better than pure. The tree growth was in order of irrigation>pruning>soil barrier.

The grain yield of intercrops (blackgram, soybean, mustard and wheat) was less in 1st row from tree base as compared to 2nd, 3rd and 4th row from tree base. In general, grain yield of crops increased gradually with increasing distances from tree base. Pruning of trees up to 70% plant height produced significantly ($P<0.05$) higher grain yield as compared to trees allowed to grow normally. Similarly, soil barrier in trees allowed to grow normally also gave better yield.

3. *Agroforestry models based on gum yielding trees*

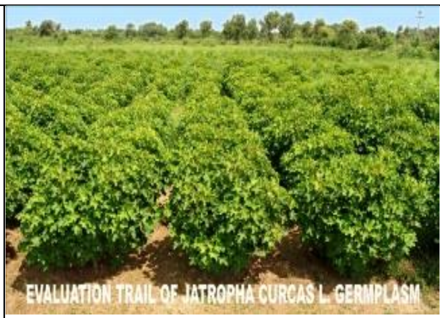
Six agroforestry models (4 at research farm and 2 at farmers' fields) were developed representing agri-horti-silviculture and horti-silviculture systems of agroforestry. The main species planted for gum production are *Acacia senegal* and *Acacia nilotica*, and horticulture species *Emblica officinalis*, *Citrus limon* (Lemon), *Aegle marmelos* and *Carrissa carandus*. 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. *A. nilotica* and *A. senegal* planted at farm started exuding gum, whereas no gummosis has been observed on farmers' fields.

Biomass improvement through silvipastoral interventions

The degraded lands producing only 2-3 t ha^{-1} $year^{-1}$ biomass are now producing 8-10 t ha^{-1} $year^{-1}$ biomass with silvipastoral interventions. One of the systems includes planting of 200 plants of *Albizia amara,* 200 plants of *Dichrostachys cinerea* and 380 plants of *Leucaena leucocephala* in 1.0 ha. In between two lines of trees *Chrysopogon fulvus* as a grass, planted at a spacing of 100 cm between row to row and 50 cm between plants to plant. The legume component *i.e.* a mixture of *Stylosanthes scabra* and *S. hamata* was sown between two rows of grass.

Evaluation, characterization and conservation of germplasm of agroforestry species

<table>
<tr><td>Neem (Azadirachta indica A. Juss)
Total of 276 accessions were collected from Maharashtra, Andhra Pradesh, Rajasthan, Uttar Pradesh, Madhya Pradesh and Orissa over a period of time.
Eleven progenies for high azadirachtin content, 12 progenies for high oil content and 52 progenies for high fruit and good growth were identified.
Seed orchard from the promising lines was established for further multiplication and location trial.</td><td></td></tr>
<tr><td>Shisham (Dalbergia sissoo Roxb.)
Thirty two candidate trees were selected from Bundelkhand region based on fast growth, clear bole and close canopy.
Seed orchards of PT-2, PT-6, PT-9, PT-10 and PT-19 were established for further multiplication.</td><td></td></tr>
</table>

Jatropha (*Jatropha curcas L.*) • A total of 284 accessions of Jatropha were collected from different parts of the country through exploration and cryo-preserved to NBPGR, New Delhi. • A large variation in seed oil content i.e. 23 to 43% has been recorded.	
Karanja (*Pongamia pinnata L.*) • A total of 143 accessions were collected. • Out of these 143 accessions, 62 accessions reported oil content more than 35%.	
Kardhai (*Anogeissus pendula*) • Thirteen accessions of *Anogeissus pendula* multiplied through tissue culture were obtained from TERI, New Delhi and evaluated.	
Babul (*Acacia nilotica* ssp. *indica*) • 53 accessions were collected from different regions • Significant variation has been observed in provenances for pod length, pod width, seeds per pod, seed length, seed width, seed thickness, 100 seed weight and 100 seed volume at p<1% level.	
Leucaena spp. A total of 34 accessions belonging to five different species *viz*., *Leucaena diversifolia*, *L.shannoni*, *L.lanceolata*, *L.collinsii*, *L. leucocephala* and a hybrid (*L. shannoni* X *L. leucocephala*) were collected.	

Agroforestry based watershed approach

1. *Agroforestry based watershed and interventions at Garhkundar Dabar watershed*

The details are available in separate Lecture note of this resource book.

2. *Agroforestry based watershed and interventions at Parasai-Sindh watershed*

The details are available in separate Lecture note of this resource book.

Agroforestry Technologies Developed at ICAR-CAFRI, Jhansi

- Rainwater harvesting and recycling on watershed basis for Bundelkhand region.
- Prevention of Seepage through Rainwater harvesting structures
- Aonla based horti-pastoral system in red soil of Bundelkhand region using contour staggered trenches
- Concept of Drought Proofing of Bundelkhand Region
- Process of Participatory watershed development
- Aonla based agroforestry land use for rainfed condition in Bundelkhand region
- *Eucalyptus* based agrisilviculture system
- Superior genotype of neem (*Azadirachta indica*)
- Bundel -2 (PT-2) and Bundel-6 (PT-6) varieties of *D. sissoo* developed
- Top working of *Carissa* (wild karonda)
- Bench grafting in aonla *Emblica officinalis* Gaertn. (Aonla)
- Bench grafting in Ber (*Zizyphus* spp.)
- Vegetative propagation of neem through air layering
- Vegetative propagation of *Pongamia pinnata* through stem cuttings and air layering
- Methodology for early selection of elite trees of *Acaia nilotica*
- Development & testing of age-age correlation models

Agroforestry for improving rural livelihood and employment opportunities

Dhyani et al. (2005) have estimated the 5.763 million person-days yr^{-1} employment generation potential of agroforestry for rural development in the Himalayas alone (Table 1).

Agroforestry policy for changing the scenario of agroforestry in India

The landmark National Agroforestry Policy 2014 also recommends the sound database for Agroforestry in India and setup the institutional mechanism for promoting agroforestry research at national level, ICAR-CAFRI has taken up it. The NAP, 2014 also recommends the insurance and credit facility for the agroforestry practitioner. Credit facility and insurance to small and marginal land holder will boost the area under agroforestry. Tamilnadu being the first state in India started the tree insurance by United India Insurance, Chennai. The insurance agency is ensuring the insurance against natural calamities (flood and cyclone), wild animal damage, and pest and disease for the species (Chavan *et al*., 2015). In coming days more states are likely to come out with there own state agroforestry policy or rule which will definitely promote the agroforestry in the country. The Prime Minister of India has also emphasized on several occasions about tree plantation on farm boundary.

Way Forward

Agroforestry is bound to play a major role, not only for its importance in food and livelihood security, but also for its role in combating the environmental challenges because country’s land area cannot be stretched. Agroforestry and trees outside forest will be a key issue in providing a solution to global warming, climate change and enhancing the per unit productivity of the land and converting degraded and marginal lands into productive areas. The major focus of research in the coming years will be on developing agroforestry technologies for critical areas like arid and semi-arid zones and other fragile ecosystems such as Himalayan region and Coastal eco-system to sustain these areas for higher productivity and natural resource management.

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Table 1: Employment generation potential of agroforestry in India

Agroforestry system	Area (million ha)	Additional employment (Person-day ha^{-1} yr^{-1})	Total annual employment (million person-days)
Silviculture	1.8	30	53.3
Agrisilviculture (irrigated)	2.3	40	91.3
Agrisilviculture (rainfed)	1.3	30	38.0
Agrihorticulture (irrigated)	1.5	50	76.1
Agrihorticulture (rainfed)	0.5	40	20.3
Silvipasture	5.6	30	167.4
Tree-borne oil seeds	12.4	40	497.1
Total	25.4	-	943.4

Source: NRCAF (2007)

Doubling Farmers Income- Policy Initiatives and Innovations in India

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A Brief on Doubling Farmers' Income Report
The Report of the Inter-Ministerial Committee on Doubling Farmers' Income (DFI) is documented in 14 volumes. The Committee focuses on seven major sources of growth, operating within (6) and outside (1) the agriculture sector. The priority assigned to each will vary depending on the status of agricultural development in States and Union Territories. These sources are:

Within the agriculture domain
Improvement in crop productivity. Improvement in livestock productivity. Resource use efficiency or saving in cost of production. Increase in cropping intensity. Diversification towards high value crops. Improvement in real prices received by farmers. Outside the agriculture domain · Shift from farm to non-farm occupations.

The DFI Committee addresses agriculture as a value led enterprise and suggests empowering farmers with "improved market linkages" and enabling "self-sustainable models" as the basis for continued productivity-production and income growth for farmers. This builds the basic strategy direction for five primary concerns:

1. Optimal monetisation of farmers' produce,
2. Sustainability of production,
3. Improved resource use efficiency,
4. Re-strengthening of extension and knowledge based services, and
5. Risk management.

In Volume-I, the growth of agriculture in the last 70 years is analysed with the current status. An appropriate context is set, with farmers' income as the basis of agriculture, in place of production as it has been, for a comprehensive understanding of the needed directional change. In Volume-II, the DFI Committee tables the "growth targets" for doubling farmer's real income while improving the ratio between farm and non-farm income from 60:40 as of now, to 70:30 by 2022-23. It suggests the following strategy:

a. Adopting a "demand-driven approach" for efficient monetisation of farm produce and to synchronise the production activities in Agriculture & Allied Sectors.
b. Improving and optimising input delivery mechanism and overall input efficiency [technologies, irrigation methods, mechanisation, Integrated Pest Management (IPM), Integrated Nutrient Management (INM), farm extension services, adaptation to climate change, integrated agri-logistics systems, Integrated Farming Systems Approach, etc.].
c. Offering institutional credit support at the individual farmer and cluster levels.
d. Strengthening linkages with micro, small and medium enterprises (MSMEs), to accelerate growth in both farm as well as non-farm incomes along with employment creation. Farmers' income is directly related to cost of agricultural production (including input costs) and profitable monetisation of the agricultural produce, through effective market linkages. In Volumes III–XIII, the DFI Committee deliberates upon specific economic activities and topics that have a durable impact on farmers' income.

Some of these are categorised as follows:

i. Demand Driven Agricultural Logistics System for post-production operations such as produce aggregation, transportation, warehousing, etc.

ii. ii. Developing Hub and Spoke System at back-end as well as front-end to facilitate and promote a new market architecture so that all kinds of farmers can avail services that empowers them to physically connect and supply to any market in the country of their choice.

iii. Marketing Intelligence System to provide demand led decision making support system - forecasting system for agricultural produce demand and supply, and crop area estimation to aid price stabilisation and risk management.

iv. Agricultural Value System (AVS) as an integration of the supply chain and to drive market led value system – District level, State level and National Level Value-System Platforms to promote individual value chains to integrate into a sector-wide supply chain.

v. Farmer-centric National Agricultural Marketing System by restructuring for a new market architecture, consisting of Primary Retail Agriculture Markets (PRAMs/GrAMs numbering 22,000) and Primary Wholesale Agricultural Markets (APMCs/APLMs-other markets numbering around 10,000), as also secondary & tertiary agricultural markets, all of which are networked by online platforms to facilitate a pan-India market access; as also integrating the domestic market with export market by considering the latter as a targeted market activity and not just an add-on.

vi. Promoting Sustainable Agriculture – Climate Resilient Agriculture, Rainfed Agriculture, Conservation Agriculture, Ecology Farming, Watershed Management System, Integrated Farming System, Organic Farming, Agro-Climatic Regional Planning, Agricultural Resources Management and Micro-Level Planning, etc.

   While the above alternate systems are to be adopted & scaled up, the modern agro-chemical based cultivation practices shall be promoted based on the principle of evidence based, minimal/ integrated and efficiency targeting resource use (e.g. Soil Health Card recommendations as the basis for soil nutrient management). It is essential that sustainable agriculture is not limited to certain geographies alone, but reaches larger cultivation practices and incorporates evidence based and good agricultural practices.

vii. Effective Input Management achieving Resource-Use-Efficiency (RUE) and Total Factor Productivity (TFP) – Water, soil, fertilisers, seeds, labour-farm mechanisation, credit and precision farming, so as to reduce farm losses, while ensuring sustainable and eco-friendly practices.

viii. Enhancing Production through Productivity– to achieve & sustain higher production out of less and release land and water resources to diversify into higher value farming for enhanced income.

ix. Farm Linked Activities to include secondary agriculture that utilises local manpower and biological resource in the vicinity of farms. These can also comprise manufacturing and services activities of KVIC (Khadi and Village Industries Commission) and Micro, Small and Medium Enterprises (MSME) scale, for promoting near-farm and off-farm income generating opportunities as well as to facilitate more of the farm produce to capture more of the market value.

x. Agricultural Risk Assessment and Management including drought management, demand & price forecast, weather forecast, management of biotic stress including vertebrate pests, access to credit among farmers for farming operations; providing long term credit, post-production finance to preventing distress sale by farmers, and crop & animal risk management through insurance.

xi. Empowering Farmers through Agricultural Extension, Knowledge Diffusion and Skill Development.

xii. Research & Development and ICT designed to support the Doubling of Farmers' Income strategy in the short run, and help accelerate the pace of income enhancement on a sustainable basis in the long run.

xiii. Structural and Governance Reforms in Agriculture, including building a database of farmers, facilitating farmer & produce mobilisation, institutional mechanism at district, state & national levels for coordination & convergence, digital monitoring dashboard at district, state & national level for seamless & real-time monitoring of field delivery, utilising Panchayat Raj Institutions, and farm income measurement as key delivery channels for transparent and inclusive development. It also calls for paying special attention to non-timber forest produce (NTFP) to support tribal farming communities to capture higher value and non-farm incomes therefrom.

Sustaining Income Growth

Five Pillars The recommendations that emanate from the preceding 13 different volumes, under different themes, strive to align with one or more of the five pillars, that the DFI Committee identifies, as essential to doubling farmers' income, and sustaining a steady income growth in the long run. These include:

i. Increasing productivity as a route to higher production.
ii. Reduced cost of production / cultivation.
iii. Optimal monetisation of the produce.
iv. Sustainable production technology.
v. Risk negotiation all along the agricultural value chain.

Layout of the Recommendations

The individual volumes of the Report of the Committee on Doubling of Farmers' Income, communicate about a specific subject, to first prepare the context and deliberate on the logic, before leading to the concluding recommendations for the selected subject.

The recommendations put forth in the first thirteen volumes, are both specific and generic, and will be germane to policy makers, implementing agencies, farmers and farmers' bodies, farmer-centric opinion makers, NGOs, public and private sector entrepreneurs and investors, subject matter experts and students, as also international bodies interested in Indian agriculture.

It is not possible to capture all the recommendations and lay them in relevant flow and framework, without adding to the bulk and being repetitive. There is also a fear of them being taken out of context and therefore out of step with the logic adopted in each of the volumes. Hence, in compiling the comprehensive recommendations in the final Volume XIV, certain thematic lines have been adopted, yet the readers would benefit more from referring the recommendations to the respective chapters and volumes as per their requirement.

In the last volume, the recommendations have been assigned a period, short term and/or long term. These indicate the opinion of the Committee on the time period required for initiation of action and when its outcome would be realised. Short term indicates a period of maximum of 3 years and long term refers to a period beyond that. While short term activities should be initiated at the earliest, the long term initiatives may take some more time, but should preferably be rolled out as early as feasible so that rise in farmers' income can be sustained even beyond 2022-23.

As regards the responsibilities for the initiatives, the name of the department(s) and/or ministry (ies) has/have been indicated at a generic level, to allow them to decide on the specific division/ organisation to own it up. The Committee is also conscious that there could be several other department(s) and/or ministry (ies) or even organisations in Public /Private / NGO sectors who may also find it useful to act upon the recommendations in their own way. This will bring in greater synergy and spread at the field level.

Conclusion

Committee has recommended to set up an Empowered Body, headed by an officer of appropriate seniority, to monitor the new set of activities, as they are operationalised. This Empowered Body or Authority, can also be mandated to develop guidelines, based on an implementation framework, and provide the needed support system to the principle stakeholders, namely DAC&FW, DAHDF, DARE, other Departments and Ministries.

The DFI Committee was advised to make recommendation in parallel to developing a comprehensive report. In response the Committee not only made several recommendations but also supported rolling out several of them. Over the last three years, various important recommendations that have been adopted and rolled out by the government and are also incorporated in the Union Budget from 2017-18 onwards. A full list of these is in Chapter 12 of Vol-XIV.

The underlying theme of the DFI Report is to promote agriculture as an enterprise and farmer as an entrepreneur necessitating adoption of business principles for positive net returns. Further, agriculture sector as a profession will become wholesome, when transition happens from, food security to nutrition security for the consumers, extractive production system to sustainable production system for the ecology, and from a mere Green Revolution to move towards a Farmers' Income Revolution or Income Revolution for the farmers.

Adoption of Agroforestry Practices- Policy Initiatives and Innovations in India

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Abstract
In India, agroforestry is recognized as an important part of the 'evergreen revolution' movement and has been identified as one of the resilient systems at the national level. For implementation of National Agroforestry Policy, Government of India, state governments and other organizations have initiated a number of schemes where agroforestry is recognized as a component and being promoted as such.

Key words: *Intergovernmental Panel on Climate Change (IPCC), UN Convention to Combat Desertification (UNCCD); UN Framework Convention on Climate Change (UNFCCC)*

Agroforestry, evergreen agriculture, and smallholder production systems have attracted considerable attention and tree-based production systems are being promoted, the world-over. The potential of agroforestry to contribute to sustainable development has been recognized in many international policy declarations also. For example, the United Nations Framework Convention on Climate Change (UNFCCC) and the Intergovernmental Panel on Climate Change (IPCC) acknowledged it as a component of climate-smart agriculture and is frequently mentioned as having a strong potential for climate change adaptation and mitigation. The United Nations Convention to Combat Desertification (UNCCD) acknowledges agroforestry's potential to control desertification and rehabilitation. It is also seen as an important element in the ecosystem approach promoted by the Convention on Biological Diversity (CBD) for agrobiodiversity conservation.

In India agroforestry has been identified as one of the resilient systems at the national level as

- Trees have greater tolerance to abrupt climatic abrasions for longer duration,
- They serve multiple purposes, and
- Also provide insulation to companion crops through shade, moisture conservation, nutrient recycling, etc.

National Agroforestry Policy

Agroforestry has been receiving greater attention by researchers, policy-makers and others for its perceived ability to contribute significantly to economic growth, poverty alleviation and environmental quality. Agroforestry is now recognized as an important part of the 'evergreen revolution' movement in the country. India on 10th February 2014 launched National Agroforestry Policy (NAP- 2014) (http://agricoop.gov.in/sites/default/files/National_agroforestry_policy_2014.pdf) and became the first country in the world to have a National Agroforestry Policy (http://ccafs.cgiar.org/publications/ indias-new-national-agroforestry-policy). The policy is not only seen as crucial to India's ambitious goal of achieving 33 per cent tree cover but also to mitigate GHG emissions from agriculture sector.

The major theme of the NAP 2014 was to integrate the practice of planting trees, crops and on the agriculture land, to achieve sustainability in agriculture while optimizing its productivity and mitigating climate change impact.

NAP 2014 includes

- National level coordination, convergence, synergy and facilitation mechanism - establishment of an Agroforestry Mission/Board
- Amendments and simplification of unfavorable legislations/ regulations, especially related to harvesting/ felling, and transportation of agroforestry produce
- Creating standards for production and certification of planting material
- Securing land tenure and sound database of land records - developing an MIS for agroforestry
- Mainstreaming agroforestry in agricultural policies and strategies
- Investments in research, extension and capacity building

NAP provides

- Improvement in famers' access to required inputs and services, such as extension and technology packages for different farming systems
- Facilitation of institutional credit and insurance cover
- Encouraging participation of industries in agroforestry.
- Encouraging the industry by deregulation / single point clearance and lifting bans
- Strengthening farmers' access to markets
- Offering incentives to farmers for adopting agroforestry
- Promoting sustainable agroforestry for renewable energy, carbon sequestration and environmental services

Implementation of National Agroforestry Policy

There are a number of schemes of Government of India, state governments and other organizations where agroforestry is recognized as a component and being promoted as such. Some of the schemes and programs in which agroforestry is a component are:

- Integrated Watershed Management Programme (IWMP)-now part of *Pradhan Mantri Krishi Sinchai Yojana* (PMKSY),
- Mahatma Gandhi NREGA (MoRD),
- Green India Mission (http://moef.nic.in)
- National Horticulture Mission,
- National Bamboo Mission and
- National Mission on Medicinal Plants (DAC, MoA) to name a few.
- Green Highways (Plantation & Maintenance) Policy under National Green Highway Mission (NGHM) 2015 to develop 140,000 km long "tree-line" along both sides of national highways
- Innovative Actions by State Govt. (Harit Haran Yojana in Telangana, Shambhar Koti Lagwad Yojana in Maharashtra, Mission 22 Crore Tree plantation by UP)
- Plantation under Namami Gange
- Plantation through Corporate Social Responsibility (CSR)

Post 2020 Climate Action Plan

India intends to reduce the emissions intensity of its GDP by 33 to 35 % by 2030 from 2005 level and to create an additional carbon sink of 2.5 to 3 billion tonnes of CO_2 equivalent through additional forest and tree cover by 2030. Agroforestry is playing a crucial role in meeting the INDC targets.

Relaxation in regulatory regime
Earlier felling, transit and processing of trees grown on farms required approvals and permits from government agencies, and this was a significant impediment to establishing agroforestry systems.

To promote agroforestry, 20 multipurpose tree species (MPTS) which are commonly grown by the farmers were prioritized (ICAR 2013). On 18th November, 2014, Ministry of Environment, Forest & Climate Change (MoEFCC) issued fresh guidelines to all State/UT governments for simplification of felling and transit regulation of tree species grown on non-forest/private lands. So far 27 states have de-notified a number of tree species from felling and transit regulations, which will make it much easier for landowners and farmers to practice agroforestry.

A Sub-Mission on Agroforestry under the National Mission for Sustainable Agriculture (DAC&FW, Ministry of Agriculture, Govt. of India) being implemented to assist all the states to scale up agroforestry in a targeted manner.

Agroforestry contribution
India is heading in the right direction to achieve its pledge of restoring 13 million hectares of degraded land by 2020 under the Bonn Challenge, with an additional 8 million hectares by 2030.

Between 2011 and 2017, India restored approximately 9.8 million hectares of degraded land, with nearly 95% of the restoration activities reported being led by government agencies.

Agroforestry is one of the major contributing plantation approaches in the restoration efforts by government, NGOs and private sector in India. The India State of Forest Report (ISFR-2017) (Forest Survey of India (FSI), Ministry of Environment Forest & Climate Change, Government of India) reported 8,021 sq. km (0.94%) increase in the forest and tree cover of the country as compared to assessment of 2015, of which 15.5% is reported from tree cover that includes Trees Outside Forest (TOF) (ISFRI, 2017).

Indian government recently amended the Indian Forest Act, 1927, exempting bamboo grown in non-forest areas from felling or transit permit facilitating bamboo as agroforestry component in small landholders reach.

Agroforestry

- It is being practiced throughout the country in different forms-
    - ✓ Punjab, Haryana, Western UP--- Timber based systems
    - ✓ Karnataka, West Bengal, UP--- Fruit Based
    - ✓ Kerala, Tamil Nadu--- Spice based
    - ✓ Northeast--- Tea, Rubber
    - ✓ Rajasthan--- Fodder based
    - ✓ Other states- various forms
- Estimated agroforestry extent is about 25 million ha in the country
- It helps in meeting country's 65% of timber requirement worth $ 28-30 billion (approx.)/ year
- Rs 2000 crore annually are being invested on agroforestry through various schemes and programs.

Role of Forest Policies in Promotion of Forest & Tree Cover in India

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Agroforestry & its importance

- Agroforestry has been considered as the major option for promotion of trees in the country by undertaking tree cropping along with agriculture and also in other culturable areas.
- Agroforestry helps to improve the income form agricultural fields while providing valuable raw materials for the wood based industries.
- Promotion of agroforestry helps to save valuable foreign exchange due to import substitution.
- Agroforestry helps to increase the CO_2 sequestration and help to achieve the NDC targets of the country as committed in the Paris Agreement.
- It helps to increase the productivity of agricultural lands when suitable tree species are grown along with the crops.

Policy framework for supporting Agroforestry

- National Commission on Agriculture in 1976 advocated for social forestry with farm forestry as a major component.
- National Forest Policy 1988: advocated enrichment of forest areas, afforestation and tree planting on all degraded and denuded lands outside forest areas through Social & Farm Forestry.
- NFP 1988 has laid the foundation for taking up Agro Forestry as a major activity for increasing Forests & Tree Cover in the country.
- Subsequently, Agroforestry Policy 2014 of Mininstry of Agriculture & Farmers Welfare laid the foundation for systematic promotion of Agro Forestry in the country. The major theme of the Agroforestry policy 2014 is to integrate the practice of planting trees, crops and on the agriculture land, to achieve sustainability in agriculture while optimizing its productivity and mitigating climate change impact.
- National Environmental Policy, 2006: seeks to extend the coverage, and fill in gaps that still exist in environment management and is intended to mainstream environmental concerns in all development activities.
- National Policy for Farmers 2007: For a holistic approach to development of the farm sector by focusing on the economic well being of the farmers in addition to production and productivity.
- Green Highways (Plantation, Transportation, Beautification and maintenance) Policy 2015- a Policy to promote greening of highway corridors with the participation of communities, farmers, private sectors, NGOs and Govt. Institutions.
- National Biofuel Policy : Promotes cultivation of tree oil seeds
- The UNFCCC Paris Agreement 2015: sequestration of an additional 2.5 to 3 billion tonnes of Co2 by 2030.

Major Schemes and Programmes of MOEF&CC and other central ministries for promotion of trees

- National Afforestation Programme
- Green India Mission
- Intensification of Forest Management
- CAMPA
- National Adaptation Fund on Climate Change
- MGNREGA (Min. of RD)
- National Bamboo Mission(MoA)
- Mission on Agroforestry(MoA)
- Integrated Development of Horticulture (MoA)
- National Green High Ways Mission (M/o RT&H)

Legal & Regulatory framework initiatives for promotion of Agro forestry in India

- IFA 1927 empowers State Governments for regulating collection and transport of forest produce:
- The recent advisories to States resulted in relaxation/ removal of felling and transit of trees in 27 States & UT's. This is going to have major boost to cultivation of trees in farm lands
- Amendment of IFA 1927 in 2018 by removing bamboo grown in private areas from the category of trees removed the restriction on felling & transport of bamboos. This will promote cultivation of bamboo in the country.
- Proposed Commissioning of a Pan India Transit Portal for facilitating the transport of timber & other forest produce will help farmers and others who promote Agro forestry in the country.
- The various policy & regulatory facilitation along with various central & State sector schemes will pave way for the rapid growth of Agroforestry in India.
- The new thrust on promotion of trees outside forests will certainly boost Agroforestry in the country.
- It is estimated that the area under Agroforestry will double from the present 25 Million Ha by 2050 due to various interventions and also due to shift to tree farming by farmers and others

Reference:

Infromation can be accessed through the below links at the website of the Ministry of Environment, Forest and Climate Change (MoEFCC)

- http://moef.gov.in/
- http://164.100.154.103/
- National Forest Policy: http://moef.gov.in/wp-content/uploads/2017/07/introduction-nfp.pdf
- National Environmental Policy: http://moef.gov.in/wp-content/uploads/2017/07/introduction-nep2006e.pdf
- Green India Mission: http://moef.gov.in/division/forest-divisions-2/green-india-mission-gim/about-the-mission/

Quality Planting Material: Need for Guidelines and Accreditation

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Abstract
Trees are an integral part of agricultural landscapes and are playing increasingly important roles in income provision for rural households. Our farmers still prefer to purchase planting material rather than producing their own. Often the nurseries operate with minimal inputs and outdated techniques, and produce poor seedlings. Disappointment about slow development or even seedling death is common, and many farmers loose interest in tree planting out of frustration over bad planting material. If the tree nurseries fail to produce high quality seedlings, deforestation and loss of valuable genetic resources will continue and will devastate our landscapes. Easy access to, and unhindered availability of, Quality Planting Material (QPM) of agroforestry species is the need of the hour, especially in focus of the government's various missions on greening through plantations, agroforestry, horticulture, and road side plantations. To ensure production and supply of quality planting material of tree species, a nationally accepted guidelines for both production and accreditation of nursery is urgently needed.

Keywords: Nursery certification, accreditation, tree planting material, guidelines

Introduction

The diverse agro-climatic conditions prevailing in different parts of the country offer an enormous scope for cultivation of a wide variety of trees for timber, fruits, pulp, firewood, fibre, medicines, and multipurpose trees (MPT). One of the most imperative factors contributing towards production and productivity is timely access to quality seed and planting material. Inadequacy of quality planting material is the major bottle-neck in production. There is immense scope to acquire self-sufficiency in planting material production, but lack of awareness and technical know-how hampers this objective. Our farmers still prefer to purchase planting material rather than producing their own. Development of nursery system / network not only ensures high quality planting material for the farmers, it can be a valuable to fight poverty and starvation because it can be a source of income to small farmers.

Often the nurseries operate with minimal inputs and outdated techniques, and produce poor seedlings. Disappointment about slow development or even seedling death is common, and many farmers loose interest in tree planting out of frustration over bad planting material. If the tree nurseries fail to produce high quality seedlings, deforestation and loss of valuable genetic resources will continue and will devastate our landscapes.

Availability of quality planting material is a prerequisite to the success of various schemes under different missions of the Government for plantations, agroforestry, horticulture and agriculture. Inadequate availability of quality planting material is one of the important deterring factors in such efforts of sustainable development. It is of special significance especially in perennial crop, like fruit trees, timber trees, etc. which has a long gestation period and effects are known only in later stages. Supply of huge quantity of disease free, true to type quality planting material is a big challenge and needs to be addressed at the right time. Conventional propagation method which includes sowing of seeds, propagation by cutting, layering etc. suffers from the inherent limitations in the number that can be produced, non-uniformity of quality and incidence of diseases. Hence, there is an urgent need for guidelines for the nursery for production of high quality planting material and accreditation of these nurseries for validation of the material thus produced.

In the private sector, especially companies doing large scale plantation for pulp and timber, plant Tissue Culture has emerged as an important biotechnology and commercially viable tool to multiply elite varieties of high quality, disease free and high yielding plants rapidly in the laboratory irrespective of the season of the year. The tissue culture industry in India is growing at a rate of 15% per annum. Government of India, in 2016, established the NCS-TCP and authorized the DBT as the Certification Agency under the Seeds Act, 1966 with the objective of mentoring the tissue culture companies for production and distribution of disease-free and quality tissue culture plants (https://pib.gov.in/newsite/PrintRelease.aspx?relid=146683).

For availability of quality planting material (QPM) two aspects are essential for recognition of the nurseries:

a) Guidelines for production of quality planting material of one or more specified crops by adopting Good Nursery Management Practices,
b) Accreditation of the nursery premise only where sale of specified quality planting material of recognized source are being carried out by creating necessary infrastructure facilities and proper record keeping.

The estimated annual requirement of some of the most popular tree propagules, such as eucalypts, poplars, and other Multi-Purpose Tree Species for agroforestry is about 10 million each while the requirement of casuarinas is about 8 million. The country is presently planting annually an estimated 1.5 million ha in forest and in private land using about 3 billion plants. In addition, the requirement for a range of fruit and timber species is enormous, and the demand of QPM for all these species is expected to continue to increase due to factors discussed above. Therefore, a decentralized nursery network operating according to a nationally recognized set of guidelines to produce QPM is the need of the day.

There are about 6000 small and large plant nurseries in India, of which 70% are privately owned and 30% government owned. There is a need to regulate these nurseries to enable them to produce quality planting material, based on scientific knowledge and principles.

Nursery

A nursery is a managed site, designed to produce seedlings grown under favourable conditions until they are ready for planting. The National Horticulture Board in its Guidelines for Recognition of Horticulture Nursery, has estimated that in 2008 the country had just over 100 big nurseries. There were a number of Government nurseries also in different states, especially in those states that had implemented the Seeds Act and the Nursery Registration Act of 1996, namely, State of Punjab, Maharashtra, Himachal Pradesh, Uttar Pradesh, Uttrakhand, Jammu and Kashmir, Orissa and Tamil Nadu. Planting material is also being produced by ICAR institutes and State Agriculture Universities (SAUs).

Only 30-40% demand of planting material is being met by the existing infrastructure. Private nurseries operating in the country play an important role in multiplication of planting material of horticulture and agroforestry crops, however, many of them follow traditional / conventional methods and lack adequate infrastructure and sell plant material of unknown pedigree. Of many other constraints, un-availability of standardized root stocks and non- maintenance of healthy stocks of elite varieties are worth mentioning.

A good Nursery has three important aspects to look into:

a) The Nursery Infrastructure;
b) Production System and Quality Parameter of Planting Material adopted; and
c) Adoption of Good Nursery Management Practices.

The "Handbook of Seed and Planting Material Testing Manual for Horticultural Crops" published by ICAR, provides technical specification for planting material in spices and its production procedure. With these three aspects put together, a Model Nursery can be defined in terms of Nursery Infrastructure, Production System and Quality Parameter of Planting Material and Good Nursery Management Practices in a Comprehensive Manner.

Criteria for selection of Nursery site

As defined in the Guidelines for Establishment of Cashew/Cocoa Nurseries under MIDH, the model nursery site should have the following features:

- Nursery site should be easily accessible.
- Soil should be well drained preferably sandy loam.
- Availability of adequate labour force from the vicinity of the nursery
- Availability of good quality water
- Availability of good quality top soil preferably of alluvial type.
- Protection from cattle and wild animals.

Guidelines for Production of Quality Planting Material

General Quality Standards for Nursery Plants (as adopted from Ratha Krishnan, et al., 2014)

- The shoot and root development of nursery plant should be in proper ratio. The nursery plants should be free from weeds
- Color of leaf, morphology of leaf should be in proper standard in accordance to variety and species
- The nursery plant should be free from disease and pest and have a vigorous growth
- The graft union should be healthy and the size of scion and rootstock should be equal
- After shifting and transporting, seedling should not show symptoms like leaf drying, yellowing, stress, etc.

Quality Propagules Production and Good Seed Collection Practices are detailed in the book, Plant Nursery Management: Principles and Practices published by the Central Arid Zone Research Institute, ICAR Institute, Jodhpur, Rajasthan. Figure 1 depicts some of the good nursery practices to be followed and wrong practices to be avoided in nursery.

The time of sowing/initiation of propagules production depends on how long the seedlings will take to reach an optimum size characteristic for the species and site and purpose of planting. In India plant size appropriate for plating should be ready at the time of initiation of monsoon (July for South-West monsoon and October for North-East monsoon areas). Generally, it is assumed that the area of nursery should be about 1 acre for every 30,000 plants to be produced with an assured daily supply of about 200 litres water per 1000 seedlings.

Refer, Guidelines to Produce Quality Planting Material of Agroforestry Species for the quality standards for nurseries and plants produced, especially multipurpose trees

Accreditation of the Nursery Premises

The main objective of accreditation is to ensure the production and distribution of quality plant materials of recommended crop varieties / species that are true to type and free from pests and diseases. Large scale production of quality planting material can only be achieved through a regulated network of nurseries set up for production of certified planting material.

The nurseries must be under the monitoring of a National Accreditation Authority approved by the Ministry of Agriculture& Farmers Welfare, Government of India. The nurseries should undergo an accreditation process involving application to the Authority for approval based on certain essential and desirable criteria and granting of Accreditation for a year based on inspection by the commodity specific Directorate. Recognition to nurseries should be based on their infrastructure, production system & quality parameters of planting material and management practices adopted.

Advantages of Accredited Nurseries

- Entitled for identified scion/plant propagules from the government recognised / approved scion groves.
- Access to technical assistance and supervision.
- Create network in selling their produce.
- Access to government program in terms of marketing.

Once a nursery is registered, recognized, or accredited, it should be empowered to produce high quality planting material following a protocols described in guidelines produced for different crops and trees species, as listed in eth reference material. As part of a standard operating procedure, nurseries should be required to provide a guarantee of purity, and a phytosanitary certificate for the material produced and sold.

Certification of Quality Planting Material

Criteria to be considered while issuing certification of QPM are:

1. Identification of source of planting material: Correct identification of tree species should be done by an acknowledged expert in tree taxonomy. Modern and advance technologies, such as DNA barcoding for precise identification may be used to confirm the species identity.
2. Mass production of planting material: Correctly identified seeds and genetically superior clones of a tree species obtained with the necessary certificates of origin, preferably from seed and clonal orchards established by State Forest Departments, research institutes, and agricultural universities.
3. Maintaining traceability: Documentation of the chain-of-custody of seed and or vegetative material used for producing planting stock will be maintained by the accredited nursery at all stages from the certified mother trees through any of the mass propagation systems to the point of sale from where the farmers procure the planting stock

Way Forward

Trees are the core of agroforestry, horticulture and agriculture for increasing the income of farmers, making system climate resilient and sustainable. Guaranteed performance in terms of higher yield and quality of crops could be achieved only with reliable high quality planting material and good management practices. To meet the increasing demand for agroforestry species, there is a need that the nurseries produce large quantity of quality of planting material in terms of genetic makeup, varietal purity, robustness, and being free from diseases and pests. The guidelines for the nursery management and accreditation network system is a robust way to ensure availability of quality material to the farmers. It not only increases the confidence of farmers in plantations, it also help in increasing their income through establishment of nursery and sale of plants.

Such guidelines and accreditation system for QPM becomes more important in light of the NDC commitments, Bonn Challenge and SDG goals that the countries have to achieve within the designated time. QPM availability will ensure faster achievements of these inter-related gaols and commitments.

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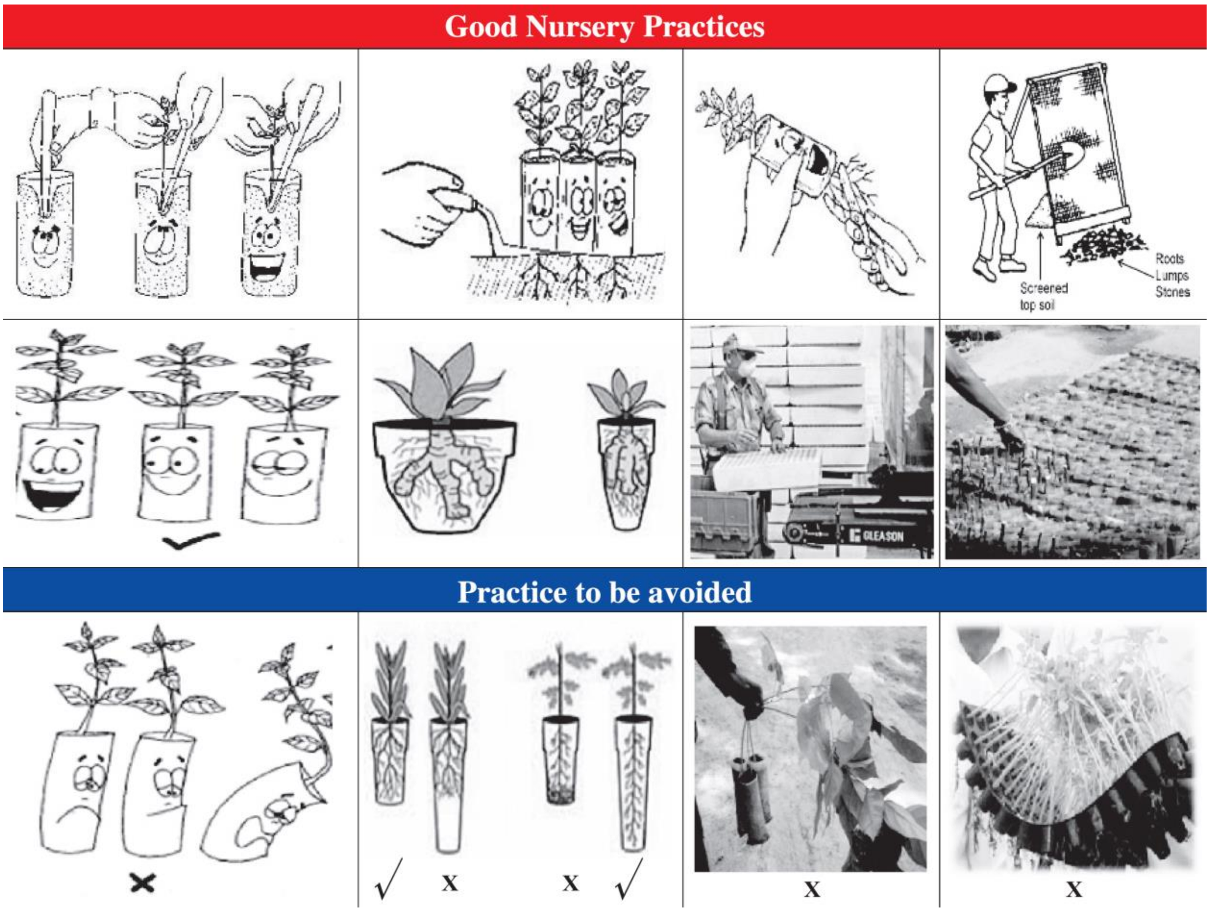

Figure 1: Good nursery practices to be followed and wrong practices to be avoided

Source: Ratha Krishnan, et al 2014.

Emerging Aspects in Agroforestry in the Asian-African Region

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Abstract
Agriculture world over is facing diverse challenges and constraints due to growing demographic pressure, increasing food, feed, pulp, fodder and timber needs, natural resource degradation and climate change. Diversification of land use with agroforestry as a component can address some of these challenges. In fact agroforestry, forest conservation, restoration of ecosystems and their services, and improved, sustainable land management are central efforts under the Paris Agreement (2015) to address climate change. The paper discusses the emerging aspects in agroforestry in the Asia and Africa region.

Key words: adaptation, agroforestry system, carbon sequestration, national agroforestry policy

Introduction

Agriculture with tree farming, enhances livelihood and supports food and nutritional security through (1) the direct provision of tree foods such as fruits and leafy vegetables and by supporting staple crop production; (2) by raising farmers' incomes through the sale of wood, timber, and other tree products and surplus staples; (3) by providing fuelwood for cooking; (4) by providing green fodder to the livestock, especially during natural calamity; and (5) by supporting various ecosystem services such as pollination that are essential for the production of some food plants.

While challenges for such a system in supporting food and nutritional security include policy and market constraints and underinvestment in research, strong opportunities exist to promote multifunctional, climate-smart agricultural methods involving trees. To better support food and nutritional security, reforms in existing relevant policies, and/or development of new agroforestry policy are urgently required to reform tree and land tenure for the benefit of small-scale farmers in Asia and African countries. Policy reforms are also needed to ensure quality supply of agroforestry inputs (tree seed and seedlings), credit and insurance, recognizing agroforestry products as agriculture products, and removing currently imposed restrictions on felling and transporting wood and timber. Therefore, investments are needed at policy & advocacy, research and development, and out scaling of proven agroforestry systems according to respective agro-climates and needs of local communities.

There is evidence from around the world that combinations of locally adapted and appropriately chosen cereals and legumes with high-value cash crops (e.g. spices, medicinal, nutraceutical, fruits) increase production of nutritive balanced food for humans, fodder and feed for small and large livestock, and timber, and biomass for cooking and energy purposes.

The woody species not only provide the climate resilient backbone of the system, but they also offer high-value products and ecosystem services that can be stored – alive or dead – and therefore, offer greater economic resilience through a 'piggy-bank' savings function for capital investments. Additionally, they offer a last-resort safety net in case the crops fail.

National Agroforestry Policies: Country specific/Regional Opportunities

ICRAF experience with policy advocacy and development indicate trans-formational change requires: Massive Adoption which,

- Requires identification and removal of bottlenecks at national level
- Needs an effective instrument/tool to deal at national/sub-national level
- Necessitates insulation from existing rules/laws/guidelines/ restrictions

Massive, incremental & transformational impact needs policy interventions: Recommendations-

- Nationwide mainstreaming of agroforestry
- De-notify tree species from felling, transit and processing regulations
- Incorporate tree plantation in government supported programs
- Identify and demarcate clusters (area) to be free from above regulations
- Link producers with industry and development of value chain
- Endorse and facilitate CSR investment in agroforestry
- Guide production, certification and supply of high quality planting material
- Facilitate lifting / relaxing the legal ban on saw mills in non-forest areas
- Promote research and development in agroforestry
- Promote public private partnership/ investments
- Correct tree and land tenure

Impact of policy in India: a case study

Extent of Contribution to National Economy & Climate Resilience

One of the most important successes of agroforestry in India, is the fact that the country through agroforestry fulfils,

- 64 % of country's timber requirement from trees on-farm
- Generates about $ 25 billion/ year, significant share of smallholders
- Co-benefits through timber and allied businesses, carbon sequestration and ecosystem services
- Meeting the international commitment on climate change by creating additional sink

Agroforestry and INDC Fulfill international commitments:

India intends to reduce the emissions intensity of its GDP by 33 to 35 % by 2030 from 2005 level and to create an additional carbon sink of 2.5 to 3 billion tonnes of CO_2 equivalent through additional forest and tree cover by 2030. Agroforestry is playing a crucial role in meeting the INDC targets.

On the basis of research conducted so far, agroforestry practices applicable to different suitable sites for sequestering atmospheric carbon in wood biomass as well as soils can be selected as below;

a) For Expanding Carbon Sinks

i. Agri-silviculture or agri-horticulture systems for food and wood/fruit production
ii. Boundary and contour planting for wind and soil protection
iii. Silvi-pasture system for fodder production as well as soil and water conservation
iv. Complex agroforestry systems, viz. multistrata tree gardens, home gardens, agri-silvi-horticulture and horti-silvi-pasture systems for food, fruits and fodder especially in hill and mountain regions
v. Non-timber tree farms for rubber, tannins, medicines, bamboo, rattan, etc.

vi. Bio fuel plantations
vii. Taungya system which is applied in tandem with forest management
viii. Hedgerow intercropping
ix. Improved fallows

b) Biofuel Substitution
i. The use of sustainably grown biomass for fuels will delay the release of carbon from fossil fuel for as long as fossil fuel remains unused.
ii. Wood derived from renewable agroforest if used as substitute for wood obtained from natural forests will also delay carbon release.

What is to be done?

- Suitability mapping for agroforestry using Geo-informatics
- Need assessment for various rural communities
- Sub-national planning and awareness
- Capacity building of all stakeholders at Federal, Provincial, District and Local Government level(Municipalities)
- Pilot demonstrations on various agroforestry systems (food, nutrition, fodder, fuel, timber and pulp, medicinal, agrivoltaic)
- Nursery establishment and guidelines to produce/ certify QPM
- Value chain and market linkage

Way Forward

Tremendous success of India's agroforestry policy in increasing awareness about the benefit and potential of agroforestry; removal of legal hurdles in planting, felling and transporting agroforestry products (mainly timber and wood); and in channelizing huge resources to mainstream agroforestry in the national agenda has exhibited ripple effect in the South Asia region and beyond. ICRAF recently worked with the Governments of Bangladesh and Nepal (http://kathmandupost.ekantipur.com/news/2017-11-05/nepal-gearing-up-to-draft-agroforestry-policy.html), and with some South East Asian countries (ASEAN AF Strategy, http://www.worldagroforestry.org/region/sea/publications/detail?pubID=4392) to develop their respective agroforestry policies/ strategies/guidelines. Nepal, working with ICRAF became the second country globally to launch its own national agroforestry policy on 3rd July, 2019. On close of this, Maldives, Bhutan and Sri Lanka have taken initiatives to develop national agroforestry policies of their own. African- Asian Rural Development Organization (AARDO) with thirty-three members including two associate members in Africa and Asia and ICRAF are working together on agroforestry policies/systems in various AARDO member countries.

Conclusion

The poverty is very significant in South Asia, South-east Asia and Africa and it is more pronounced in rural area, where majority of the people/farmers live. They have weak socioeconomic condition and largely depending on agriculture practices for their livelihood is now a day threatened due to the impact of climate change. Adopting agroforestry by the farmers is a sensible solution for achieving sustainability by optimizing the farmland diversification for meeting the demand of food, nutrition, energy, employment. This can be achieved by focusing on following areas,

- Utilization of abandoned agriculture land for agroforestry

- Agroforestry targeting increasing livelihood, reducing poverty, create local employment, increase income for women and youth and reduced migration,
- Agroforestry for women empowerment, changing role of women from ‘employee” to “employers”, reduced drudgery for women and children,
- Agroforestry for promotion of small businesses, value chains, and sustainable development
- Ecosystem services, increased green cover, climate resilience, improved quality of life

To realize the full potential and benefits of agroforestry, there is an urgent need and demand to sensitize the policy makers, and strengthen their capacities for mainstreaming agroforestry in their country’s development agenda.

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AF 2 -- Agroforestry practice for livelihood, nutritional and environmental security, and impact

Climate Change Impact and Adaptation Strategies- A National Initiative

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Introduction

The Intergovernmental Panel on Climate Change (IPCC) in its Fifth Assessment Report (AR5) stated that warming of the climate system is unequivocal and is more pronounced since 1950s. The atmosphere and oceans have warmed, the amounts of snow and ice have diminished and sea level has risen. Each of the last three decades has been successively warmer at the Earth's surface than any preceding decade since 1850 and the globally averaged combined land and ocean surface temperature data as calculated by a linear trend show a warming of 0.85°C over the period 1880 to 2012 (IPCC. 2013).

Agriculture sector in India is highly vulnerable to climate change. Higher temperatures tend to reduce yields of many crops; and are favorable to weed and pest proliferation. Climate change will have negative effects on irrigated crop yields across regions both due to temperature rise and changes in water availability, while rainfed agriculture will be primarily impacted due to rainfall variability and reduction in number of rainy days. In India, the impact of climate change on agriculture is expected to affect yields, particularly in crops like rice, wheat and maize. Yield decline are likely to be caused by shortening of growing period, negative impacts on reproduction, grain filling, decrease in water availability and poor vernalization. Biodiversity is also adversely affected which in turn affects agricultural production, particularly marginal and small farmers in India.

Low organic carbon, low biological activity and high level soil degradation are common features of dryland regions. Wide spread deficiencies of macro and micro nutrients occur due to loss of nutrients through surface soil erosion and inadequate nutrient application. The high inter and intra-seasonal variability in rainfall distribution, extreme temperature and rainfall events are causing crop damages and huge losses to farmers. Long term data for India indicates that rainfed areas witness 3-4 drought years in every 10-year period. Of these, 2-3 are of moderate and one may be of severe intensity. Each year, one or the other part in the country is affected by droughts, floods, cyclones, hailstorms, frost and other climatic events.

National Initiatives on Climate Change

In India, several initiatives were launched in the domain of climate change research. ICAR in 2004 launched Network Project on Climate Change (NPCC) with the objectives of quantifying the sensitivities of food production systems to different scenarios of climate change by integrating the response of different sectors, adaptation and mitigation strategies in agro-ecosystems and to provide policy support for international negotiations on global climate changes. Some of the key impact assessments include: loss estimate of 4-5 m t of wheat production with every 1°C temperature which could be substantially reduced (up to 50%) by adopting changes in planting dates and crop varieties. Warming induced shifts in geographical range of crops like apple from lower to higher elevations in Himachal Pradesh and expansion of geographical range of oil sardine fish species to northern latitudes and east coast were observed. Annual loss in milk production based on ambient Temperature-Humidity Index (THI) at the all India level was estimated at 1.8 m t by 2020 with maximum impact in Uttar Pradesh, Tamil Nadu, Rajasthan and West Bengal. Increased emphasis on soil conservation efforts is warranted in peninsular and central India because of projected high runoff and soil losses due to changes in rainfall. Inventories of enteric methane emissions from livestock and greenhouse gas emissions from crop production systems (rice and wheat) were quantified and suitable mitigation practices were identified. In terms of maximum carbon sequestration potential, agroforestry systems were most suitable in sub tropical climates while agri-horticulture systems were most suitable in temperate climates (Naresh Kumar *et al*., 2012).

Recognizing the need for a policy document on climate change, the Prime Minister's Council on Climate change recommended the preparation of a national document compiling action taken by India for addressing the challenge of climate change and the action it proposes to take. The National Action Plan on Climate Change (NAPCC) was subsequently formulated in 2010 consisting of 8 National Missions to represent multi-pronged, long term and integrated strategies for achieving key goals in the context of climate change. The National Mission for Sustainable Agriculture (NMSA), one of the eight missions, aims at devising strategies to make Indian agriculture more resilient to climate change. Besides, the National Water Mission, Green India Mission and National Mission for Sustaining Himalayan Ecosystem also have relevance to issues of agriculture. NMSA was formulated for enhancing agricultural productivity especially in rainfed areas focusing on integrated farming, water use efficiency, soil health management and synergizing resource conservation.

National Initiative on Climate Resilient Agriculture (NICRA)

To meet the challenges of sustaining domestic food production in the face of changing climate and to generate information on adaptation and mitigation in agriculture, the ICAR launched a flagship network project '*National Initiative on Climate Resilient Agriculture*' (NICRA) during 2011, presently renamed as National Innovations in Climate Resilient Agriculture. The major objectives of the project are: to enhance the resilience of Indian agriculture to climatic variability and climate change through strategic research on adaptation and mitigation; to validate and demonstrate climate resilient technologies on farmer's fields; to strengthen the capacity of scientists and other stakeholders in climate resilient agriculture and to draw policy guidelines for wider scale adoption of resilience-enhancing technologies and options. The project is being implemented through 3 major components viz. Strategic research through network and sponsored/competitive grants mode, Technology demonstration & dissemination and Capacity building.

NICRA - Strategic Research

In the strategic research component, both short term and long term research programs with a national perspective have been taken up to evolve adaptation and mitigation strategies in crops, horticulture, natural resources, livestock, fisheries and poultry. About 41 ICAR Institutes, State Agriculture Universities, Indian Institute of Technology (Chennai), NGOs are involved in strategic research. The State of art research infrastructure was developed like high throughput phenotyping platforms, free air temperature elevation systems in open fields, network of 100 automatic weather stations, environmental growth chambers with CO_2 and temperature controls and special calorimetric system to study livestock response to heat stress (NICRA, 2016). The salient achievements are as follows:

- Climate resilient technologies have been developed viz., climate smart crop varieties/cultivars tolerant to abiotic stresses for different crops, livestock breeds and management practices to bring climate resilience in agriculture
- Prepared first ever Vulnerability Atlas of India at district-level for all the 572 rural districts. Considering the IPCCC AR-5 and census data this Atlas is being revised with updated details
- In rice, wheat, maize, pigeonpea and tomato crops, core sets of genetic resources were assembled and field phenotyped at different institutions with a view to identify sources of tolerance to climatic stresses and related genes and traits (Maheswari *et al.,* 2019).
- Countrywide studies have been initiated to understand the impact of temperature on flowering behavior in mango
- A nation-wide pest surveillance and monitoring system has been put in place for all the target crops for major pests and diseases wherein real time incidence is being monitored along with weather parameters to build pest warning models.
- GHG inventory for agriculture sector in the country is being prepared by standardization of the techniques for measurement of GHG emissions in different cropping, and marine ecosystems and estimates of carbon sequestration potential through major agro-forestry systems in the country
- ICAR along with NARS has developed District Agriculture Contingency Plans for 650 districts in India and is being updated regularly.

NICRA- Technology demonstration component (TDC)

The TDC is a participatory programme of NICRA involving farmers to demonstrate site-specific technology interventions on farmers' fields for coping with climate variability in climatically vulnerable districts, to generate awareness and build capacity of farmers and other stakeholders on climate resilient agriculture and to evolve innovative institutional mechanisms at village level that enable the communities to respond to climate stresses in a continuous manner beyond the project period also. One village or a cluster of villages from each of the 151 selected districts were selected for this purpose. The Krishi Vigyan Kendra (Farm Science Centres) located in the district is implementing the programme in 121 districts, the Centers of All India Coordinated Research Project on Dryland Agriculture (AICRPDA) implementing the programme in 23 districts and the ICAR Institutes involved in the implementing in 7 districts. Eleven Agricultural Technology Application Research Institutes (ATARIs) of ICAR are involved in coordinating the project in their respective zones. At the district level, the selected KVK is responsible for implementing the project in farmers' fields by actively involving farmers. Planning, coordination and monitoring of the program at the national level is being taken up by ICAR- CRIDA, Hyderabad.

To address the climate vulnerabilities of the selected village's, technology interventions are planned and implemented under the four modules. Prioritization of interventions is done based on the climate vulnerability of the district, predominant farming situations and the resource endowments of the village. The technologies for a location were finalized in a workshop involving all the stakeholders such as the research organizations, agricultural universities, line departments, farmers and other organizations working in the villages from the basket of options available. The Climate resilient practices and technologies demonstrated are categorized into following four modules:

Module I: Natural resources : This module consists of interventions related to *in-situ* moisture conservation, biomass mulching, residue incorporation instead of burning, brown and green manuring, water harvesting and recycling for supplemental irrigation, improved drainage in flood prone areas, conservation tillage where appropriate, artificial ground water recharge and water saving irrigation methods.

Module II: Crop Production: This module consists of introducing drought/temperature tolerant varieties, advancement of planting dates of *Rabi* crops in areas with terminal heat stress, water saving paddy cultivation methods (SRI, aerobic, direct seeding), frost management in horticulture through fumigation, community nurseries in multiple dates for delayed monsoon, farm machinery custom hiring centers for timely completion of farm operations, location specific intercropping systems with high sustainable yield index.

Module III: Livestock and Fisheries: Use of community lands for fodder production during droughts/floods, augmentation of fodder production through improved planting material, improved fodder/feed storage methods, fodder enrichment, prophylaxis, improved shelters for reducing heat stress in livestock, management of fish ponds/tanks during water scarcity and excess water and promotion of livestock as such as a climate change adaptation strategy.

Module IV: Institutional Interventions: This module consists of village level institutional interventions to guide the implementation, continuation of interventions and for their long lasting impact. Village Climate Risk Management Committee (VCRMC) was conceptualized and established as supporting systems for taking up technological interventions at grassroot level and as a nodal point for organization of climate resilient villages. The activities of other institutional structures like community seed bank, fodder bank, custom hiring center (CHC) for farm machinery etc. were also established and are coordinated by VCRMCs. CHCs were established in all the NICRA villages to meet farm machinery needs of the local farming communities and to support various natural resources management (NRM) interventions and various agricultural operations. The revenue generated from the CHCs is used for the maintenance of these implements and to purchase new implement based on the availability of revenue and needs of the farming community. Seed banks were established to provide quality seed of climatically resilient varieties to famers in the NICRA villages. VCRMCs facilitate seed bank activities like production of seed by the farmers in NICRA villages and their good storage until the next crop season.

NICRA-TDC-Impact

Through natural resource management interventions, over 700 rainwater harvesting structures were constructed/ renovated/repaired, while 80000 m^3 additional rainwater storage capacity was created through farm ponds alone and the cropping intensity was increased by about 20%. *In-situ* moisture conservation through ridge and furrow and raised bed planting in soybean, cotton, maize, pigeonpea, short duration pulses, vegetables, wheat, mustard, sugarcane, potato and vegetables resulted in higher benefit: cost ratios (2.6 to 4.7). Adoption of *in-situ* moisture conservation measures in crops was helpful to improve the soil moisture availability at the root zone (30-40 days) and eventually increased the productivity of crops by 15-20% in dry regions of the country in comparison to the traditional practices of farmers. Contingency crops such as horsegram, castor, foxtail millet, pearl millet, cluster bean, toria and blackgram were adopted by farmers at different locations. Resilient intercropping systems in place of sole crops contributed to stabilizing productivity under various climatic stresses.

Every year about 115 drought escaping/ tolerant cultivars were demonstrated in 3360 farmer's fields in frequently drought prone regions of the country by ICAR under NICRA project. Similarly, about 15 flood tolerant cultivars were demonstrated in 347 farmer's fields in frequently flood prone regions of the country under the project. About 594 demonstrations on zero till and direct seeded rice cultivation indicated its high potential as a sustainable alternative to conventional planting of wheat, paddy, mustard, maize and vegetable crops. In the north Eastern states, the focus has been on sustainable intensification in rice fallows and zero till sowing, raised and sunken bed planting method for cultivation of grain legumes and vegetable crops. Harvested water was used for increasing the cropping intensity by bringing more area under *rabi* crops contributed to increase in yield and returns in several crops such as wheat (Bihar, Jharkhand, Chhattisgarh, Madhya Pradesh, Rajasthan), mustard (Madhya Pradesh, Rajasthan, Jharkhand), chickpea (Uttar Pradesh, Maharashtra) and vegetable crops (Nagaland, Sikkim, Jharkhand, Bihar, Uttar Pradesh, Himachal Pradesh, Tamil Nadu).

Demonstration of location specific fodder production and its storage by silage making addressed fodder needs during the lean season in several districts in Maharashtra, Andhra Pradesh, Gujarat, Karnataka, Himachal Pradesh, Punjab and Bihar. In districts affected by extreme events (high rainfall during November month), timely advisories to minimize damage were issued and demonstrated. Timely sown wheat with happy seeder in combine harvested rice fields in Punjab and Haryana escaped crop damage due to lodging and water stagnation. To meet the requirement of the green fodder and also dry fodder for the livestock in NICRA villages especially during lean season, fodder banks were established in the NICRA villages with high yielding improved varieties of fodder such as multi cut fodder sorghum (M.P. Chari, CoFS-29, CO-3 and CO-4), maize (African tall, J-1006) etc. These crops and varieties are highly nutritious and enabled farmers to have round the year the production of green fodder and increased their income from livestock, thereby reducing their vulne*rabi*lity to climate risks.

Real Time Contingency Planning

In view of the frequent weather aberrations around the year in one or other part of the year impacting agricultural production, to minimize the losses in agriculture, to improve the efficiency of the production systems and to enhance the production and income, the need was felt to implement contingency measures on real-time basis. Thus, *Real Time Contingency Planning* (RTCP) was conceptualized under NICRA-TDC by All India Coordinated Research Project for Dryland Agriculture (AICRPDA) and implemented in NICRA villages. RTCP is considered as "Any contingency measure, either technology related (land, soil, water, crop) or institutional and policy based, which is implemented based on real time weather pattern (including extreme events) in any crop growing season" (Srinivasarao *et al*., 2013) and implemented since 2011with two pronged approach viz. preparedness and real-time response to cope weather aberrations such as delayed onset o monsoon and early/midseason/terminal drought during cropping season.

The first step was to select a representative village in a most vulnerable district to weather aberrations such as drought, extreme events such as floods etc. The implementation of RTCPs are facilitated by VCRMCs with supporting systems like CHCs, seed banks, fodder banks, nutrient banks (vermicomposting units etc). The action plans were prepared for each village with details of activities along with roles and responsibilities of stakeholders, period and budget for each intervention.

The impact of RTCP measures in 32 adopted villages indicated that introduction of short duration drought tolerant varieties during delayed onset of monsoon gave about 15-35% higher yields compared to local/farmers' varieties. During early season drought, *in-situ* moisture conservation and mulching which helped in adaptation of crops and realizing improved yields by 16-31% compared to no contingency measures. RTCP measures of foliar sprays of thiourea and KNO_3 in mitigating midseason drought/dry spells gave 10-20% higher yield in different crops compared to no spray.

The effect of terminal drought on different crops was mitigated mostly by providing supplemental irrigation from harvested rainwater in ponds, and foliar sprays. Supplemental irrigation improved yields by 25% in cotton, 40% in groundnut and 55% in soybean at different locations. Similarly, foliar spray of 1% KCl in rice during dry spell at flowering-milking stage increased yield by 25% compared to no spray. Similarly, foliar application of water soluble NPKS complex fertilizer (18:18:18:6) @ 0.5% + $ZnSO_4$ @ 0.5% increased maize grain yield (2961 kg/ha) by 36% compared to water spray (2192 kg/ha) (AICRPDA-NICRA, 2012; Ravindra Chary *et al*., 2017; AICRPDA-NICRA, 2018).

Agroforestry as an adaptation strategy to climate change under NICRA

Trees on farms help adaptation to climate change by reducing vulnerability to climate impacts. Trees on farms can diminish the effects of weather extremes such as high temperatures and droughts. The important aspects of agroforestry that contribute towards adaptation consists of modification of micro climate in arid and semi arid regions, early crop vigour and growth due to enhancement of soil fertility, arresting soil erosion and land degradation, stability of income and enhancement of income through diversification from trees even under extremely low rainfall situations (Dhyani and Handa, 2013).

Under NICRA-TDC, quantification of carbon Sequestration potential (CSP) in agroforestry system has been completed in 17-States (Karnataka, Odisha, Bihar, Andhra Pradesh, Maharashtra, Himachal Pradesh, Tamil Nadu. Madhya Pradesh, Uttar Pradesh, Punjab, Haryana, West Bengal, Chhattisgarh, Rajasthan, Gujarat, Telangana and Jharkhand) covering 58 districts. Overall, the tree population in agroforestry system in different states is about 17.8 trees/ha. The maximum tree density (41 trees/ha) is recorded in Maharashtra followed by Andhra Pradesh and Himachal Pradesh. Carbon Sequestration potential in agroforestry system existing on farmer's field varied from 0.11 to 0.82 tons C per hectare per year in these states. The maximum CSP of agroforestry system is observed in Maharashtra followed by Andhra Pradesh and Himachal Pradesh. The proven agroforestry practices are being demonstrated in frequently drought prone regions. The focus is on agri-horti systems. The experience shows that during the years of low and variable rainfall, tree systems provided minimum returns and helped to stabilize incomes.

Capacity building

Building the capapcity of farmers on various aspects of resilient agriculture and climate resilient technologies is critical for the adoption and spread of the climate resilient practices. About 10636 courses in different thematic areas of climate change were taken up involving 5,14,816 farmers so far for awareness and capacity building of farmers on various aspects of climate change and climate resilient practices.

Scaling out Climate resilient technologies/practices

These resilient practices are spreading beyond the NICRA villages and being integrated in to the district agricultural development plans of the districts where NICRA programme is being operational. The comprehensive approach adopted in this project is being adopted by Maharashtra State Government in POCRA (Project on Climate Resilient Agriculture) where the concept of climate resilient villages are being scaled up to 5000 villages. Other state governments are also planning to spread the concept of climate resilient villages addressing the climatic vulnerabilities comprehensively. The experiences gained in NICRA-TDC and the concepts of climate resilient villages are being shared in various international and national platforms, and have been appreciated.

Way forward

Globally, the climate change impacts on agriculture and allied sectors are evident. NICRA as flagship programme of ICAR in India has been addressing to minimize impacts of climate change/variability in agriculture and allied sectors through strategic research and technology demonstration capacity components. Many implementable climate resilient technologies/ practices are developed/identified for scalinig up and scaling out. Further, capacity building is done to various stakeholders, particularly the farmers to enhance their adaptive capacity to climate change. The experiences gained so far indicate that the convergence of relevant climate resilient practices with national, state and district level programmes would lead towards climate resilient agriculture.

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Agroforestry Systems in Different Agroecological Zones of India: An Overview

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Abstract
Agroforestry has a tremendous potential to contribute significantly towards livelihood security and meeting the environmental challenges based on proper selection of tree species. There is an increase in number of trees outside forests which can be attributed to the development and adoption of suitable agroforestry systems by different stake holders. These achievements were realized after the initiation of organized national research programme on agroforestry in India in the form of an All India Coordinated Research Project (AICRP) on Agroforestry about three decades earlier and establishment of National Research Centre on Agroforestry (later on upgraded as central Agroforestry Research Institute). Diagnostic survey and appraisal under the project revealed that agroforestry practices abound in the country, but there are considerable variability in the nature and arrangement of the components and the ecological and socio-economic conditions under which such systems are practiced.

Keywords: Agroforestry systems, agro-ecological zones, MPTs

Introduction

Agriculture remains the primary occupation for a majority in rural India, and with increasing focus on rainfed areas, diversification of agricultural practices and the new initiatives in agroforestry are likely to increase in future. Agroforestry is playing a major role in meeting the demands of the rural households for fuelwood and fodder requirement of livestock. It is estimated that the total annual consumption of fuel wood is estimated at 216.42 m tonnes, out of which only 58.75 m tonnes is extracted from forests and rest is met through Agroforestry. The focus on small and medium industrial enterprises consuming a large proportion of forest products is likely to boost agroforestry. The increasing urbanization and the growth of the Indian economy at the rate of 9% per annum puts pressure on environmental resources for physical infrastructure and consequently for wood based construction material and this would give a boost to agroforestry. Agroforestry research in the country has been accepted and emphasized by the researchers, policymakers and farmers for its apparent ability to contribute significantly to economic growth, poverty alleviation and environmental amelioration.

Agroforestry Systems in different agro-ecological zones

Agri-silviculture, agri-horti-silviculture, agri-horticulture, hortipastoral, silvipastoral and some other specialised combinations for specific conditions are the major Agroforestry systems practiced in varying intensities in different agro-climatic zones (Table 1). Agrisilviculture and agihorticulture are the overall most popular Agroforestry systems. The detailed situation in different agro-ecological regions is described below.

Eastern-Himalayas

Among several shade tree species in large plantation areas of eastern Himalayas, alder (*Alnus nepalensis*) is most abundant and preferred tree, which is a non-leguminous nitrogen fixing tree. Besides large cardamom, many food crops like maize, millet, potato, barley, chillies and colocasia are grown with alder. The tree not only provides shade to arable crops, timber and fuelwood but also ameliorates the soil and protects it from erosion on hilly slopes. A yield of

400-500 kg $ha^{-1}$of cardamom has been reported in a year under shade trees. If a village with 100 families could set aside about 120 ha of land to grow alder trees, all families would be able to get sufficient fuelwood every year and at the same time raise crops under the alder in about 30 ha area every year. Cultivation of coffee, ginger, cardamom, turmeric and medicinal plants under the shade of naturally growing trees in Meghalaya is one of the best examples of successful combination of trees with annual crops. Department of Agriculture in Mizoram has developed its own contour trench-farming for jhum areas on hills where top portion is of undisturbed forest, middle portion is with horticultural crops and down the hill, terraced rice is cultivated with pineapple and grasses on contours. Many species of bamboo, palms (coconut, arecanut and species of *Licuala, Phoenix, Wallichia, Corypha, Caryota)* and rattans (*Calamus* spp.) are cultivated widely in north-eastern areas as mixed or boundary plantations. Pasture in forests is also a common practice.

It has been found that sericulture based system is highly relevant for these areas. Mulberry with French bean-groundnut followed by mustard is a profitable cropping system with mulberry, guava/lemon/pear and pineapple in paired rows and grasses on the bunds is an ideal system for silk production and additional income from fruits and cattle rearing. Pedi-cum-sericulture is said to be more viable as the cash returns are more frequent.

Shifting cultivation or slash and burn agriculture (locally called as *Jhum*) is the main form of agriculture in the hills of North Eastern region of India. Due to mountainous terrain, settled cultivation constitute only a small proportion of the total cultivated land which is confined mostly to Assam and valley lands in the hill states. Shifting cultivation in the region is a complex system with wide variation that depends upon the ecological variation in the area and cultural diversity among various tribal clans. However, the basic cropping practice has many similarities. Shifting cultivation in its traditional form was not so harmful when the jhum cycle was 15-20 years. But with reduction of jhum cycle, it has become environmentally destructive and a faulty land use practice having very low output-input ratio. The primary reason may be increase in population which led to increase demand of food, ultimately resulting in reduction of jhum cycle to 2-4 years. Such faulty land use led to severe land degradation due to soil erosion and associated factors such as reduction in soil organic carbon, nutrients etc., which resulted in decrease in crop yield. There is decline of forest cover due to shifting cultivation in the NEH region although the degree varies from one state to the other. Total area under Jhum also varies among the different hill states.

Western Himalayas

In the Western Himalayas, 60 to 70% requirement of the firewood is met from the arboreal components and several MPTs along the bunds of agricultural lands or scattered trees on the pasture lands were developed depending upon the needs, economics and environmental status of the land. High rate of net primary productivity has been reported in agri-hortisilvicultural systems (206 t $ha^{-1}yr^{-1}$) or agri-horticultural systems (23 t $ha^{-1}yr^{-1}$a) and the species number in these systems is as high as 15 tree species. Generally 50 to 100 trees are planted in a hectare for fulfilling a part of the fodder and fuelwood requirements. *Grewia optiva, Celtis australis, Bauhinia variegata, Albizia chinensis, Bombax ceiba, Melia azedarach* and *Toona ciliata* are common MPTs while plum (*Prunus domestica*), apricot (*P. armeniaca*), peach (*P. persica*), almond (*P. dulcis*) and pear (*Pyrus communis*) are common fruit trees of these systems. Hedge-row intercropping is feasible and important on sloping hilly lands when prunned biomass during cropping season can be used for fodder and fuelwood. Kinnow based horti-silvi-agricultural system at Dhaulakuan, kinnows planted at a spacing of 5m x 5m, has been highly successful. The inter–row spaces were utilized for sowing *Leucaena leucocephala* in the form of hedge rows or scattered trees and maize, soyabean, vegetables and wheat were grown as annual crops. To accommodate the demand for wood for packing of horticultural produce in the region, a horti-silvi-pastoral system was also developed growing trees of Santa Rosa plum at a spacing of 8m x 8m and the interspaces and field boundary were utilized for growing *Populus deltoides* with excellent economic returns.

Cold Desert region

The lack of vegetation and natural forests is major concern for practicing agriculture in cold desert region due to extensive soil erosion. The local population is aware about the importance of forests and practicing agroforestry in form of boundary plantation or block plantation to fulfill the basic requirements of food, fodder, fuel and small quantity of timber *etc*. Traditional agroforestry system of the region exists in the form of agri-silviculture system that is the combination of agricultural crops with boundary plantations particularly with two species Willow (Salix spp.) and Poplar (Populus spp.). These two species are main source of fuel wood and fodder. There are about 20 species of local willows and 10 of poplar growing at different altitudes of Ladakh. Out of them, some worth mentioning are: *Populus nigra, P. alba, P. ciliata, P. balsamifera, Salix alba, S. excelsa, S. angustifolia, S. schlerophyla, S. tetrasperma.* In agri-silviculture agroforestry system, a leguminous plant alfalfa (*Madicago sativa*), is grown in the dense plantation of poplar (yulat). This system of agroforestry is very popular in Ladakh. In silvi-pastoral system, plantations are managed for producing fuel wood as well as rearing of animals. This agroforestry system is practised in high altitude pastures like Changthang of Ladakh. Caragana, Hippophae and willows can be grown in the pastures. Silvi-pastoral agroforesty system is designed for the concurrent production of agricultural crops, forest trees and rearing of domestic animals. In poplar and willow stand, alfalfa is grown. Sometimes alongwith poplar and willow trees, Robinia species is also grown. Thus, this system of agroforestry provides food, fodder, fuel wood and timber. Horti – pastoral-system, consists of growing of fruit orchard and raising of animals. As for instance, in the fields of alfalfa fruit trees like apricot or apple are grown. In place of alfalfa, forage grasses/ and or oat plants and mustard are also planted. In lower agricultural zone of Ladakh, the plantation of poplar and grape is done. Between the spaces of poplar and grape, alafla is grown.

Indo-Gangetic Plains

Indo-Gangetic plains (IGP) comprises of four agro-climatic zones viz. Lower, Middle, Upper and Trans Gangetic plains covering West Bengal, Bihar, Uttar Pradesh, Delhi, Uttarakhand, Chandigarh, Haryana, Punjab and Rajasthan states. It's having 169 districts with total geographical area of 43.70 million ha. The Indo-Gangetic plains are one of the most populous region of the country. The area of the IGP is nearly 13 % of the total geographical area of the country, and it produces about 50 % of the total food grains to feed 40 % of the population of the country. Rice-wheat system is very common and popular system of the region. The continuous cropping of rice-wheat system degraded soil health dramatically over the years. Hence incorporation of trees in agriculture would be better option to improve soil as well as livelihood of the famers in IGP.

Agriculture is the major enterprise of the region that is most vulnerable to climate change particularly smallholder farmers because they do not have adequate resources to adapt to climate change. A considerable proportion of agroforestry area located in IGP and some of the promising tree species like poplar, eucalyptus, bakain, mango, shisham and babul are very common on farmer's fields. The farmers of Punjab, Haryana and western Uttar Pradesh are commercially growing eucalyptus and poplar under agroforestry system that attracted the timber market in these area.

Humid and Sub-humid Region

In Tripura tree component is used along with livestock and poultry component, whereas in irrigated areas fish component is also incorporated. Agrisilviculture is common in Raipur and Ranchi areas. *Acacia nilotica, Terminalia arjuna, Butea monosperma, Albizia* spp. are grown in Raipur area while *Zizyphus mauritiana, B. monosperma, Aegle marmelos, Mangifera indica, Schleichera oleosa* (Kusum) in Ranchi area. Homestead Agroforestry is also being practised using *Gmelina arborea, Artocarpus heterophyllus, Madhuca latifolia, Zizyphus mauritiana* etc.. In Bhubaneswar area agrisilviculture (*Cocos nucifera* for boundary plantation, block plantation of *Casuarina equisetifolia, Anacardium occidentale*) and homesteads are being practised. At both the centres (Raipur and Ranchi) *Gmelina arborea* is also used as timber while *Tectona grandis*, *Acacia nilotica* are used as timber trees at Raipur and *Shorea robusta* at Ranchi. *Leucaena leucocephala* is used at Raipur and Ranchi for fodder and *Pongamia pinnata, Acacia nilotica* and *Dalbergia sissoo* are also used as fodder at Raipur. *Mangifera indica* and *Artocarpus heterophyllus* are grown for fruits. Other fruit trees are *Moringa oleifera and Syzygium cumini,* in Raipur area and *Psidium guajava, Carica papaya* in and around Ranchi. *Terminalia arjuna* for raising silk worm and *Butea monosperma*, *Schleichera oleosa* for Lac cultivation are being used by the farmers in Ranchi area.

Arid and Semi-Arid Regions

In most of the arid region of the north-western India, Khejri (*Prosopis cineraria*) based silvi-agriculture system is prominent. Almost in all the fields' most useful khejri trees and small fruit yielding *Zizyphus nummularia* are found grown in association with rainfed crops. *Zizyphus nummularia* is used for its leaves as fodder for camel and goats and berries for edible purposes. *Acacia tortilis, A. nilotica, A. senegal, A. leucophloea, Capparis decidua, Tecomella undulata, Salvadora persica and S. oleoides* are other common trees found on various grazing lands or as sand stabilizers. *Calligonum polygonoides* is another interesting bush in Bikaner region. *Lasiurus sindicus* and *Cenchrus ciliaris* are prominent grasses in grazing fields as well as in sand dunes. In Arid regions of Western India, introduction of compatible fuel, fodder and fruit trees in pastures as in agricultural fields acts as an insurance against frequent crop failures, and trees play a pivotal role towards peoples' survival and sustenance in such fragile ecosystems.

In Central India, *Dalbergia sissoo, Acacia nilotica, A. eburnea, A. leucophloea, A. catechu, Albizia lebbeck, Azadirachta indica, Butea monosperma, Pongamia pinnata, Holoptelea integrifolia, Balanites roxburghii* and *Dichrostachys cinerea* form important constituents of a silvi-pastoral system.

In semi-arid regions of Peninsular India the systems are more complex as the problem of frost does not exist, therefore, a vast number of trees (both fruit yielding and MPTs) exist on agricultural fields. *Borassus flabellifer, Tamarindus indica, Acacia leucophloea, A. catechu, Casuarina equisetifolia, Cassia siamea, Eucalyptus tereticornis, Albizia lebbeck*, and many others are frequent trees on farms. *Leucaena leucocephala* has also been adopted as a common hedge-row-crop in many areas.

Coastal and Island Regions

Low lying water logged marshy areas, flood plains, and ill-drained lands are the common features in the coastal areas swamps and river banks are occupied by the mangroves and associate halophytes. Other natural vegetation includes evergreen, semi-evergreen and deciduous forests on uplands and grazing lands in pockets. Plantation crops integrated with livestock and poultry and rice fields are main features of this region.

The systems and practices of Agroforestry range from apparently 'simple' forms of shifting cultivation and farming in forests to sophisticated hedgerow intercropping systems, from systems involving sparse stands of trees on farm lands to high density, complex multistoryed home- gardens of lowland; and from systems in which trees play a predominantly 'service' role (e.g. shelterbelts) to those in which they provide the main commercial product (e.g. intercropping with plantation crops). Most of the systems are site-specific with very few examples of their extrapolatibility. Though many scientific inputs are given to plantation crops and multiple cropping systems are adopted but quite large areas under coconut plantation are still neglected and remain open for grazing. These areas may be brought under multistoreyed cropping systems. Spices like clove and cinnamon may be planted as middle storey crops and pineapple or forage grasses like hybrid napier (*Pennisetum purpureum*), kazungula (*Setaria anceps*) and guinea (*Panicum maximum*) and legumes like *Stylosanthes guianensis* or industrial grasses like lemon grass (*Cymbopogon fulvus*) may be grown as cover crops. Rubber and red oil palm plantations may also be integrated with other spice or forage crops particularly the legume covers. Monoculture of plantation crops should be discouraged and a multi- storeyed plantation system should be raised as has been demonstrated in Jirka Tang Farm in Andaman where even the forest-trees are retained in multi-storeyed plantations and almost all plantations including spices, coffee and fruit trees have been accommodated as under-storey crops.

Successful agroforestry technologies in different regions

Alder - large cardamom based agrisilviculture

The first inhabitants of Sikkim-the Lepchas collected capsules of large cardamom from natural forests. New plantations and large patches of large cardamom based agroforestry systems have been converted in to monoculture of N_2 fixing actinorhizal *Alnus nepalensis* as shade tree. Thus it is conducive to conservation of tree biodiversity in north eastern region and agroforestry is one of the favored land management systems for sustainable development in the mountain areas. Large cardamom agroforestry is almost a closed system that does not depend on the external input. The system requires about 800 to 1000 kg/ha of raw fuel-wood for curing the capsules that can be managed from the shade trees within the agroforestry. The annual production of woody biomass in cardamom based agroforestry ranges between 4.5 to 5.5 t/ha which is five times more of fuel wood requirement for curing. The share of gross income from large cardamom (Rs. 27 crores) was next to cereals over Sikkim state income from all crops. The benefit –cost ratio is more than 6 from fourth year onwards.

Poplar based agroforestry system

Diversification from rice wheat rotation is the need of the hour in Punjab and the state government has decided to bring about 2.0 lakh ha under agroforestry as per the state's crop diversification plan. Poplar (*Populus deltoides*) based agroforestry system has been adopted by the farmers especially along the river bed sites. The crops are cultivated in between the rows of trees. Trees are grown at a spacing of 8 m x 2.5 m or 5 m x 4 m accommodating about 500 trees per hectare. They get an annual income from the sale of intercrops while at the same time maintain trees for 6-7 years. All the *rabi* (winter) and *kharif* (summer) crops can be grown successfully under poplar plantations during the first two years except paddy. Different *rabi* crops like wheat, mustard, potato, barley, berseem can be successfully grown with poplar throughout its rotation age. However, in *kharif* season shade of trees reduces the crop yield. Therefore, crops in *kharif* should only be grown during first 3-4 years of tree age. The yield of various *kharif* and *rabi* crops and net returns during different years of poplar age indicate that poplar intercropped with turmeric has the highest benefits followed by poplar intercropped with pearlmillet-wheat rotation. Higher productivity of poplar plantations can be achieved by adopting suitable cultural and management practices such as intercultivation, irrigation application in channels during wheat growing season, following proper year wise fertilizer schedule for poplar, correcting deficiency of zinc and control of insects and diseases throughout its growth years.

***Eucalyptus* based agrisilviculture system**

The inter-cropping with eucalyptus in boundary as well as block planting is found to be beneficial as it has increased the possibility of timely sowing more crops during *rabi* season thereby increasing and stabilizing income of the farmer. It diversifies and stabilizes the production system and also provides industrial raw materials. Clonal eucalyptus under boundary and block plantation with rotation cycle of five years was introduced. Intercrops like wheat, rice, soybean, rapeseed, mustard, veg pea are grown. Under block plantation at the spacing of 5m x 2m crops can be grown during first three years, however under boundary plantation at 2.0 m spacing any crop can be grown upto the rotation age of eucalyptus. Eucalyptus based agri-silvi system produced wheat 3000 kg ha^{-1}, soybean 2000 kg ha^{-1} and eucalyptus 125 t ha^{-1} resulting higher net profit. Besides this, litter fall residues of eucalyptus added 27.1, 2.0 and 7.0 kg NPK $ha^{-1}yr^{-1}$, respectively.

Bamboo based agri-silvicultural system

High yielding genotypes of bamboo species viz., *Bambusa balcooa B. tulda, , B nutan, D asper in tarai region and Dendrocalamus hamiltoniiin low and mid hills* under block plantation of 5m x 5m and on boundary at the spacing of 5m or 3m were introduced. Intercrops like wheat, soybean, rapeseed, bean, mustard are grown successfully for first two years. The total cost of cultivation in bamboo based system is about Rs. 110000. Output in terms of net profit per unit area is Rs. 180000-200000 ha^{-1} yr^{-1} after four years of age.

Aonla based agroforestry system

Productivity of rainfed crops continues to be low; it is one half to one third of that obtained with irrigated crops. Aonla (*Emblica officinalis* Gaertn.) is the best option among the semiarid and arid fruit crops and has all required qualities for rainfed areas. In-situ moisture conservation techniques such as sunken method of planting, stone mulching, sunken method of planting in association with deep tillage in rainfed marginal lands where moisture stress is most serious problem in crop cultivation may help to conserve rainwater otherwise, precious amount of water is lost through runoff. Deep tillage breaks hard layer of soil and facilitate water penetration into deeper soil layer where moisture can be retained for quite long time, which may be beneficial in the long run to the fruit trees and crop as well. Aonla gives 481.95 kg fruit ha^{-1} at age of four years and fruit yield increased gradually in 6^{th} and 7^{th} year. In 7^{th} year per plant fruit yield was observed 75 kg and total fruit yield from a hectare of land is about 3421.26 kg. Besides fruit yield, greengram produced about 145.35 kg grain every year from same unit of land. The total income from the system increased after four year when aonla started fruiting and it goes up to Rs. 44,172 during 7^{th} year.

Prosopis based agroforestry

The khejari (*Prosopis cineraria*) based natural agroforestry system has large area in Rajasthan. This tree has beneficial effect on crop yields besides giving fruit, fodder and fuel wood. In addition to increased agriculture production at optimum density *P. cineraria* provides utilizable biomass of 19.96 tones ha^{-1} including leaf fodder of 0.85 tones ha^{-1} per year at 12 year age. Legumes are more suitable than *Penisetum glaucum* (pearlmillet). Yield of agricultural crop increased when density of *P. cineraria* was appropriate (i.e., optimum tree density), which varied with tree size/age because of competition for soil resources. Agroforestry system existing on farmers field in Rajasthan has potential to sequestered 0.49 t C ha^{-1} yr^{-1} and total carbon sequestration potential of the state is 0.482 million t C with an area of 2.051 million ha under agroforestry. *P. cineraria* is less competitive with crop as compared to the other tree species.

Melia dubia based Agroforestry system

Melia is a fast growing tree and yields good quality industrial timber in a short rotation. This tree is promoted under block plantation and bund planting under agro forestry system. In addition, the seeds of *Melia* are also being used for extraction of bio pesticides. This tree is cultivated in most the agro climatic zones, on an average 14-15 cu. feet of timber was recorded within a short rotation of 10-12 years besides 20 per cent top for chip wood and for fuel. Moreover, the tree leaves are also used as fodder for ruminants. In view of this, the field study on performance of *Melia* under different spacing was conducted. The results indicated that in block plantation planting of *Melia* at 5 x 5 m or 6 x 6 m recorded on par yield per tree. However, 5 x 5 m recorded 15-20 per cent higher yield as compared to 6 x 6 m. Further bund planting 3 m, 4 m and 5 m intra row spacing with 24 m or 30 m apart sustain the productivity of associated crops like ragi, red gram and field bean *etc*.

Way Forward

Agroforestry will be a key issue in providing a solution to global warming, climate change and enhancing the per unit productivity of the land and converting degraded and marginal lands into productive areas. The selection of suitable agroforestry technology for a specific agro-ecological region will be very important for providing livelihood security particularly to the small and marginal farmers. Screening and evaluation of selected multipurpose trees (MPT) for higher returns and better compatibility with intercrops is essential to increase dry land productivity. Standardization, refinement and dissemination of agroforestry based amelioration technologies for problem soils, development, standardization and adoption of agroforestry models linked with market for enhancing productivity and profitability of small holding farmers is one of the important solutions to meet the future challenges.

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Table 1: Agroforestry tree species in various Agro-climatic regions of India

Agro-climatic zones	States	Rainfall/ precipitation	Soil type	Agroforestry species	Other (fruit, medicinal etc.)	Agroforestry system
Arid ecosystem						
1) Western Himalaya (Cold Arid)	J &K and Himachal Pradesh	< 150 mm	Shallow skeletal soils	Poplar species, *Ulmus wallichiana*, *Hippophae*, *Betula*, *Salix*	Apple, Apricot, almond, Pistachio nut, peaches, pears, cherry, almond, walnut	Agrisilviculture Boundary plantation Silvi-horticulture, silvipasture
2) Western Plain, Kutch and Part of Kathiwar peninsula (Hot arid)	Gujarat, Rajastham, Haryana, Punjab	< 400 mm	Desert & saline soils	*Prosopis cineraria*, *Dalbergia sissoo*, *Ailanthus excelsa*, *Tecomella undulata*, *Poplar*, *Eucalyptus*, *Melia*	Neem *(Azadirachta indica)*, Ber, Guava (*Psidium gujava)*, Kinnow	Agrisilviculture and bund planting
3) Deccan plateau (Hot arid)	Andhra Pradesh, Telangana and Karnataka	400-500 mm	Red & black soils	*Eucalyptus* hybrid, *Acacia nilotica*, *Leucaena leucocephala*, *Melia*, *Tectona grandis*	Neem	Agrisilviculture and bund planting
Semi Arid						
4) Northern Plains and Central Highlands including arvallis	Gujarat, Rajasthan, UP, MP, Haryana and Punjab	500-1000 mm	Alluvium derived soils	*Ailanthus excelsa*, *Prosopis cineraria*, *Acacia nilotica*, *Hardwickia binnata*, *Eucalyptus* hybrid	Ber *(Zizyphus mauritiana)*, *Acacia catechu*	Agri-silviculture, bund planting, scattered trees
5) Central Highlands (Malwa), Gujarat plains and Kathiwar Penninsula	Gujarat and MP	500-1000 mm	Medium & deep black soils	*Acacia nilotica*, *Dalbergia sissoo*, *Tectona grandis*, *Gliricidia sepium*	Neem,	Scattered trees, Boundary plantation, Agrisilviculture
6) Deccan plateau	Karnataka, Andhra Pradesh, Maharashtra Madhya Pradesh	600-1000 mm	Shallow and medium (with inclusion of deep) black soils	*Eucalyptus tereticornis* and *Bambusa* spp.	*Acacia catechu*, Aonla *(Emblica officinalis)*, Ber, Mango	Agri-silviculture, Agri-horticulture, Boundary plantation

7) Deccan Plateau and Eastern ghat	Telangana & Andhra Pradesh	600-1100 mm	Red & black soils	*Tectona grandis*, *Eucalytpus* hybrid	Neem, Moringa (*Moringa oleifera)* Tamarind, Cashew, Coconut	Agrisilviculture
8) Eastern Ghat, TN uplands and Deccan Plateau	Karnataka, Tamilnadu, Kerla	600-1000 mm	Red loamy soils	*Casuarina equisetifolia*, *Eucalytpus* hybrid, *Ceiba pentendra*	Neem, Moringa, Tamarind, Cashew, Coconut	Agrisilviculture , Boundary plantation
Sub-Humid						
9) Northern plains	Bihar, Uttar Pradesh and Punjab	1000-1200 mm	Alluvium derived soils	*Dalbergia sissoo, Melia composita, Populus deltoides, Eucalyptus tereticornis*	Aonla, Ber, Mango	Agrisilviculture , Boundary plantation
10) Central Highlands (malwa, Bundelkhand and Eastern Satpura)	Madhya Pradesh and Maharashtra	1000-1500 mm	Black and red soils	*Leucaena leucocephala, Tectona grandis, Dalbergia sissoo, Acacia nilotica, Hardwickia binata, Cordia rothii, Bambusa* spp.	*Butea monosperma*, Aonla, Bael *(Aegle marmelos)*, Ber, *Sesbania sesban, Madhuca longifolia*	Agrisilviculture , Boundary plantation
11) Eastern plateau	Chhattisgarh	1200- 1600 mm	Red & Yellow soils	*Gmelina arborea, Terminalia* spp., *Beutea monosperma, Albizia procera*, bamboo	Mango, Jackfruit, Guava, Moringa, *Annona reticulata*	Agrisilviculture , Boundary and block plantation
12) Eastern (Chhota Nagpur) plateau and Eastern Ghat	Orissa, west Bengal, Bihar, Chattisgarh, Madhya Pradesh and Maharashtra	1000-1600 mm	Red & lateritic soils	*Gmelina arborea, Casuarina equisetifolia, Ceiba pentendra, Eucalyptus* hybrid	*Butea monosperma, Pongamia pinnata, Madhuca longifolia, Terminalia arjuna*	Agrisilviculture , Boundary and block plantation
13) Eastern Plains	Uttar Pradesh and Bihar	1400-1800 mm	Alluvium derived soils	*Dalbergia sissoo, D. latifolia*	Mango, Litchi, Mulberry *(Morus alba)*	Agrisilviculture , Boundary plantation
14) Western Himalaya	J&K, Himachal Pradesh and Uttarakhand	1000-2000 mm	Brown forest and podzolic soils	*Populs deltoides, Grewia optiva, Salix* spp., *Eucalyptus* hybrid	Mulberry, *Melia azedarech*	Agrisilviculture , Boundary plantation
Humid per-humid						

15) Bengal and Assam plains	West Bengal and Assam	1400-1600 mm in Ganga Plain ranges and 1800-2000 mm in Barak Basin (Tripura Plain) and the Teesta-Brahmaputra plains	Alluvium derived soils	*Anthocephalus cadamba, Lagerstromia speciosa, Bombax ceiba, Tectona grandis*	Mango, Areca nut *(Areca catechu),* Agar *(Aquillaria agalocha), Acacia auriculiformis ,*	Agrisilviculture, Boundary planation, Agrihorticulture
16) Eastern Himalaya	Arunachal Pradesh, Sikkim, west Bengal	2000 mm	Brown and red hill soils	*Alnus nepalensis,* Bamboo, *Anthocephalus cadamba*	*Flemingia macrophylla, Indigofera tinctoria*	Agrisilviculture, Boundary planation
17) North Eastern Hills (purvanchal)	Tripura, Mizoram and Meghalaya	2000 - 3000 mm	Red and lateritic soils	*Alnus nepalensis, Gmelina arborea, Bamboo, Albizia lebbeck, Lagerstromia speciosa, Bombax ceiba*	Spices and *Ammomum subulatum,*	Agrisilviculture, Boundary planation
Coastal						
18) Eastern coastal plains	Tamil Nadu, Puducherry, Andhra Pradesh, Odisha and West Bengal	900-1100 mm	Coastal alluvium derived soils	*Borassus flabellifer, Casuarina equisetifolia, Acacia mangeium, Ceiba pentendra, Erythrina indica*	Coconut	Agrisilviculture, Boundary planation
19) Western ghats and Coastal plains	Gujarat, Diu & Daman, Maharashtra, Goa, Karnataka, Kerala	> 2000 mm	Red, lateritic and alluvium-derived soils	Bamboo, *Tectona grandis, Terminalia* spp., *Grevellia robusta, Erythrina indica*	Spices and coconut	Agrisilviculture, Boundary planation
Island						
20) Andaman, Nicobar and Lakshadweep	Andaman, Nicobar and Lakshadweep	in Andaman and Nicobar 3000 mm & in Lakshadweep Islands 1600 mm	Red loamy and sandy soils	*Erythrina indica, Ceiba petandra, Albizia lebbeck, Pterocarpus dalbergioides , Tectona grandis*	Mango, Jackfruit, Jamun (*Syzygium cumini), Gliricidia sepium,* Arecanut	Homegardens, Agrisilvihorti system, Silvipasture

Climate Resilient Livestock Production and Management Practices

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Introduction

India possesses a huge population of livestock, more than 512 million head, which plays a major role in contributing around 27% of agricultural GDP. It provides livelihood to many poorest people in rural areas. It provides food, income, employment and many other contributions to rural development viz. draught power, means of transport, organic manure for crop production and domestic fuel, hides and skin etc. It contributed about 16% income or even more in states like Gujarat (24.4%), Haryana (24.2%), Punjab (20.2%) and Bihar (18.7%). Due to economic growth and urbanization, the demand for foods of animal origin is growing and it is apparent that the livestock sector will need to expand more in future with the growing population. Although the prospect of animal productivity and its share to food security and national GDP is on the upward swing, livestock is adversely affected by the prevailing scenario of heat stress, land and water scarcity and the ensuing climate change (Srivastava, 2017).

The Intergovernmental Panel on Climate Change has indicated a wide range of effects of climate change, including regional warming, changes in precipitation, extremes in weather, severe drought, earlier snowmelt, rising sea level, effects on water supply, and other changes, which will alter different ecosystems and societies significantly (Pinchot, 2008) including the sustainability of livestock production systems. At present, high environmental temperature is the major constraint on livestock production in tropical and sub-tropical regions. In fact, high environmental temperature exerts a negative influence on the performance of livestock population. It has been predicted that by 2100, the surface temperature will be about 1.4-5.8 ^{o}C more than the 1990 levels (IPCC, 2007). With increase of 1.5 ^{o}C to 2.5 ^{o}C, approximately 20 to 30 percent of plant and animal species are expected to be at risk of extinction. The impacts of climate change are visible all over the world, but India is categorized among the most vulnerable areas, as rural economy is primarily dependant on crop-livestock production systems, and almost 70 percent of livestock in India is owned by small and marginal farmers, and landless labourers. Animals of such livestock owners with poor resources are more vulnerable to climate change, and thus at a greater risk. India is currently losing nearly two per cent of the total milk production, amounting to a whopping over Rs 2,661 crore due to rise in heat stress among cattle and buffaloes because of the global warming. Majority of the areas in India show higher Temperature Humidity Index (THI= 75 or more) and 85% places in India experience moderate to high heat stress during April, May and June (NDRI Vision Document 2030, 2011).

Impact of climate change on livestock

Despite uncertainties in climate variability, the IPCC Fifth Assessment Report identified increase in global average surface temperature is must. Accordingly the potential impacts on livestock include changes in production and quality of feed crop and forage, water availability, animal growth and milk production, diseases, reproduction and biodiversity (NAAS, 2016). These impacts are primarily due to an increase in temperature and atmospheric carbon dioxide (CO_2) concentration, precipitation variation, and a combination of these factors. However, temperature affects most of the critical factors for livestock production, such as water availability, animal production, reproduction and health. Forage quantity and quality are affected by a combination of increases in temperature, CO_2 and precipitation variation.

Livestock diseases are mainly affected by an increase in temperature and precipitation variation. Hence, climate can affect livestock both directly and indirectly. Direct effects influence animal performance such as growth, milk production, wool production and reproduction, while indirect effects influence the quantity and quality of feedstuffs such as pasture, forage and grain, water availability and the severity and distribution of livestock diseases and parasites. Indian livestock productivity has been severely affected by vector-borne livestock diseases which are known to be climate sensitive.

Milk production

One of the direct impacts of climate change on livestock is on the milk production. Increase in number of stressful days (THI more than 80) and their frequency is expected to impact milk yield and production performances of cattle and buffaloes. A thermal environment is a major factor that can negatively affect milk production in dairy cows, especially in animals of high genetic merit. It was reported that milk yield was declined by 0.2 kg per unit increase in THI when THI exceeded 72. Even there was the variation in milk yield (9%), milk fat (13%), feed intake (5%) and rectal temperature due to variation in THI, attributed to weather condition. However, the extent of milk yield decline observed in heat-stressed cows is dependent on several factors that interact with high air temperature. The milk yield losses seem positively related with milk yield of cows. The increase in milk yield increases sensitivity of cattle to thermal stress and reduces the threshold temperature at which milk losses occur. When high milk producing cattle were kept in hot climatic zones, metabolic heat production was intensified that resulted in an increase respiratory rate, consequently, decrease in the milk production.

The stage of lactation is also an important factor affecting lactating cows' responses to heat. It was observed the extent of decline in milk yield were less at mid lactation stage than either late or early stage or decline in yield varied from 10-30% in first lactation and 5-20% in second or third lactation in Murrah buffaloes (Chauhan and Ghosh, 2014).

Growth and reproduction

The rise in temperature due to global warming will negatively impact growth and time to attain puberty in animals. The negative impact of THI rise on animals growing at higher rates (500 g/day or more) will be more than slow growing (300-400 g/day) cattle. The crossbreds have been observed to be more sensitive to rise in THI than either Zebu cattle or buffaloes. The temperature changes are also likely to affect the normal reproductive rhythm of animals. Heat stress due to high environmental temperature accompanied with excess humidity during summer months causes infertility in most of the farm animals and have adverse effect on reproductive performances in India. During hot dry and hot humid seasons, the THI values exceed 80 in most parts of India. The pattern of estrus varies among cattle and buffaloes. Most of the buffaloes exhibit sexual activity during cooler parts of the year (October- Feb), when the THI generally remains < 72 (Upadhyay *et al.*, 2009). A temperature rise of more than 2°C in unabated buffaloes may cause negative impacts altering respective hormone functions, whereas in case of cattle, the effects of heat stress on fertility appear to carry into the autumn (October and November) even though the cows are no longer exposed to heat stress. An increase in uterine temperature of 0.5° C above average is associated with a decline in conception rate of 12.8%. Low temperature and THI during nights in summer (April and May) provide an opportunity to buffaloes to dissipate heat during night hours compared to day hours. This may be the reason that buffaloes experienced less stress during hot dry season compared with hot humid season. Diurnal pattern of estrus behaviour has been observed in majority of Murrah buffaloes. During heat stress, motor activity and other manifestations of estrus are reduced and the incidence of anestrus and silent ovulation is increased (Singh *et al.*, 2011).

Reproductive processes in male animals are very sensitive to heat stress with reduction quantity and quality of sperm production and decreased fertility. Sperm production (ejaculate volume, sperm concentration and total sperm number) and percentage of normal sperm cells decreased during the hot season even in *B. indicus* bulls. Dairy cows experienced heat stress during late gestation had calves with lower birth weights and produced less milk than cows not exposed to heat stress. In male buffaloes also the semen quality and libido get affected by heat stress. The problem of low libido and poor quality of semen is one of the major constraints even under existing climatic conditions. Further rise in temperature due to climate change will impose additional stress on these animals.

Animal health

Climate change, in particular global warming, is likely to affect the health of farm animals. Global climate change alters ecological construction which causes both the geographical and phonological shifts. Increase ambient temperature may increase the rate of growth of pathogens and parasites during their life cycle outside animal host, leading to larger populations. Similarly, those pathogens and parasites, which are sensitive to humidity level may be affected by changes in rainfall, soil moisture and the frequency of floods. Thus warming and changes in rainfall pattern may lead to changes in spatial or temporal distribution of diseases such as anthrax, haemorrhagic septicaemia, foot and mouth, and vector borne diseases. Changes in winds could affect the spread of certain pathogens and vectors. Increase in frequency of extreme climatic events like floods and droughts are expected to affect the incidence of several parasitic, bacterial and viral diseases. Outbreak of infectious diseases in areas affected with floods is a major problem.. Thus climate change may bring about substantial shifts in disease distribution, and outbreaks of different disease (Das et al., 2016).

Biodiversity

Climate will continue to change rapidly and accordingly the natural resources, including fresh water, will diminish and disappear at an accelerating rate; agricultural and farm communities will deteriorate further while we lose more genetic diversity among crops and farm animals (Chauhan and Ghosh, 2016); biodiversity will decline faster as terrestrial and aquatic ecosystems are damaged; harmful exotic species will become ever more numerous. Out of the 3831 breeds of ass, water buffalo, cattle, goat, horse, pig, and sheep recorded in the twentieth century, at least 618 had become extinct by the century’s end, and 475 of the remainder were rare. A report on animal genetic resources indicates that 20% of reported breeds are now classified as at risk, and that almost one breed per month is becoming extinct (FAO, 2007). However, this genetic erosion is attributed to livestock production practices and changes in production systems and local breeds. Several breeds of cattle, buffalo, goat and sheep in India have become extinct or have been declared threatened because of various factors including climatic factors. Cross breeding, changes in land use and animal husbandry practices have also played some role in extinction of breeds in India. The number of indigenous breeds is well adapted to harsh environment and diseases. But increase in environmental temperature may be stressful even for these animals. It is estimated that 20-30 % of all animal breeds assessed so far would be at high risk of extinction with a rise of 2.5 ^{0}C. Indeed, we have to keep in mind that animal genetic resources are non-renewable resource, once gone, they are gone forever.

Water availability

Water availability issues will influence the livestock sector, which uses water for animal drinking, feed and fodder crops, and product processes (Rojas Downing *et al.*, 2017). The livestock sector accounts for about 8% of global human water use and an increase in temperature may increase animal water consumption by a factor of two to three. To address this issue, there is a need to produce crops and raise animals in livestock systems that demand less or in locations with water abundance. Water requirement for different livestock systems varies from 1L per animal per day in extensive grazing system to 125 L per animal per day in commercial landless pig production system. Irrigated area is continuously increasing and water use in other sectors is increasing even at faster rate. The key issue relating to water is its uneven distribution. The surface water bodies like ponds and lakes have been meeting the water requirement of animals in pastoral and semi-intensive system of animal rearing in India. These water bodies have been decreasing in many parts of India resulting in more pressure on ground water use for animals. Such contribution of ground water to extensive grazing system and semi-intensive system will become even more important in future in the face of climate change. The increased reliance on ground water in future for livestock and crops in addition to human requirement could lead to problems associated with the sustainability of water resources in the country.

Feed resources availability

Climate change is expected to affect livestock production by altering the quantity and quality of feed available for animals. Climate change will change the species composition (and hence biodiversity and genetic resources) of grasslands as well as affect the digestibility and nutritional quality of forage. However, the effect on forage quantity and quality depend on the region and length of growing season. An increase of 2 ^{0}C will produce negative influence on pasture and livestock production in arid and semiarid regions and positive influence in humid temperate regions. The length of growing season is also an important factor for forage quality and quantity because it determines the duration and periods of available forage. A decrease in forage quality can increase methane emissions per unit of gross energy consumed. Therefore, if forage quality declines, it may need to be offset by decreasing forage intake and replacing it with grain to prevent elevated methane emissions by livestock. Droughts and extreme rainfall variability will also trigger periods of severe feed scarcity, especially in dry land areas, with devastating effects on livestock populations.

Adaptation and mitigation strategies

Since climate change is expected to increase of heat stress, all methods to help animals cope with or at least alleviate the influence of heat stress will be useful to mitigate the impacts of climate change on animal responses and performance. Accordingly different managemental options to reduce heat stress as described by Pankaj *et al*. (2013) are-

Genetic approach

Many local breeds are having valuable adaptive traits that have developed over a long period of time which includes-

- Tolerance to extreme temperature, humidity etc
- Tolerance /resistance to diseases
- Adaptation to survive, regularly produce/ reproduce in low/ poor management conditions and feeding regimes.

Therefore, genetic approach to mitigate the climate change should include measures such as-

- Identifying and strengthening the local genetic groups which are resilient to climatic stress/ extremes
- Genetic selection for heat tolerance or bringing in types of animals that already have good heat tolerance and crossbreeding the local genetic population with heat and disease tolerant breeds.
- Identifying the genes responsible for unique characteristics like disease tolerance, heat tolerance, ability to survive in low input conditions and using it as basis for selection of future breeding stock will help in mitigating the adverse effect of climate stress.
- Changing of breeding animal for every 2-3 years (exchange from other district herd) or artificial insemination with proven breed semen will help in enhancing the productivity.
- Promoting of local climate resilient breeds of moderate productivity over susceptible crossbreds

Nutritional approach

The feed intake of animals during heat stress is significantly lower than those in comfort zone. Hence, the care should be taken to provide more nutrient dense diets, which will help to minimize production losses due to the high temperatures as well as those feed which generates less heat during digestion. This can be achieved adopting following measures-

- Incorporation of dietary fat at level of 2-6 % will increase dietary energy density in summer to compensate for lower feed intake
- Adjusting animals' diets to minimize diet-induced thermo genesis (low fibre and low protein diets). High-fiber diets generate more heat during digestion than lower fiber diets. Using more synthetic amino acids to reduce dietary crude protein levels. Excessive dietary protein or amino acids generate more heat during digestion and metabolism.
- Feeding of antioxidant (Vitamin A, C & E, selenium, Zinc) reduces the heat stress and optimize feed intake
- When daytime temperatures and humidity are high, special precautions must be taken to keep livestock comfortable and avoid heat stress. Allow for grazing early in the morning or later in the evening to minimize stress.
- Supplementation of concentrate mixture (22% CP and 70% TDN) prepared with locally available feed ingredients to all categories of animals. When no green fodder is available, addition of vitamin supplement in concentrate mixture helps in mitigating heat stress.

Managemental approach

- Animals must have access to adequate clean, fresh and cool water during heat stress. Much of the water is needed for evaporative heat loss *via* respiration to help them cool off. Cleaning the feeding trough frequently and providing fresh feed will encourage the animals to take more feed. Splashing the cool water over the animals at regular intervals during the hot period will reduce the heat stress.
- Providing feed to the animals during cool period i.e. evening or night will improve the feed intake by the animals.
- Reduction in stocking density during hot weather will help the animals in dissipating the body heat more efficiently through manifestation of behavioural adaptation.
- The use of shades is an effective method in helping to cool animals. Shades can cut the radiant heat load from the sun by as much as 40%. Shades with straw roofs are best because they have a high insulation value and a reflective surface. Uninsulated aluminum or bright galvanized steel roofs are also good. The best shades have white or

reflective upper surfaces. Provision of trees at certain distance from the shed which will provide shade to the animals.

- Provision of vegetative cover over the surrounding area will reduce the radiative heat from the ground. The surface covered with green grass cover will reflect back 5 – 11% of solar radiation as compared to 10 – 25% by dry bare ground and 18 – 30% by surface covered by dry sand adding to thermal stress.
- Increasing the ventilation or air circulation in the animal sheds will aid the animals in effective dissipation the heat. The air circulation inside the shed can be increased by keeping half side wall i.e., open housing system, use of fan, increasing the height of the building etc.

Other approaches

- *Adoption of promising drought tolerant forages and varieties*: The area under forage crops is 8.5 m ha and wide array of forage crops/species are grown in different regions of the country. There is great diversity in forage crops & varieties in varied regions and different growing seasons. We have large basket of perennial grasses, range legumes, cultivated forage cereals & legumes. But forage varieties with tolerance in drought/water scarcity situations holds promise and can fit well in existing farming systems. (Table 1).

- *Rejuvenation of common property resources (CPRs)*: CPRs are good sources of forages for ruminant animals. However, there is no control over the number of animals allowed to be grazed, causing severe damage on the re-growth of number of favourable herbaceous species in grazing lands. Thus causing adverse impact not only on herbage availability from CPRs but also quality of herbage affecting the productivity of animals; hence there should be some restriction on number and species of animals to be grazed in any CPR as a social regulation. CPRs need to be reseeded with high producing legume and non-legume fodder varieties at every 2-3 years intervals as a community activity.

- *Intensive fodder production systems:* Growing of two or more annual fodder crops as sole crops in mixed strands of legume (stylo or cowpea or hedge Lucerne, etc) and cereal fodder crops like sorghum, ragi in rainy season followed by berseem or lucerne etc., in rabi season in order to increase nutritious forage production round the year. Fodder crops like *Stylosanthes hamata* and *Cenchrus ciliaris* can be sown in the inter spaces between the tree rows in orchards or plantations as hortipastoral and silvopastoral systems for augmenting fodder resources.

- *Use of unconventional feed resources as feed:* The available waste products form food industries like palm press fibre, fruit pulp waste, vegetable waste, brewers' grain waste and all the cakes after expelling oil etc., and thorn-less cactus should be used as feed to meet the nutritional requirements of animals as well as stress

Conclusion

Climate change is considered as a major threat to the sustainability of fodder- livestock production systems. Like human beings, livestock and animal resources also suffer due to natural disasters, higher temperatures, salinity intrusions and floods. In changing climate scenarios, fodder production may decrease and mortality rates in animal (not only due to malnutrition but also due to change in habitat) may rise, which may threaten the viability of the livestock production in future (Kumar and Tuti, 2016). Hence, we needs to focus on research and development of new technologies to reduce the impacts of climate change on fodder and livestock sector. The crop lands, pastures and forests that occupy 60% of the Earth's surface are progressively being exposed to threats from increased climatic variability and, in the longer run, to climate change. Abnormal changes in air temperature and rainfall and resulting increases in frequency and intensity of drought and flood events have long-term implications for the viability of these ecosystems.

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Table1. Promising drought tolerating varieties of cultivated fodder and grasses/legumes

Crop	**Varieties**	**Production potential (green t ha^{-1})**	**Adaptable region**
Sorghum	Pusa Chari-1, CO-27, SSG 59-3 (Meethi Sudan), CSH-20MF (UPMCH- 1101), PAC 981, CSV–15	35-45	Whole country except temperate hills
Bajra	Avika Bajra Chari (AVKB-19), Raj Bajra Chari-2, CO-8, APFB-2, PCB-164	30-40	Whole country except temperate hills
Maize	Pratap Makka Chari 6	40-50	Whole country
Sudan grass	Meethi Sudan, Sweet Sudan Grass, Punjab Sudex Chari-1 (LY-250)	45-65	Whole country except temperate hills
Oat	FOS-1/29, Bundel Jai-822, Bundel Jai 992 (JHO 99-2), JHO-2009-1	35-45	North , central & North western, hill region
Cowpea	Bundel Lobia-1, Bundel Lobia-2 , S 450	20-25	Whole country
Guar	Durgajay, Durgapura Safed, HFG-119, Bundel Guar- 1, Bundel Guar- 2, Bundel Guar- 3	20-25	Whole country except temperate hills
Sem	Bundel Sem-1	20-22	Whole country except temperate hills
NB hybrid	CO-1, NB-37	150-180	Whole country except temperate hills
Guinea grass	Bundel Guinea-1 (JHGG-96-5), Bundel Guinea-2 (JHGG 04 –01)	120-150	Whole country except temperate hills (very high altitude)
Dinanath grass	Bundel-1, Bundel-2, COD-1	35-45	Whole country except temperate hills
Anjan grass	Bundel Anjan-1, CO-1 , Bundel Anjan-3	25-35	Whole country
Motha dhaman grass	CAZRI-76, Marwar Dhaman (CAZRI-175)	25-35	Central, western & dry arid region
Black spear grass	Bundel Lampa Ghas -1	25-30	Whole country (arid & semiarid region)

Stylosanthes sp.	*S. hamata, S. seabrana & S. scabra*	25-30	Whole country (semiarid region)
Clovers	White & red clovers	20-25	Temperate/sub-temperate region

Agroforestry for Sustainable Soil Quality for Increased Food Production and Food Security

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Abstract

Strong link exists between soil quality and agricultural sustainability. Agroforestry. Since beginning the major tenets of agroforestry have been its soil conservation value and sustainability of agricultural production system. The scientific community intervened to harness full benefits of agroforestry land use system and address global issues of land degradation, agricultural sustainability and more recently the climate change and food security. The horizontal (expansion of area) and vertical (innovative research) growth of agroforestry has made significant stride towards wellbeing of the people. The surging interest in agroforestry to search solution for global problem of climate change and food security is based on the scientific revelations that the tree components of agroforestry not only supplement and compliment growth of agro-components by improving soil health but also contribute toward mitigation of climate changes and food security. This review is an attempt to organise research advances of agroforestry in logical order to understand contribution of agroforestry towards complex problems of maintaining soil fertility, meeting goals of climate change and food security. The paper also lists some of the research gaps for future.

Key words: Agroforestry land-use, carbon sequestration, climate change, nutrient recycling and soil quality

Introduction

India is blessed with different types of agro-climatic conditions, so there are huge variations in agroforestry systems in their structural complexity and species diversity, their productive and protective attributes and their socio-economic dimensions. They range from apparently simple forms of shifting cultivation to complex home-gardens; from systems involving sparse stand of trees on farmlands (e.g. *Prosopis cineraria* in arid regions of Rajasthan) to high-density complex multi-storied homesteads of Kerala; from systems in which trees play a predominantly 'service' role (e.g. shelter belts) to those in which they provide main saleable products (e.g. intercropping with plantation crops) (Dhyani *et al.*, 2005 and 2009). In all these agroforestry systems, the components of trees, crops and animals are integrated in such a way that it provides long-term conservation, ensures sustainable production and protects the environment (Dhyani *et al.*, 2005).

In recent times, Indian agriculture is facing diverse challenges and constraints due to growing demographic pressure, increasing needs of food, feed, pulp, fodder and timber, degradation of natural resources and climate change **(**Pandey, 2007; Dhyani *et al.*, 2013, NRCAF, 2013). It is assumed that diversification of land-use system with agroforestry can address some of these challenges. Therefore, agroforestry has been receiving greater attention by researchers, policy-makers and others for its perceived ability to contribute significantly to economic growth, poverty alleviation and environmental quality. Today, agroforestry is recognized as an important part of the evergreen revolution's movement in the country. India launched the National Agroforestry Policy 2014 with focus on improving productivity of small and marginal farmers and providing them sustainable livelihoods; besides helping in natural resource management and improving forest cover (Dhyani, 2014).

Agroforestry and Soil Quality

Soil quality is considered a key element of sustainable agriculture (Warkentin, 1995) and refers to its capacity to perform specific function (SSSA, 1987). Assessment of soil quality refers to measurement of relative changes in soil characteristics over time brought by human management under different land-use systems. Strong link between soil quality and agricultural sustainability is well proven; hence, the overriding objective of agroforestry has been to develop integrated land management systems involving trees, crops and/or animals, which would contribute substantially to decrease deforestation, increase food production, enhance biodiversity, protect environment and improve soil quality. It is always argued that presence of woody perennials in agroforestry system affects several bio-physical and bio- chemical processes that determine the health of the soil substrate. The most obvious effects of trees on soil include amelioration of erosion primarily through surface litter cover and under story vegetation; maintenance or increase of organic matter and diversity through continuous degeneration of roots and decomposition of litter; nitrogen (N) fixation; enhancement of physical properties such as soil structure, porosity and moisture retention due to extensive root system and the canopy cover; and absorb and recycle nutrients in the soil that would otherwise be lost through leaching.

In any agroforestry system, competition between woody perennial and annual agro-crop and/or grass for sharing underground resources particularly the nutrients (N, phosphorus (P) and potassium (K)) and others due to varying nature of growth, nutrient requirement and genetic makeup is quite obvious. The nature and quantum of tree–crop interactions and their effects are not uniform, and depend on many factors like nature of the species grown, age and size of trees, density of components, management practices (spacing, training, pruning, irrigation, fertilization etc.) and environmental factors (Kaushal and Verma, 2003).

The hypothesis that agroforestry improves soil is based on studies of the efficient transfer of nutrients from litter to trees in natural ecosystems (Vitousek and Sanford, 1986) and on observations of higher crop yields near trees or where tree were previously grown. It is based on assumption that trees in agroforestry systems transfer nutrients to intercropped plants. Palm (1995) examined several issues related to the transfer of nutrients from agroforestry trees to intercropped plants. He concluded that the amount of nutrients provided by pruning are determined by the production rate and nutrient concentrations, both depending on climate, soil type, tree species, plant part, tree density and tree pruning regime. A large number of screening and alley cropping trials in different climate-soil environments indicate that pruning of various tree species contain sufficient nutrients to meet crop demand, with the notable exception of P. It has been observed that tree biomass containing sufficient nutrients to meet crop demand is not enough; the nutrients must be supplied in synchrony to crop needs (Swift, 1987). Nutrient release patterns from organic materials are, in part, determined by their chemical composition or quality. Leguminous plants known as N-fixing trees or fertilizer trees release N immediately, unless they contain high levels of lignin or polyphenols. Non-legumes and litter of both legumes and non-legumes generally immobilize N initially. Field trials with agroforestry species ranging in quality show that as much as 80% of the nutrients are released during the course of annual crop growth but less than 20% is captured by the crop, a low nutrient-use efficiency (Palm, 1995). Published values for leguminous trees in different agroforestry systems show average annual additions of dry matter biomass of up to 20 $tha^{-1}yr^{-1}$ (Young, 1997). Leguminous trees in alley cropping systems can contribute as much as 358 kg N ha^{-1}, 28 kg P ha^{-1}, 232 kg K ha^{-1}, 144 kg calcium (Ca) ha^{-1} and 60 kg magnesium (Mg) ha^{-1} (Palm, 1995). Fertilizer trees like *Indigofera, Leucaena, Sesbania, Albizia*, etc. have been experimented as alley crop or hedgerow crop. On an average, pruning of N-fixing hedgerow species add 20-80, 3-4 and 8-38 kg ha^{-1} yr^{-1} of N, P and K, respectively (Subba Rao and Saha, 2014).

Evaluation of soil chemical properties of traditional agroforestry system in north-eastern region indicated a spectacular increase in soil pH, organic carbon, exchangeable Ca, Mg, K, and build-up of avai1able P (Bray's P_2-P) under different agroforestry practices within 10-15 years of practice. Accumulation of 2.91% organic carbon was observed under areca nut + jackfruit + black pepper + cinnamom (Tejpata), followed by 1.85% under areca nut + betelvine + miscellaneous trees as against 0.78% only in a degraded land within 10-15 years of this practice. A sharp increase in exchangeable Ca, Mg, K and sodium (Na) was noticed in all the agroforestry interventions over adjoining degraded lands. The exchangeable Aluminium (Al), potential cause of infertility of these lands disappeared completely within 10-15 years of agroforestry practice. This was attributed to the addition of fresh organic matter which complexed exchangeable Al during decomposition possibly due to formation of Al-humate and accumulation of Ca, Mg, K and Na cations. It eventually increased soil pH by 0.6 to 1.7 units under these agroforestry practices. Thus, the potential agroforestry practice was found to have built in dynamism for the restoration of soil fertility and sustained yield (Singh *et al.*, 1994). Similar results were obtained when multipurpose trees were evaluated in an extremely P-deficient acid alfisol in Meghalaya (Dhyani *et al*., 1994). Trees like *Alnus nepalensis*, *Parkia roxburghii*, *Michelia oblonga, Pinus kesiya* and *Gmelina arboria* with greater surface cover, constant leaf litter fall and extensive root systems increased soil organic carbon by 96.2%, helped with better aggregate stability by 24.0%, improved available soil moisture by 33.2% and in turn reduced soil erosion by 39.5% (Subba Rao and Saha, 2014).

Improvement in soil health due to integration of trees in croplands has been reported by various researchers (Prasad *et al*., 2016 and 2017). Assessment of soil quality by developing a composite soil quality index (SQI) based on soil indicators was carried out in a well-established 20 years old *Hardwickia binata*-based agroforestry system at ICAR-CAFRI, Jhansi, aiming to evaluate the effect of tree densities on SQI and how soil quality indicators respond in respect to tree density. The trial consisted of four treatments *viz*., control (pure crop), 200, 400 and 800 trees ha^{-1}. Increase in tree density of *H. binata* has shown favorable effect on most of the studied soil quality indicators. Maximum SQI was observed in density of 800 trees ha^{-1} while minimum in control. In comparison to baseline, the improvement in SQI was minimum in control (6.8%) and maximum in agroforestry plot (35.1%) having density of 800 trees ha^{-1}. The improvement in soil quality over control ranged from 17.2 (200 trees ha^{-1}) to 30.4% (800 trees ha^{-1}) (Figure 1).

The computed value of SQI ranged from 0.355 to 0.547 and had sensitivity of 1.54, reflecting its sensitiveness to density management. The infiltration rate (water movement), available K and biological activity appeared to be sensitive and critical indicators for soil health in Bundelkhand region of central India (Figure 2).

Nutrients Recycling and Crop Productivity

It is scientifically proved that agroforestry promotes efficient cycling of nutrients that benefits intercrops. Agroforestry can partially provide the N requirement of crops; however, it depends on a variety of factors including the decomposition rate of organic mulches, biological N-fixation and residue management. Trees can provide N inputs in agroforestry systems through biological N-fixation and deep nutrient capture. The presence of active nodules in roots of leguminous species indicates that biological N-fixation can supply considerable N inputs to crops via litter in soils. The non-fixing trees, such as *Cassia* accumulate more N in their leaves than N-fixing legumes, presumably because of their greater root volume and ability to capture nutrients which can be added to the soil as green leaf manuring. *Gliricidia*, *Leucaena* and *Sesbania* are also known for their N-fixation and green-manuring potential. Deep nutrient capture by tree roots at depths where crop roots are not present are considered as an additional nutrient input in agroforestry systems because such nutrients are otherwise leached as far as the crop is concerned. They become an input on being transferred to the soil via tree litter decomposition (Yadav *et al*., 2008). Agroforestry, however, cannot supply most of the other nutrients required by crops. P is often a critical nutrient in agroforestry.

Combinations of organic and inorganic sources of P may result in a more efficient use of nutrients. The deep capture of P is likely to be negligible because of the very low concentrations of available P in the subsoil. Many agroforestry systems do accumulate P in their biomass and return it to the soil via litter decomposition, but such cycling does not constitute an input from outside the system. However, through cycling, some less available inorganic forms of P in the soil may be converted into more available organic forms. A study conducted at ICAR-CAFRI, Jhansi has revealed that the intensity of pruning management in *Albizia procera*-based agroforestry system had influenced P sorption capacity of soil and uptake by wheat intercrop (Figure 3).

Maharudrappa (1999) reported that incubation of litter of different multi-purpose tree species (MPTS) enhanced nutrient availability. The release of K to soil was more dependent on the quantity and quality of the litter. *Tectona grandis* recorded significantly higher values than other tree species. The increase in available K may be attributed to the fact that K is not strongly bound in organic structures, unlike that of N and P.

Inclusion of legumes in the agroforestry system makes it N self-sufficient. Introduction of suitable legumes in rangelands, pastures, silvi-pastures and agroforestry has great significance. The important legumes, which are suitable for introduction in arid and semi-arid silvi-pastures are *Dolichos lablab, Clitoria ternatea, Atylosia scarabaeoides, Macroptilium atropurpureum* and *Stylosanthes* species, while pigeonpea, green-gram, black-gram, chickpea, groundnut, soybean, cowpea, pea, lucerne, berseem, etc. can be introduced under cultivated agroforestry (Suresh and Rao, 2000). There are significant differences in estimates of biological N-fixation in trees, ranging from high rates up to 472 kg N ha^{-1} yr^{-1} in *L. leucocephala*, *Gliricidia sepium, Calliandra calothyrsus* to low rates <50 kg N ha^{-1} yr^{-1} in *Acacia melanoxylon* and *Acacia holoserica* (Giller, 2001). In another beneficial interaction, mycorrhizal fungi associated with trees can help in taking up nutrient from deeper soil layers and increasing the availability of less mobile nutrients like P. Among non-legumes, *Alnus*, *Myrica* and *Casuarina* are widely recommended for agroforestry system, which fix N in association with *Frankia*. The N-fixing potential of *Casuarina equisetifolia* is 50-80 N kg ha^{-1} yr^{-1} and *A. nepalensis* is 29-117 N kg ha^{-1} yr^{-1} (Sharma and Kapoor, 2005).

Agroforestry for Food Security

The major challenge in ensuring food security is increasing productivity of *rainfed* agriculture which remains low to the extent of half to one–third of that obtained in *irrigated* condition. Continuous rise in human population has led to the cultivation of marginal and sub-marginal lands that accelerated degradation process of land resources. Choice of farming enterprises in *rainfed* regions is guided by climatic conditions and status of soil health. Constrained with both of these requirements, the *rainfed* areas are more vulnerable to the vagaries of nature (Prasad and Dhyani, 2010). It demanded attention of scientific community to develop sustainable land-use practices that assure continuous production and also improves soil (Prasad *et al*., 2012 and 2016). Agroforestry has been shown to provide a number of benefits to farmers. Regarding adaptation of agricultural production to climate change, agroforestry has potential to moderate climate extremes, in particular high temperatures, as well as intra-annual climatic fluctuations. Tree canopies can create a more adequate microclimate for crops and more resilient ecosystems for better food production. Although microclimatic effects may convey adaptation benefits to the farmers, added resilience through enhanced productivity and farming portfolio effects may be a greater contribution to coping with climate change at the farm level. Establishing agroforestry on land that currently has low tree cover has been identified as one of the most promising strategies to raise food production without additional deforestation (Garrity *et al*., 2010**).**

Agroforestry adoption by smallholders

Scaling up of agroforestry adoption among smallholder farmers has always been a key challenge. Agroforestry has not been picked up by smallholders despite its excellent carbon sequestering/production capabilities. Adoption of agroforestry depends on many management goals, drivers and contextual factors. In most cases, assets related to ecosystem services and to food security are main motivating factors in agroforestry adoption (DeSouza *et al*., 2013). Agroforestry has supportive functions also, for example, soil fertility improvement or water recycling, particularly when management techniques such as mulching or conservation agriculture are applied **(**Bucagu *et al*., 2013)**.** Agroforestry is therefore, often considered as a way to intensify farming practices for enhanced food security using socially and cost-effective management techniques. Many agroforestry options achieve this through low external input requirements, high recycling rates and crop-livestock integration (Koohafkan, *et al*., 2012)**.** These may thus be a viable option for smallholder farmers with limited resources, but where land holdings are small, farmers are often unwilling or unable to spare land for agroforestry establishment (even if this promises higher returns in the long run). Where land holdings are also insecure, farmers are often reluctant to invest in the long-term endeavour of establishing trees that may benefit the next owner of their land rather than themselves.

Another reason for non-adoption of agroforestry in India appears to its long juvenile phase during which resource poor small and marginal farmers (70% farmers of the India) do not get any return and consequently hesitate in adopting agroforestry land-use. For scaling up agroforestry adoption in India, Tewari *et al*. (2013) opined that the best option is to utilize provision of watershed development projects, which can be used as a tool to promote tree-based farming systems. The Integrated Watershed Management Programme (IWMP) operational in the whole country offers a good launching pad for promotion of agroforestry among smallholders and marginal farmers.

The important constraint that discourages agroforestry adoption by smallholders is the lack of proven set of management packages for agroforestry systems. The agro part (herbaceous component) of agroforestry is as important as its woody (tree) part; however, in most of the discussions, innovation and improvement are sought and centred on trees ignoring agronomic components. In most cases, crop varieties that are developed for high performance under conditions of optimum supply of light, nutrients, and water and freedom from pests and diseases are integrated in agroforestry system where such optimum conditions are lacking. This results in poor yield of crops which, ultimately questions the economic viability of particular agroforestry system. Hence, there is an urgent need to develop crop varieties and cultivars which perform well in below-optimal growth conditions commonly exist in agroforestry. There have been many breeding efforts to develop crop varieties suitable for some special conditions such as drought, water-logged, saline and sodic soils and nutrient deficient soils but breeding or selection of crops varieties that are suitable for sub-optimal light conditions (as exists in agroforestry) has never been attempted. Similarly, there is need to develop set of agronomic package of practices for crop grown as intercrops in agroforestry systems. A review on agronomic practices under agroforestry by Ghosh *et al*. (2014) opines that though the basic principles of agronomy remain the same, the agronomic practices are slightly modified owing to presence of perennial component in agroforestry.

Synergies between food security and climate change

Climate change mitigation has not traditionally been a driver of farmers' decisions, and it is unlikely to become a major driver in the future. Clearly, sequestering carbon on farms for the sake of climate change mitigation may not be attractive for a smallholder farmer, especially if mitigation efforts do not lead to short-term increases in income or welfare. Farmers may be very reluctant to sacrifice any part of their often meagre farm incomes to sequester carbon. If such farmers are to contribute to mitigation anyway, carbon-sequestering land-use strategies must either be subsidized, to an extent that makes them equivalent to foregone profits from alternative land-uses or they must be profitable in their own right without any compensation. Agroforestry is one the few land-use strategies that promises such synergies between food security and climate change mitigation. It is also less likely than other strategies to negatively affect the provision of non-carbon ecosystem services, such as water cycle regulation or biodiversity conservation (Mbow *et al*., 2014).

Agroforestry for Climate Change

Indian agriculture is highly prone to the risks due to climate change; especially to drought because 2/3rd of the agricultural land in India is *rainfed* and even the *irrigated* system is dependent on monsoon (Pathak *et al*., 2015). The increasing concern for global climate change is that the future rate of climate change will be much faster than in the past and will produce combinations of temperature and precipitation that have no previous analogues. The main cause of global warming is the increase in concentration of greenhouse gases (GHGs) in the atmosphere (Van Noordwijk *et al*., 2011).

To tackle the issues of climate change and put a break on global warming, various mitigation and adaptation strategies have been suggested. The concept of low carbon economy, originated as a response to mitigate GHGs, envisages that the basic activities of a modern society, including production of goods and services,and transportation should have near zero carbon emissions or minimum value to cease or at least slow down the global warming phenomenon. Agroforestry land-use can be used as low carbon agricultural technology since it embraces trees into farming systems for producing various marketable food and non-food products besides offering great potential of sequestering atmospheric carbon and an almost zero cost approach for restoration of badly degraded land through N-fixing trees and shrubs (Prasad *et al*., 2014). In context of climate change, since agroforestry supports both adaptation (ensuring that the land cover can deal with likely climate changes without major loss of function) and mitigation (reducing net emissions by enhancing terrestrial carbon storage), it is referred as 'mitigadaptation' (Van Noordwijk *et al*., 2011). As a mitigadaptation strategy, agroforestry offers additionality over the other option of mitigation. The additionality factor of agroforestry comes from its conservation value and services to the environment (Newaj and Dhyani, 2008).

Carbon sequestration

Agroforestry is often considered a cost-effective strategy for climate change mitigation. Tree-based farming systems store carbon in soils and woody biomass, and they may also reduce GHG emissions from soils. Compared to plantations of forestry species, carbon sequestration in agroforestry is relatively slow. Majority of the agroforestry systems have potential to sequester carbon which may vary according to tree species (Prasad *et al.*, 2012) and management practices (Newaj *et al.*, 2001). With adequate management of trees under agroforestry systems, a significant fraction of the atmospheric carbon could be captured and stored in plant biomass and soils. Carbon storage in plant biomass is feasible in the long rotation agroforestry systems including wind-breaks, shelter belts, woodlots, boundary plantations and others. The average carbon storage by agroforestry practices has been estimated as 9, 21, 50 and 63 Mg C ha^{-1} in semi-arid, sub-humid, humid and temperate regions, respectively. For smallholder agroforestry systems in the tropics, potential carbon sequestration rate ranges from 1.5 to 3.5 Mg C ha^{-1} yr^{-1} (Montagnini and Nair, 2004). Considerable quantities of carbon (1.1–2.2 Pg) could be removed from the atmosphere in the next 50 years if agroforestry systems were implemented on a global scale (Albrecht and Kandji, 2000). A study in ICAR-CAFRI, Jhansi revealed that in different agroforestry systems, soil organic carbon (SOC) stock ranged from 23.4 to 31.7 Mg ha^{-1} while SOC built rate from 1.1 to 3.2 Mg ha^{-1} yr^{-1} (Figure 4).

A preliminary estimate indicated area under agroforestry in India as 25.32 million ha (Dhyani *et al*., 2013), which 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. According to Pandey (2007), carbon sequestration in Indian agroforests varies from 19.56 Mg C ha^{-1} yr^{-1} in north Indian state of Uttar Pradesh to a carbon pool of 23.46–47.36 Mg C ha^{-1} in tree-bearing arid agro-ecosystems of Rajasthan. CAFRI conducted a survey in 32 districts of 12 states in the country for carbon sequestration potential (CSP) of existing agroforestry systems in the farmers' fields. It revealed that agroforestry is practiced in all parts of India and is recognized as having high potential for carbon sequestration. The CSP of existing agroforestry systems at district level has been estimated to range from 0.05 to 2.78 Mg C ha^{-1} yr^{-1}. Based on this study, the average CSP of the existing systems at country level was 0.34 Mg C $ha^{-1}yr^{-1}$ or equivalently agroforestry systems in India has the potential to mitigate 1.245 Mg CO_2 $ha^{-1}yr^{-1}$. Thus, the trees in existing agroforestry systems on farmers' fields are estimated to mitigate more than 33% of the total GHG emissions from agriculture sector annually at the country level (Ajit *et al.,* 2017). The average cost of sequestering carbon through agroforestry systems is lower than other CO_2 mitigation options. It has been estimated that in India in addition to the existing area, 17.85 million ha area is potentially suitable for converting into agroforestry and a 25-30% conversion of this land into agroforestry by the year 2030 can sequester up to 47.23 M t C y^{-1} which is substantial (Dhyani, 2012), and is higher than the annual increment of C stock of 38 M t from the forests and tree cover (FSI, 2009).

Ecosystem services

Agroforestry systems are believed to provide a number of ecosystem services. Trees with deep rooting systems in agroforestry can also improve ground water quality by serving as a ''safety net'' whereby excess nutrients that have been leached below the rooting zone of agronomic crops are taken up by tree roots. The other benefits include effectively protecting buildings and roadways from drifting snow, savings in livestock production—by reducing wind chills, protecting crops, providing wildlife habitat, removing atmospheric carbon dioxide and producing oxygen, reducing wind velocity and thereby limiting wind erosion and particulate matter in the air and reducing the noise pollution.

Agroforestry is playing the greatest role in maintaining the resource base and increasing overall productivity in the *rainfed* areas in general and the arid and semi-arid regions in particular (Prasad and Dhyani, 2010). Agroforestry land-use increases livelihood security and reduces vulnerability to climate and environmental change. There are ample evidences to show that the overall (biomass) productivity, soil fertility improvement, soil conservation, nutrient cycling, microclimate improvement and carbon sequestration potential of an agroforestry system is generally greater than that of an annual system (Dhyani *et al*., 2009). Agroforestry has an important role in reducing vulnerability, increasing resilience of farming systems and buffering households against climate related risks. It also provides ecosystem services- water, soil health and biodiversity. Agroforestry based watershed interventions enhanced provisioning ecosystem services (e.g. crop intensification and yield) and regulating ecosystem services (enhancing base flow, reducing siltation and enhancing groundwater availability), income and livelihood of farmers in Bundelkhand region (Singh *et al*., 2014).

Future Research and Planning

Agroforestry land-use has the real potential to contribute to food security, climate change mitigation and adaptation, while preserving and strengthening the environmental resource base of rural landscapes (Mbow *et al*., 2014). For millions of farmers whose livelihoods are threatened by climate change and land degradation, agroforestry offers a pathway toward more resilient livelihoods. However, not all agroforestry options are viable everywhere, and the current state of knowledge offers very little guidance on what systems work where, for whom and under what circumstances. The following questions that remain unanswered for most places need to be answered by future research and policy planning:

- Which tree-crop-site combinations are characterized by synergistic interactions?
- What extension methods are most effective for promotion of climate-smart agroforestry systems?
- Which agroforestry systems support healthy, ecologically functional landscapes?
- How can ecosystem service delivery through agroforestry systems be optimized?
- How will agroforestry species respond to climate change?
- Are adaptation benefits from agroforestry greater than those of alternative land-uses?
- How, if at all, can smallholder farmers benefit from carbon payments or payment for ecosystem services that agroforestry provides?

The above list is by no means exhaustive. In fact, knowledge gaps in agroforestry are greater than the actual body of knowledge on most aspects. It is therefore essential that research efforts on these important cropping systems are intensified, so that future scaling-up of agroforestry can be rooted in robust scientific findings rather than the intuitions of governments and development actors.

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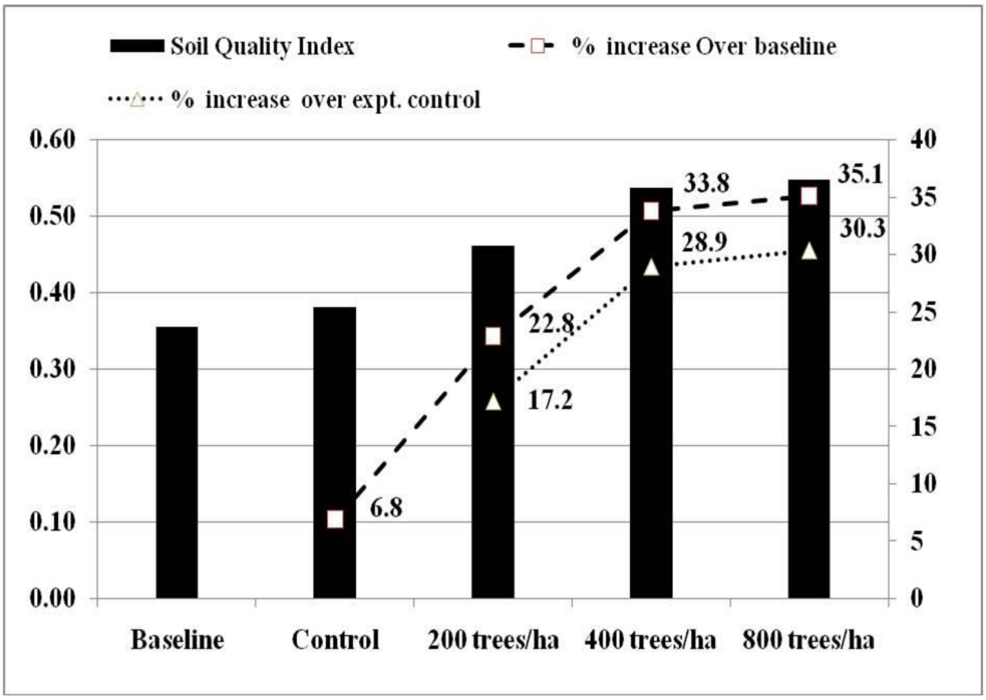

Figure 2: Effects of tree density on soil quality index in Hardwickia binata-based agroforestry system in Jhansi.

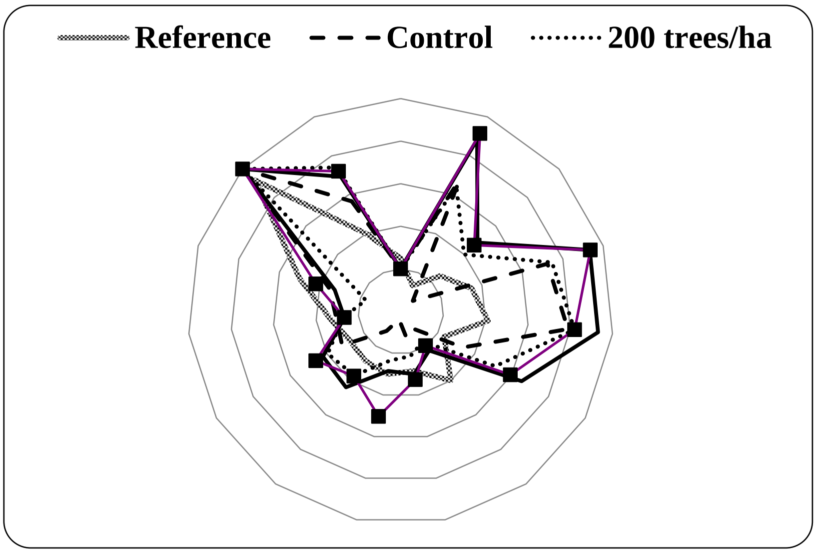

Figure 3: Radar plot of soil quality index and linear scores of soil quality indicators in Hardwickia binata-based agroforestry system, Jhansi.

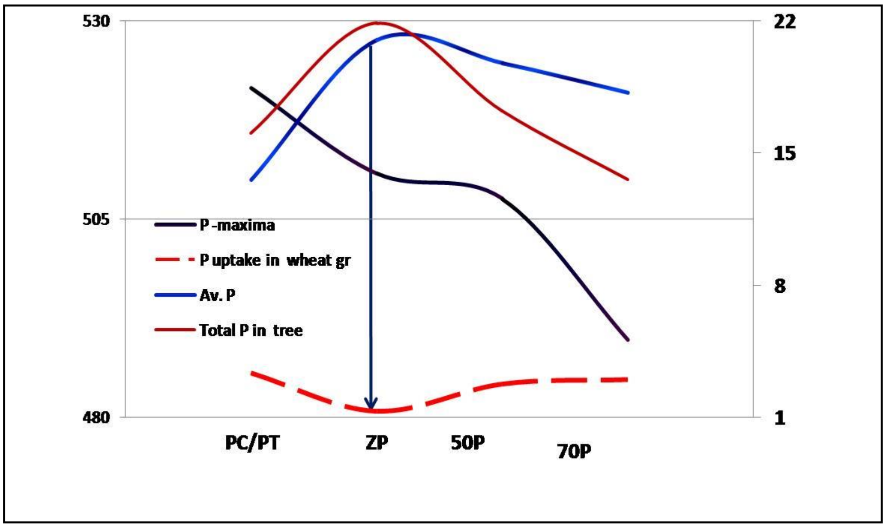

Figure 4: Phosphorus uptake in Albizia procera-based agroforestry system.

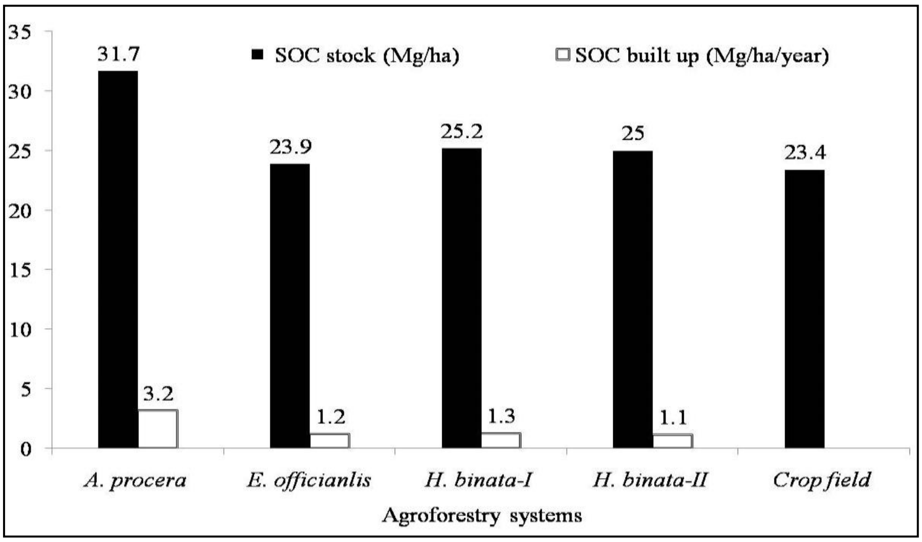

Figure 5: Soil carbon stock and built up in different agroforestry systems at ICAR-CAFRI Jhansi.

Agroforestry for Livelihood, Nutritional and Environmental Security in Arid and Semi-arid Zone

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Abstract
Trees and forests have always been an integral part of the culture in Indian subcontinent and also in Africa. Planting of trees is/was regarded sometimes as a religious and at other times as noble act which has helped in maintaining desired level of tree cover in the different countries. But increasing population has changed this scenario to a scale that gap between demand and supply of tree products (fuel, fodder and timber) has become very wide. Thus, in process, forests are being ruthlessly exploited to meet this demand. Hence, concepts like multiple use of land, multifunctional agriculture with multipurpose tree species have become immensely important. Therefore, agroforestry, which is a form of multiple land use system, need be popularized, encouraged and adopted. Different workers at various places in Indian arid and semi-arid regions have reported the beneficial effect of agroforestry both in terms of production and improved soil conditions. Growing trees and fodder crops, including fodder trees is more economical in marginal lands of hot arid and semi-arid areas than conventional cropping. Tree species such as Prosopis, Albizia, Hardwickia, Zizyphus and Acacia provide many times more returns per unit of land than agriculture in these areas. The present lecture note envisages, significance of agroforestry including number of tangible and intangible benefits. Some inherent limitations in widespread adoption of agroforestry like constant need to adapt in view of changing crop varieties, limited research in improving genetic potential of trees, limited availability of suitable farm machinery and increasing/changing regulations governing harvesting of farm trees have also been discussed.

Key words: Traditional System; Evolving Agroforestry, Limitation in wide spread adoption

Introduction

Agroforestry is a summary term for practices that involves integration of trees and other large woody perennials into farming systems through the conservation of existing trees, their active planting and tending, or the tolerance of spontaneous tree regrowth (Schroth et al., 2004). Farmers have placed trees among their crops to enhance soil health, raise marketable fruits and protect row crops from damaging winds for a long time. Yet agroforestry, as this practice is known, is generally considered a rarity among mainstream farmers. Recent report of Word Watch Institute (*http://www.worldwatch.org/node/6244; assessed on August 06, 2019*) suggests that more farmers practice agroforestry than previously appreciated.

Nearly half of the World's farmlands have at least 10 per cent tree cover which aggregates to more than 10 million square kilometres in total. This study reported large areas under agroforestry in South America (3.2 million squared kilometers), sub-Saharan Africa (1.9 million squared kilometers), and Southeast Asia (1.3 million squared kilometers) and offered convincing evidence that farms and forests are in no way mutually exclusive. Trees are in fact critical to agricultural production everywhere. Agroforestry has long been promoted by advocates of sustainable agriculture but the practice is now gaining increased attention for its potential to sequester large amounts of carbon dioxide. UNEP estimated that 6 Pg of carbon dioxide equivalent could be sequestered on farmland by 2030, as agroforestry is more widely adopted as an agricultural practice. In addition to absorbing carbon dioxide from the atmosphere, some trees can also capture nitrogen and therefore, reduce the need for energy-intensive nitrogen fertilizer. In the subsequent paragraphs we have discussed agroforestry in context of arid zones of India.

The arid zone of India occupies an area of 32 million hectare which is about 13% of the geographical area of the country. It is spread over Rajasthan (62%), Gujarat (19%), Punjab and Haryana (9%) and Andhra Pradesh and Karnataka (10%). The main problems of these areas are low availability of rainfall (Table 1), limited irrigation water and high frequency of droughts which adversely affect growth of vegetation. Also there is continuous increase of human and animal population in these areas which has nearly doubled up during the last one decade. Consequently, grain, fodder and fuel wood requirements has increased meagre natural resources of the region are being overexploited due to large scale cutting of trees, shrubs and even roots to meet fuel wood and fodder needs. Pasture lands have been degraded due to over and indiscriminate grazing. This has accelerated erosion processes and converted productive lands to wastelands. Continuous exploitation of the ground water is leading to lowering of the water table and deterioration of its quality.

Science of agroforestry

Tropical forests show existence of nearly closed nutrient cycles. Nutrient inputs from atmospheric deposition, biological nitrogen fixation and weathering of primary soil minerals are in balance with nutrient losses owing to leaching, denitrification, runoff and erosion. Nitrogen, phosphorus, potassium, magnesium, calcium as well as sulphur and micro-nutrients are absorbed by forest roots and returned to the soil *via* decomposition of litter and roots as well by through-fall and stem-flow. Tropical humid forests accumulate huge quantities of nutrients in their vegetation as the forest grows, with a mature forest reaching steady state values of 700 to 2000 kg N, 30 to 150 kg P and 400 to 3000 kg K, Mg or Ca per hectare (Dembner, 1996). The soil also contains large quantities of nutrients. The efficient cycling of nutrients from the soil to the biomass and back to the soil makes possible the lush tropical forest growing even on relatively infertile soils, as long as there are no major biomass removals from the system. These processes in arid and semi-arid region lead to a fertility island near the tree (Figure 1). On the other hand agricultural systems differ from natural systems in one fundamental aspect i.e. there is a net output of nutrients from the site via crop harvest removals. This nutrient removal can result in net negative balances if nutrients are not replenished. Thus in contemporary agriculture, nutrient depletion is offset by fertilizers, manures from outside the field and other nutrient inputs. But, nutrient replenishment does cause economic burden on farmers and raises question on its sustainability.

One fundamental principle of sustainability is to return to the soil the nutrients removed through harvests, runoff, erosion, leaching, denitrification and other loss pathways. Agroforestry, the growing of trees with crops and/or livestock on the same piece of land, is believed to promote a more efficient cycling of nutrients than agriculture. This hypothesis is based partially on studies of the efficient cycling of nutrients from litter to trees in natural ecosystems, and the assumption that trees in agroforestry systems will likewise transfer nutrients to intercropped plants. This is supported by observations of higher crop yields near trees of *Prosopis cineraria* in Indian arid zone and *Faidherbia albida* in the Sahel and where trees have been recently removed, as in the case of bush and tree fallows. Trees, often improve soil fertility, but for better crop growth in association with trees, one must also consider the relative importance of other factors such as soil structure, soil organic matter and the competition for light, water and nutrients in a particular system.

Two key principles set agroforestry systems apart from agricultural or forestry systems: competition and complexity. They in turn determine two desirable properties: profitability and sustainability. All four can be combined as biophysical and socioeconomic issues. The biophysical bottom line of agroforestry is how to manage the competition between the tree component and the crop for light, water and nutrients to benefit farmer. Although agroforestry systems have been classified in a myriad different ways, there are two functionally different types, simultaneous and sequential systems.

Simultaneous agroforestry is where the tree and the crop components grow at the same time and sufficiently close to each other and at time lead to competition for light, water or nutrients as in case of parkland and alley cropping. These systems can also vary greatly in the relative proportions of trees and crops, in their spatial arrangement, in extent of competition and is generally higher in alley cropping than in parkland. Sequential agroforestry systems are those where the maximum growth rates of the crop and the tree components occur at different times, even though both components may have been planted at the same time and are in close proximity. Examples of this type are shifting cultivation, improved fallows, taungya and some multi-strata systems. Competition for growth resources is minimized in sequential agroforestry because the peak demands for light, water and nutrients occur at different times for each component. In tropical ecosystems, both natural and derived, nitrogen and particularly phosphorus frequently limit production and in arid, moisture is added to this list.

Traditional agroforestry in Arid and Semi-Arid India

In arid areas the farmers have been traditionally protecting *Prosopis cineraria*, *Ziziphus* spp. and *Acacia* spp. in their farmlands with a firm conviction that these trees besides conserving, add to the fertility and overall productivity of soil. These species are drought hardy and well adapted to the climatic conditions of the desert. *Prosopis cineraria* forms climatic climax of western Rajasthan and dominate the alluvial flats while *Ziziphus* is one of the main co-dominant species on the flood at plains of arid and semi-arid zones. Studies carried out during 90s reported large variations in the density of *P. cineraria* 30 to 104 trees ha^{-1} in the region. Tree density of even 80 tree ha^{-1} was reported to improve crop production in sandy plains due to number of factors but mainly due to build-up of soil fertility. Besides these two tree species, *Acacia nilotica* and *A. nilotica var. cuperessiformis* and *Ailanthus excelsa* are other main species. Some of the agroforestry systems traditionally followed involving these trees are given in Table 2 and their photographs in Figure 2. The main productive functions of traditional agroforestry systems are production of cereals and other food grains, oil seeds, fuel wood, fodder, wood for agricultural implements, minor timber, minor tree products like fruits, gum, resins, and vegetables, etc. The gross returns offered by these systems is quite profitable over sole cropping (Harsh and Tewari 2007; Narain and Tewari 2005; Dayal *et al*., 2015).

Perspective Agroforestry in Arid and Semi-arid Zones -Integrated Farming System

Agroforestry is seldom practiced in isolation in arid region and is integrated with a variety of land uses which together make it an integrated farming systems. Like agroforestry, the composition of farming system at any location at a specific time is function of available natural resources and climate, available information & technology, market development, human capital, and indigenous technological knowledge (FAO, 2001). The judicious combinations of two or more land uses (components) in accordance with climate, resource availability, technology availability, market facilities, generate a location-specific IFS. But often unlike the concept of agroforestry environmentally sustainable is not the only but one of the criteria to evaluate the success. IFS need be profitable, energy self-sufficient, adapted to the climate, ensure resource conservation, efficient recycling of resources provides nutritional security and gainful employment (Behera and France, 2016). Various suitable IFS for arid and semi-arid regions were developed in farmer field and at research station by integrating various compatible enterprises such as crops (field crops, horticultural crops), agroforestry (agri-silvi culture, agri-horticulture, agri-pastoral, silvi-pastoral, horti-pastoral), livestock (dairy, pigs, poultry, small ruminants), fishery, mushroom, biogas production and tree plantation (Jayanthi *et al*., 2001; Singh *et al*., 2007; Gill *et al*., 2009; Surve *et al*., 2014) (Table 3).

The results of a long-term study conducted at ICAR-CAZRI demonstrated that for an area of 7 ha the suitable proportion of agri-horticulture, farm-forestry, agri-silviculture, agri-pasture and silvi-pasture is 30, 20, 25, 15 and 10% (Bhati, 1997). *Prosopis cineraria, Hardwickia binata, Acacia senegal, A. nilotica, Tecomella undulata* are suitable tree species for agri-silviculture systems in hot arid regions. The *Prosopis* based Agri-silviculture is most prominent prevalent in rain-fed hot, arid region, and a tree density of 100 – 200 plants ha $^{-1}$ is optimum for co-cultivation of rainfed crops in arid regions. Strip cropping of *Lawsonia inermis* and cluster bean is suitable integrated production system for Pali region of Rajasthan (Singh et al., 2005). *Azadirachta indica* and *Ailanthus excelsa* based agri-silvicultural systems involving cow-pea, green gram, cluster bean and sesame are suitable agri-silvi system for the north and north western Gujarat arid regions (Patel et al., 2008).

The horticulture based integrated production system is efficient system for improving productivity, employment opportunities, economic condition and nutritional security in arid regions (Chadha, 2002). *Emblica officinalis, Punica granatum, Aegle marmelos, Phoenix dactylifera* are suitable fruit trees for areas having irrigation facilities, whereas *Capparis decidua, Salvadora oleoides, Cordia dichotoma, C. gharaf, Ziziphus nummularia var. rotundifolia, Z. mauritiana* are suitable for areas receiving annual rainfall < 300 mm. *Solanum melongena, Lagenaria siceraria, Luffa acutagula, Luffa cylindrica, Citrullus lanatus, Citrullus lanatus var. fistulosus, Cucmis melo var. utilissimus, C. melo var. momardica, C. callosus, Cyamposis tetragonoloba* are suitable vegetable for horticultural based farming system in arid region (Pareek and Awasthi, 2008). In order to mitigate the risk of total crop failure, suitable crop combinations in the interspace of orchard during initial years can generate extra income, improve productivity, ameliorate and improve the ecological situation (Awasthi *et al*., 2008). Agri-horti system involving *Z. mauritiana*/ Z. *rotundifolia* + *Vigna radiata* / *Vigna aconitifolia*/ *Cyamopsis tetragonoloba* was found environmentally friendly and economically viable in hot arid regions (Bhati *et al*., 2008). Under limited irrigation facilities, the *Cyamopsis tetragonoloba* – *Brassica juncea* and Indian Aloe are suitable ground storey component for *Ziziphus* based agri-horti system (Saroj et al., 2003). Kinnow based agri-horti system (kinnow + mungbean, cotton, cotton – barley and cotton-chickpea) were found suitable in irrigated lands of Sriganganagar (Bhatnagar et al., 2007). The agri-horti system involving pomegranate + cluster bean/ horsegram/ mung bean / henna (Lal, 2008), and pomegranate + pearl millet / mung bean/isabgol/ sorghum/ cumin (Gupta et al., 2000) are suitable for Pali and Jalore regions, respectively. Awasthi *et al*. (2008) demonstrated that aonla based multi-storey production systems (aonla-ber-brinjal-moth bean- fenugreek and aonla-bael-karonda-moth bean- gram) are suitable farming system for irrigated conditions in Bikaner region.

Agroforestry for environmental security

Under traditionally grown tree based agroforestry systems like *P. cineraria, Dalbergia sissoo, A. leucophloea* and *A. nilotica* substantial improvement in soil biological activity in terms of microbial biomass C, N and P, dehydrogenase and alkaline phosphatase activity is reported (Yadav et al 2011). Also, agroforestry has been recognized as having the greatest potential for

C sequestration of all the land uses analyzed in the Land-Use, Land-Use Change and Forestry report of the IPCC (Nair et al. 2009;). In arid regions also tree based systems are reported to have greater carbon sequestration potential compare to arable cropping. The silvipastoral systems in arid northwestern India sequestered 36.3 to 60.0% more total soil organic carbon stock compared to the tree system and 27.1 to 70.8% more in comparison to the pasture system (Mangalassery et al 2014).

Conclusion-Agroforestry *viz a viz.* Sole Crop Production

Agroforestry is widely promoted, especially in tropical countries, as a way of reconciling multiple objectives within a single farming system, but it is important to recognize that just because agroforestry can work well in some contexts does not mean that it is the best land-use option everywhere for everything. Where agroforestry is as (or more) high-yielding as sole cropping, it could be used as part of a strategy to ensure that the footprint of farming is minimised, and that natural forests are "spared" from cultivation. Analysis of the abstracts presented in Nairobi Conference showed that primary purpose of agroforestry in tropical countries revolve around improved food security and livelihood options. Therefore, agroforestry would need to compete with sole crop based production system at least in tropics. Newer and higher yielding varieties are being evolved for all major crops of arid and semi-arid region as reflected in Figure 3 for pearl millet. These varieties are tested for suitability in sole crop based cultivation models but never under agroforestry conditions. However, they are extensively used in agroforestry based production systems. Using these varieties could alter scenario of competition especially in arid regions where the productivity is limited by water. Further, due to fast evolving crop specific management practices crop productivity is also increasing. These changes are putting agroforestry directly in competition with sole crop production in terms of profit.

Over past three decades agroforestry research has been transformed from collection of a largely descriptive studies into more scientific approach based and process-oriented research. The development of agroforestry as a science is based on management of four key features: competition, complexity, profitability and sustainability. The interplay of these factors inherently make agroforestry more complex than crop production. During last three decades, intensive production oriented research and mechanization have made crop production more profitable even on marginal lands of arid and semi-arid regions where agroforestry was traditionally more profitable. But, in spite of it, conceptually agroforestry is more sustainable approach and provide more tangible and intangible environmental benefits than crop production. Therefore, key question today is to provide a monitory value to these intangible benefits form agroforestry so that agroforestry could advance and take its due place in production systems.

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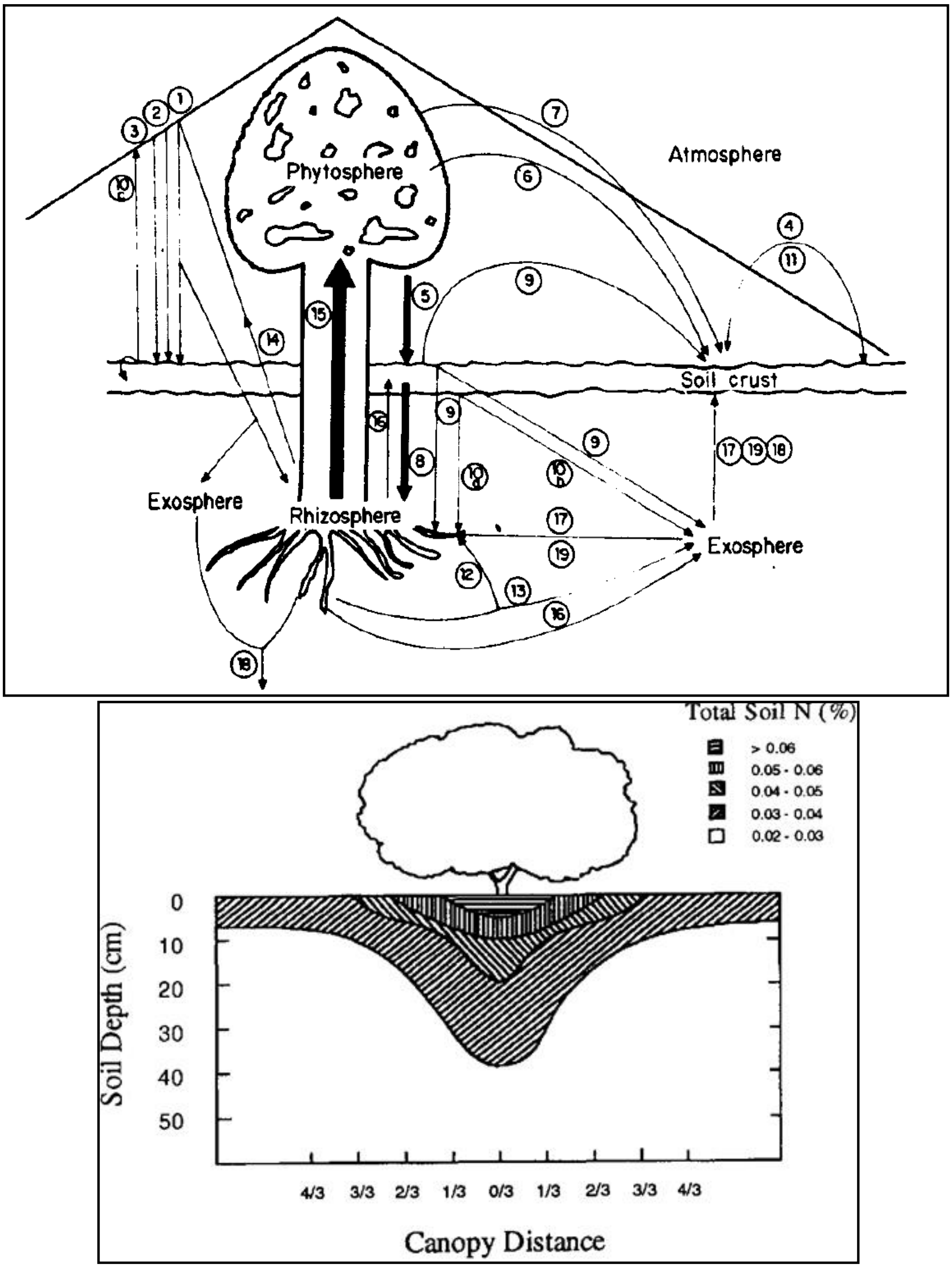

Figure 1: Processes leading to improvement of soil fertility due to trees and development of fertility islands around trees in arid zones

1. N2; 2. NOx; 3. NH3; 4. Particulate matter; 5. Litter; 6. Excreta; 7. Litter; 8. Organic N; 9. As in 8 + seeds; 10. NH3; 11. NH3+NOx on dust; 12. NH3; 13. NOx; 14. N2; 15. Plant sap; 16. Root litter; 17. NH3; 18 NOx; 19. Organic N; Reference: Garner & Steinberger (1989) https://doi.org/10.1016/S0140-1963 (18)30941-8 for details (Figure reproduced for teaching purpose only)

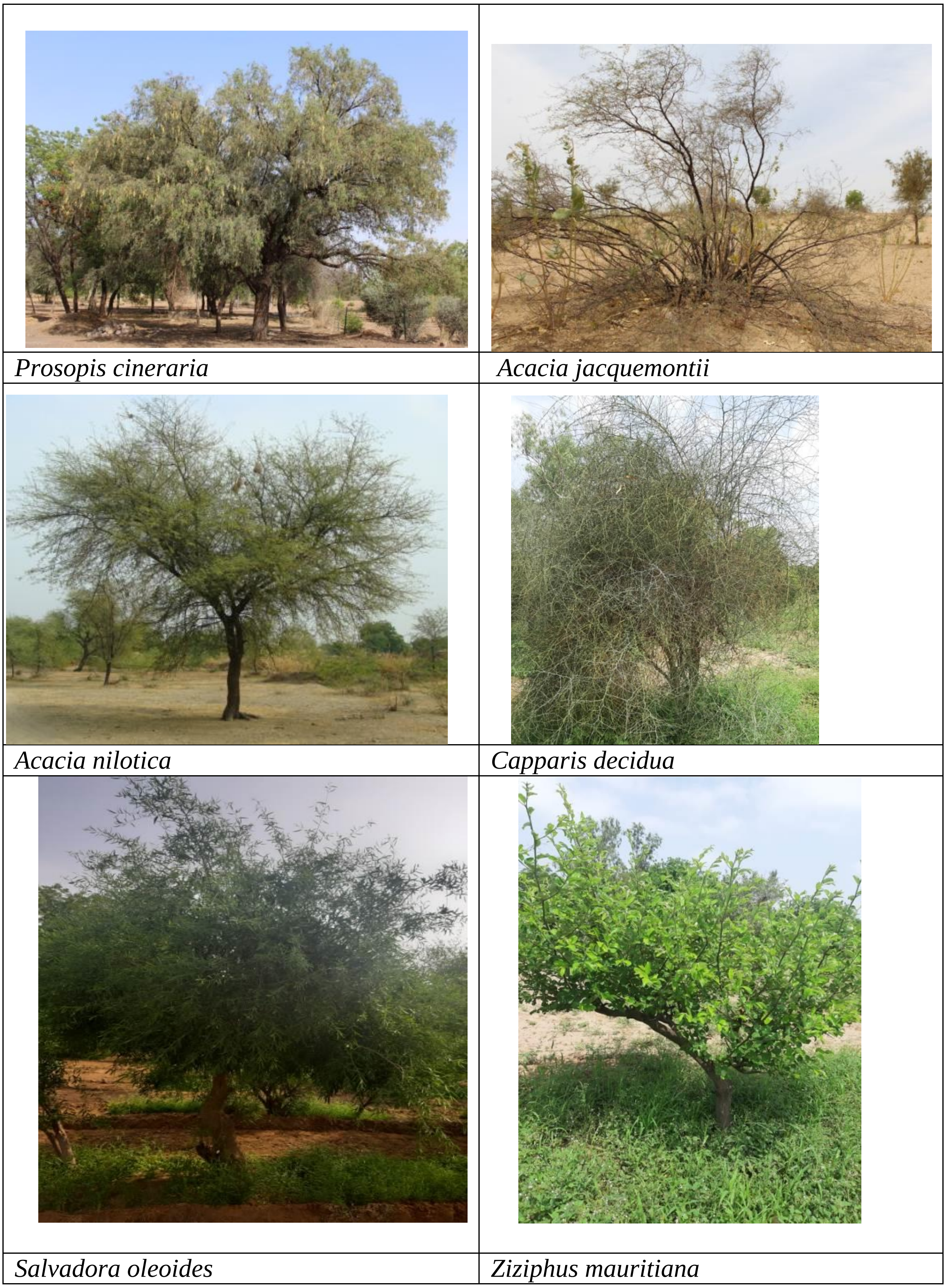

Photo credit- Dr. Kamlesh Pareek

Figure 2. Major perennial components of traditional agroforestry

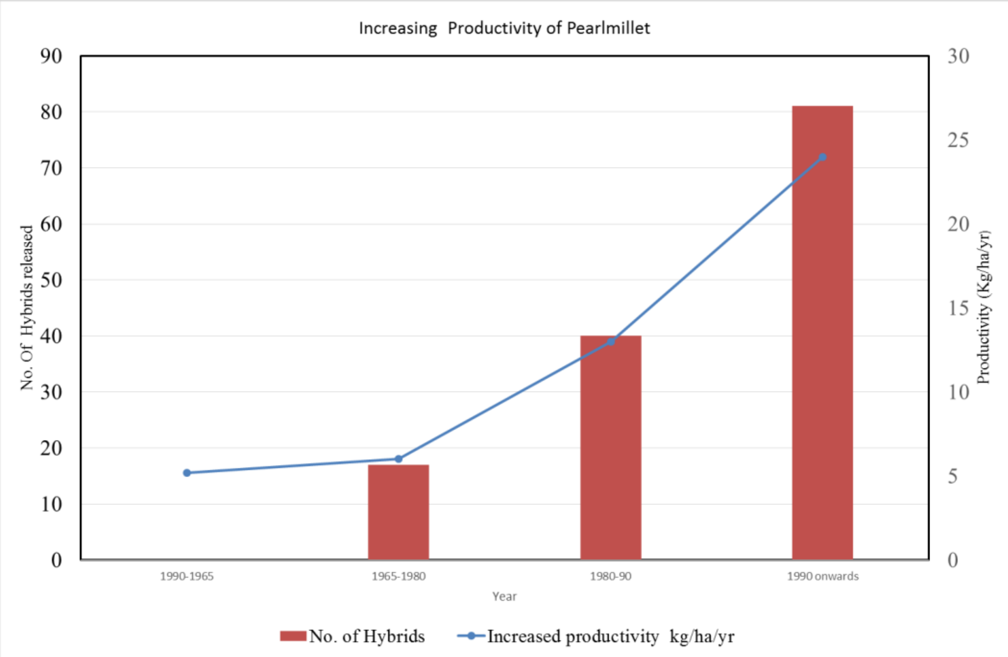

Figure 3: Periodic increase in number of released varieties of pearl millet and improvement in productivity (Yadav and Kai, 2013)

Table 1. Mean annual rainfall, moisture index, their coefficient of variation and frequencies of drought in some districts of the Indian arid zone.

Districts	Annual Rainfall (%)	C.V. of Annual (%)	Mean Moisture index	C.V. of Moisture index	* Freq. Of moderate to severe drought
Barmer	248.5	63.5	-79.0	10.0	3
Bikaner	323.4	49.0	-81.2	10.0	4
Churu	408.6	42.6	-75.1	12.1	3
Jaisalmer	214.1	66.1	-88.9	6.6	3
Jodhpur	361.4	60.7	-75.4	13.1	2

Table 2**.** Traditional agro forestry systems of T*har* Desert.

S.No	**District**	**Main tree/shrub species**	**Rainfall (mm)**	**Intercrops**
1.	Jaisalmer	*Calligonum polygonoides, Zizyphus nummularia, Prosopis cineraria, Capparis decidua*	100 – 200	Mung bean, pearl millet and cluster bean
2.	Sri-Ganganagar	*Prosopis cineraria, Acacia nilotica sub sp. Indica, Acacia tortilis*	200 - 300	Rainfed - Pearl millet, mung bean, cluster bean. Irrigated - Wheat, cotton, rice and mung bean
3.	Bikaner	*Zizyphus nummularia, Prosopis cineraria, Calligonum polygonoides, Acacia jacquemontii*	100 - 400	Mung bean, moth bean, cluster bean and pearl millet
4.	Barmer	*Prosopis cineraria, Zizyphus nummularia,Tecomella undulata, Capparis decidua*	200 – 400	Rainfed – Pearl millet, mung bean and cluster bean

5.	Jodhpur	*Prosopis cineraria, Zizyphus nummularia, Capparis decidua, Acacia Senegal*	200 – 400	Pearl millet, mung bean and cluster bean
6.	Churu, Jhunjhunu and Sikar	*Prosopis cineraria, Gymnosporia montana, Ziziphus nummularia*	300 – 600	Rainfed – Pearl millet, mung bean. Irrigated – Wheat, mung bean and mustard
7.	Nagaur	*Prosopis cineraia , Acacia nilotica*	300 – 500	
8.	Jalore	*Prosopis cineraia, Salvodora oleoides, Acacia nilotica and Punica granatum*	400 – 500	Pearl millet, mung bean, isabagol, sorghum and cumin
9.	Pali	*Acacia nilotica sub sp. Indica, Acacia nilotica var. cupressiformis, Acacia leucophloea, Acacia catechu, Salvodora oleoides*	400 - 600	Sorghum,pearlmillet, Mung bean and cluster bean

Tewari and Singh, 2006

Table 3. Productivity of integrated and conventional farming/ production systems in different arid and semi-arid regions of India.

Location/System	Remarks
Punjab	
(A) Farm-1	
CFS:Rice – wheat (2.0 ha) **IFS$_1$**: Rice –wheat (1.78 ha)+ dairy (0.22) **IFS$_2$**: Rice–wheat (1.22 ha)+ dairy (0.22)+ fishery(0.56) **IFS$_3$**: Rice–wheat(1.14ha)+ dairy (0.22)+ fishery(0.56)+ piggery (0.24)	IFS produced 65 to 79% higher yield *viz* a *viz* CFS (Gill et al., 2009)
(B) Farm-2	
CFS:Rice – wheat (2.0 ha) **IFS$_1$**: Rice –wheat (1.4 ha)+ dairy (0.6) **IFS$_2$**: Rice–wheat (0.4 ha)+ dairy (0.6)+ fishery(1.0)	IFS produced 53 to 68% higher yields *viz* a *viz* CFS
(C) Farm-3	
CFS:Rice – wheat (1.0 ha) **IFS$_1$**: Rice –wheat (0.6 ha)+ dairy (0.4) **IFS$_2$**: Rice–wheat (0.6 ha)+ dairy (0.4)+ Poultry(100)	IFS produced 100 higher yield *viz* a *viz* CFS
Tamilnadu, Coimbatore	
CFS : Cropping alone **IFS$_1$**: Crop + fish + poultry **IFS$_2$**: Crop + fish + pigeon **IFS$_3$**: Crop + fish + goat	IFS produced 161 to 255% higher yield *viz* a *viz* CFS (Jayanthi et al., 2003)
Karnataka Sriguppa	
CFS:Rice – rice (1.0 ha) **IFS**: Rice –rice (0.33 ha), Maize-sunflower (0.20 ha), Vegetable (0.20 ha), Fodder+ goat (0.21 ha), Fish (0.06 ha), Poultry (0.005 ha)	IFS produce 26% higher yield *viz* a *viz* CFS (Channabasavanna et al. , 2009)
Rajasthan	
Jodhpur	
CFS: sole *Hardwickia binnata* Sole *Cenchrus ciliaris* **IFS:** *H. binnata + C. ciliaris*	Fodder production in IFS was more than the yield under sole tree or pasture alone (Harsh and Tewari, 2007)

CFS: Sole green gram **IFS**: green gram with *Ziziphus mauritiana*	Under IFS mung bean produced 5 -20% higher yield *viz* a *viz* CFS (Singh et al., 2003)
CFS : Sole pearl millet **IFS** : Pearl millet + *Acacia senegal* (140 plant ha^{-1})	Harsh and Tewari, 2007

CFS : Conventional farm ; *IFS* : *Integrated farming systems*

Table 4. Change in productivity (kg/ha) of different crops between 2006-10 and 2011-14

Crop	**2006-10**	**2011-14**
Pearl Millet	740	794
Moong bean	369	401
Moth Bean	176	318
Cluster Bean	358	479
Groundnut	1498	1670
Seasame	265	260
Cumin	174	318

Source: Statistics of Rajasthan (2006-2014)

Concept and Application of GIS and Remote Sensing in Agroforestry

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Abstract
Geospatial technologies like GIS, GPS and satellite remote sensing have wide applications in crop area estimation, forest cover assessment, management of natural resources, watershed planning & monitoring, disaster assessment, etc. These technologies can be successfully applied in agroforestry research and development in India. Some of the fields of agroforestry research are: estimation of agroforestry area in the country, assessment of carbon stock/ sequestration under agroforestry systems, development of library of spectral signature for identification of tree species on farms, development of spatial decision support systems (SDSS) for selection of suitable agroforestry species/ systems for a particular area. This chapter has highlighted recent developments in these research areas of agroforestry. Methodology for estimating area under agroforestry using remote sensing and some country level estimates are given. How the geospatial technologies can be utilized in assessment of carbon sequestration under agroforestry systems is described. Different methods of tree species identification on farms using remote sensing have also been discussed.

Keywords: Agroforestry Mapping, Geo-spatial Technology, Hyperspectral Remote Sensing, Spectral Signatures, Sub-pixel Method, Tree Species.

Introduction

In India the diagnostic survey and appraisal of agroforestry practices in the country revealed that there are enumerable practices in different agro-ecological zones (Pathak et al. 2000). These systems/practices occupy sizeable areas. Although different estimates at country level are available, but they are not realistic as they are not based on ground verification. Dhyani et al. (2013) estimated the agroforestry area as 25.32 million ha or 8.2 percent of the total geographical area of the country. As such on an average 14.2% of total cultivated land has agroforestry in one form or the other. However, these estimates are not the true reflection as they are not based on ground verification or revenue records. They have also projected the agroforestry area for year 2050 at 53.32 million ha. Nair *et al*. (2009) estimated globally 823 M ha area under agroforestry and Silvo-pastoral systems, of these 307 M ha is under agroforestry. However these estimates come from taking the FAO estimate of agricultural land multiplied by an estimate of 20% covered by agroforestry.

The applications of geospatial technologies enable the storage, management and analysis of large quantities of spatially distributed data. These data are associated with their respective geographic features. Satellite images are used to identify what is growing, while GIS component is used to assess area, categorize it and locate its position on earth's surface to provide complete record of the site. GIS enables the storage, management and analysis of large quantities of spatially distributed data (De Mers 1997). The integration of satellite remote sensing data into GIS is one of those great ideas which have made valuable contribution in other fields but need to be utilized in agroforestry. Furthermore, remote sensing is often the most cost effective source of information for updating a GIS and it is a valuable source of current land use/land cover data. Remote sensing techniques have been utilized successfully in certain areas of application, including forestry, watershed management, agriculture and related fields, especially in developed countries where agriculture patterns are well defined and methodologies developed.

Applications of Geospatial Technologies in Agroforestry Research

In India, the agroforestry database (Agroforestry BASE) has been developed containing information on various aspects of agroforestry under four independent module/database namely MPTs, economic analysis and agroforestry intervention/innovations (Ajit et al. 2003). Acosta and Reyes (2002) developed a geographic information system for identification of areas suitable for development of silvopastoral systems in the region of Jimaguyu in the provenance of Camaguey in Cuba. Bentrup and Leininger (2002) did suitability assessment using GIS to determine the best locations for growing agroforestry specialty products. Suitability assessment matches potential products with ideal growing conditions. The Southeastern Agroforestry Decision Support System (SEADSS) developed by the Centre for Subtropical Agroforestry (CSTAF) at University of Florida brings on-line GIS capabilities directly to the extension agents and land owners. It offers county soils, land use and other spatial data for selecting suitable tree and shrub species in a specified location (Ellis et al. 2005). An assessment of the current status of the West African agroforestry parklands was launched in 2002 by ICRAF. The GIS tool was used to find out links between tree biodiversity and land use among peasant farmers in three adjacent village territories in these parklands (Rouxel et al. 2005).

A geospatial analysis of remote sensing derived global datasets investigated the correspondence and relationship of tree cover, population density and climatic conditions within agricultural land at 1 km resolution. Also at landscape scale, the correlation between tree cover and % crown cover is probably quite good within broad agroforestry systems and climate zones but this will not be true globally (Zomer *et al*. 2009). Agroforestry, if defined by tree cover on agricultural land of greater than 10%, is found on more than 43% of all agricultural lands globally. This land-use type represents over 1 billion ha of land and more than 900 million people (Zomer et al., 2014).

Agroforestry Mapping by Remote Sensing Techniques

Initiative for Agroforestry Mapping in India

In India, use of GIS-RS-GPS has also widened from natural resource management to habitat analysis. Though the agroforestry land use occupy large areas in our country, but use of these technologies to estimate area has been initiated in year 2007 with a DST sponsored project '***Spatial and Temporal analysis of agroforestry intervention in North–western India using GIS and Remote Sensing***'. For mapping and estimating area under Poplar and Eucalyptus based agroforestry systems in Yamunanagar (Haryana) and Saharanpur (U.P.) districts, IRS-P6/ LISS-3 data (spatial resolution of 23.5 m) was used and both unsupervised and supervised methods of classification were applied.

A major problem in estimating area under agroforestry is lack of procedures for delineating the area influenced by trees in a mixed stand of trees and crops. Rizvi et al. (2013) highlighted some issues in mapping agroforestry like spatial resolution, spectral resolution, time period of remote sensing data and methods to be used. Kumar *et al*. (2011) mapped trees outside forests using merged data products of LISS-IV and Cartosat-1 and found 11.09 per cent area under trees outside forest in Bilaspur block of Yamunanagar (Haryana). Tauqeer et al. (2016) mapped *Populus* and *Eucalypts* based agroforestry systems in Ludhiana district using LISS-IV multispectral data. Extensive survey was also performed for ground trothing. For accurate mapping of area under scattered trees, high resolution remote sensing data either LISS IV (5.8

m) or merged LISS IV and Cartosat-1 datasets must be used. But this would involve enormous data processing and huge cost as far as regional or country level mapping is concerned.

Methodology Developed for Agroforestry Mapping

The following methodology given by Rizvi et al. (2016a) may be adopted for mapping and estimating agroforestry area at district level, in which medium resolution remote sensing data (LISS III, 23.5m) has been used (Figure 1). Pre-processing of remote sensing images includes layer stacking, mosacing and sub setting with district boundary. Maximum likelihood method of supervised classification was applied for land uses and land covers in a district using ERDAS Imagine software. Such pixel based methods account for single major feature occurring in a pixel, even if more than one features/ land covers are present. Besides, some wrong classification may happen with pixel based methods (Figure 2). Therefore, sub-pixel method of classification was applied on agricultural land because agroforestry exist on agricultural land only.

Agricultural land including cropland and fallow land was masked from false colour composite (FCC) of the districts. Then sub-pixel classifier is applied on this agricultural area. Resultant image will consist of i) pixels covering trees plus cropland, ii) pixels covering fallow land plus trees, iii) pixels covering trees only, iv) pixels covering cropland only and v) pixels covering fallow land only. Pixels of first three categories will represent agroforestry in real sense and their total area would give an estimate of area under agroforestry. Advantage of using sub-pixel classifier is that this method not only overcomes the problem of intermingling of sugarcane with young plantations, but also gives outcome in the form of per cent tree cover within pixel. This tree cover ranges from minimum 20 to maximum 100 per cent, thus accounting for single tree, boundary plantations and block plantations on farmlands (Figure 3).

Country Level Estimates of Agroforestry Area

Dhyani et al. (2013) estimated the agroforestry area as 25.32 million ha or 8.2 percent of the total geographical area of the country. As such on an average 14.2% of total cultivated land has agroforestry in one form or the other. However, these estimates are not the true reflection as they are not based on ground verification or revenue records. They have also projected the agroforestry area for year 2050 at 53.32 million ha. As per FSI (2013) estimates of green tree cover under agroforestry, 11.15 million area was found. For agroforestry, only rural TOF has been taken into consideration and tree green cover was estimated for 14 physiographic zones of India. Rizvi et al. (2014) gave preliminary estimates for extent of agroforestry area in India by using Bhuvan LULC data (http://bhuvan-noeda.nrsc.gov.in/theme/thematic/theme.php) for the year 2011-12. These estimates have been worked out by considering minimum 10 percent of agricultural land having agroforestry. According to this, there is about 14.46 million ha area under agroforestry when fallow lands are not included and potential area under agroforestry is estimated to be 17.45 million ha when fallow lands are included.

Presently, under National Initiative on Climate Resilient Agriculture (NICRA) project, area under agroforestry systems in different agro-climatic zones of India is being estimated using same methodology discussed in section 3.3. So far 12 zones have been completed and total agroforestry in these zones was estimated to be 23.25 million ha which is about 8.69 percent of the total geographical area of these zones. Highest agroforestry area of 15.47 percent was found in Upper Gangetic region, followed by 14.18 percent in West Coast Plains & Hill region and 13.56 percent in Gujarat Plains & Hill region. Once all 15 agro-climatic zones are completed, then actual country figure of agroforestry area will be obtained.

Identification of Tree Species on Farmlands

Sapota* (*Manilkara zapota*) *based Agroforestry in Junagarh district

In Junagarh district, Sapota (*Manilkara zapota*) and Mango (*Mangifera indica*) were the dominant fruit species grown under agroforestry. For species level classification, agroforestry area already obtained by sub-pixel classifier was again used (Figure 4) and reclassified for Sapota based and other agroforestry systems. Total 195 GPS points were collected for *Manilkara zapota* trees from the farmers' fields, some of them were used for generating signatures for and remaining points were used for finding classification accuracy. Area under Sapota based agroforestry come out to be 9966.76 ha (1.13%) of the total area under agroforestry (Figure 4). Remaining 11.25 per cent area was under other agroforestry systems like *Mangifera indica*, *Emblica officinalis*, *Zizyphus mauritiana* based agri-horticulture systems (Rizvi et al., 2016b).

Identification of Bamboo & Arjun species in North-Dinajpur

Rizvi and Airon (2012) attempted to distinguish tree species like Bamboo and Arjun found in North-Dinajpur district of West Bengal using Resourcesat-1 LISS-IV data. For the identification of species, the spectral values were determined on remote sensing image with the help of GPS points collected from the fields. With the help of these spectral values, the spectral signatures were created and image was classified by method of maximum likelihood. Of the total agroforestry area in the district, Bamboo and Arjun species accounted for 2.4 and 2.7 percent, mixed species like Eucalyptus, Mango, etc. accounted for 30.7 percent area (Figure 5).

As far as identification of tree species is concerned, high resolution/ hyperspectral remote sensing data will be more useful. Remote sensing data of spatial resolution better than 5 m can be effectively used for this purpose. Rizvi et al. (2017) used Hyperion hyperspectral remote sensing data for generation of spectral signatures and mapping of *Mangifera indica* (Mango). They found very good results when Spectral Angle Mapper (SAM) was applied for identification of Mango in Lucknow and Unnao areas.

Assessment of Carbon Sequestration in Agroforestry

Very few studies have been found where geospatial technologies were applied for estimation of carbon stock and carbon sequestration under agroforestry. Singh and Chand (2012) estimated aboveground trees outside forest (TOF) phytomass and the carbon content of TOF using trees outside forest inventory data and high resolution LISS-IV satellite data. The aboveground TOF phytomass varied from 1.26 t ha^{-1} in the scattered trees in the rural/ urban area to 91.5 t ha^{-1} in the dense linear TOF along canal. Ajit et al. (2013) used dynamic CO2FIX model v3.1 to assess the baseline (2011) carbon and to estimate the CSP of agroforestry systems in three districts viz. Ludhiana (upper Indo-Gangetic plains (IGP) in Punjab), Sultanpur (middle IGP in Uttar Pradesh) and Uttar Dinajpur (lower IGP in W. Bengal). The CSP for existing AFS (30 years simulation) has been estimated to the tune of 0.111, 0.126 and 0.551 Mg C ha-1 yr-1 for Sultanpur, Dinajpur and Ludhiana districts, respectively.

Upgupta et al. (2015) demonstrated the potential of Cartosat-1 derived digital surface model and Quick Bird texture image for the estimation of stand height, stem diameter, tree count and phytomass of important timber species. Rizvi et al. (2016b) estimated carbon stock under agroforestry in Anand, Dahod, Junagarh and Patan districts of Gujarat by adopting remote sensing and modelling techniques. Total carbon stock in all four districts for baseline and simulated period of 30 years were estimated to be 2.907 and 3.251 Mt, respectively. Rizvi et al. (2019) assessed carbon sequestration and CO_2 absorption by agroforestry systems in Central Plateau and Hill region combining modelling and geospatial technology approach. Total carbon sequestered at zone level was estimated to be 17.81 Tg C and equivalent CO_2 absorption was 65.36 Tg (Tera gram).

Two way approaches may be adopted for assessment of C-sequestration in agroforestry systems. Firstly, area under agroforestry in a district is estimated through remote sensing using the same methodology. Secondly, carbon sequestration by agroforestry systems per hectare (biomass +soil carbon) is estimated through a carbon accounting CO2FIX model. Finally carbon sequestration by agroforestry systems in a particular district is obtained by multiplying the area under agroforestry with carbon sequestration per ha (Figure 6).

Development of Spectra Library and Decision Support Tools

For applications of geospatial technologies in agroforestry research like biomass/ carbon estimation, identification of tree species on farmlands is essential for which we need to have pure spectral signatures. For this purpose high-spectral resolution/ hyper spectral remote sensing can be more useful than medium spatial/ spectral resolution data. Hyperspectral images provide ample spectral information to identify and distinguish spectrally unique materials. The library of such spectral signatures for agroforestry tree species over different seasons or phenological stages would help in identification of tree species and then estimation of aboveground biomass/ carbon stock. With this aim, a project was initiated in 2016 at ICAR-Central Agroforestry Research Institute to develop a spectral library of spectral signatures for agroforestry tree species viz. Aonla, Mango, Eucalyptus, Poplar and spectral signatures were developed using EO-1 Hyperion hyperspectral remote sensing data.

For effective agroforestry planning, landowners and extension agents require information on potential tree and shrub components as well as geographic information for specific sites. A major challenge in developing agroforestry planning Decision Support Tools (DST), however, is its complex nature requiring the need to bring together a variety of information (biophysical, economic and social factors) and evaluate this information at site specific and landscape scales. Computer based DST help to integrate information to facilitate the decision making process that directs development, acceptance, adoption and management aspects in agroforestry. Computer based DST include databases, geographical information systems, models, knowledge-base or expert systems and 'hybrid' decision support systems (Ellis *et al*. 2004).

Conclusion & Way Forward

Geospatial technologies (GIS, GPS & Remote Sensing) have great potential in agroforestry research and may be used for estimating system production (biomass/yield), assessment of carbon sequestration, identification of areas suitable for agroforestry, etc. However, there are some constraints like identification of boundary plantation with crops and intermingling of spectral signatures between young plantation and crops like sugarcane. There may be also the wrong assessment of areas under agroforestry system due to road side and canal side plantations. Improved methods such as knowledge/ expert classifier, mixed pixel analysis and object oriented classification would be better approach. With the advent of hyperspectral remote sensing satellites, not only identification of tree species can be done but tree canopies leaf area index can also be assessed. Besides this tree counts, their heights, canopy structure can also be easily measured with the help of synthetic aperture radar (SAR) microwave remote sensing data.

The temporal pattern of spectral reflectance for agroforestry tree species over different ages and the effect of tree canopy cover on spectral pattern of established agroforestry systems can also be investigated. Development of Digital Library of Spectral Signatures for major agroforestry species would help in assessment of species-wise area under agroforestry in different agro-climatic regions. Therefore, there is need to develop Spatial Decision Support System (SDSS) for agroforestry, which would help the planners and researchers in identifying suitable agroforestry systems for various agro-climatic regions.

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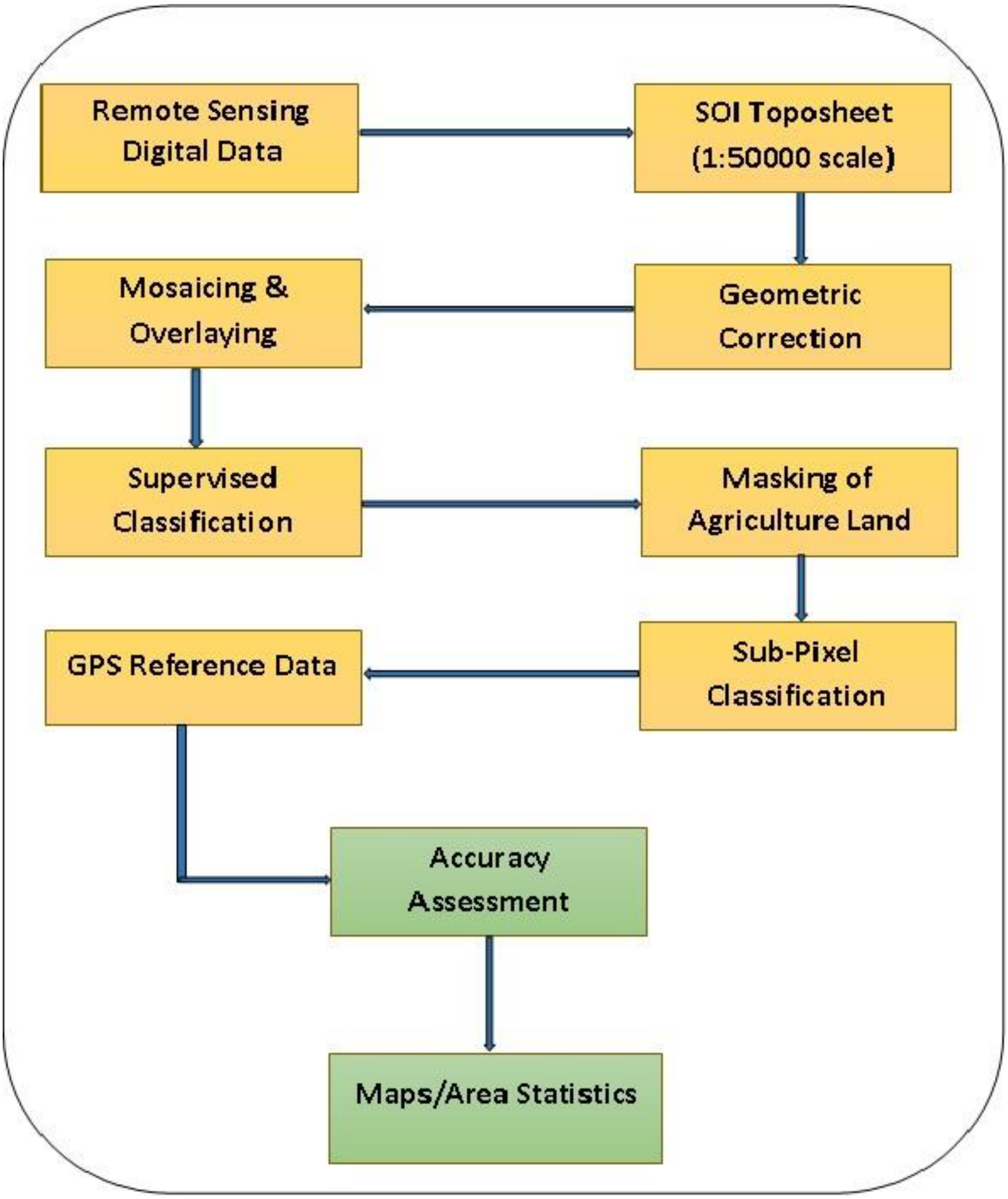

Figure 1: Flowchart of methodology for estimating agroforestry area at district level

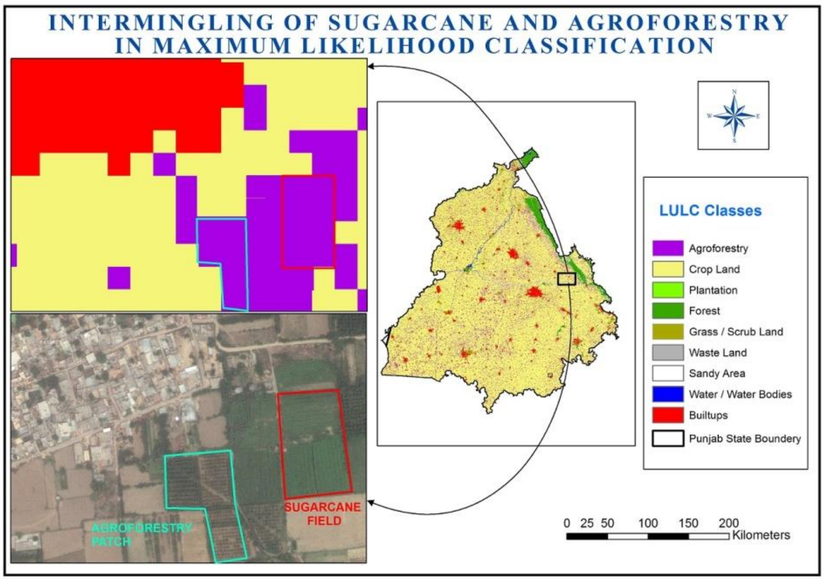

Figure 2: Intermingling of sugarcane and agroforestry in maximum likelihood classifier

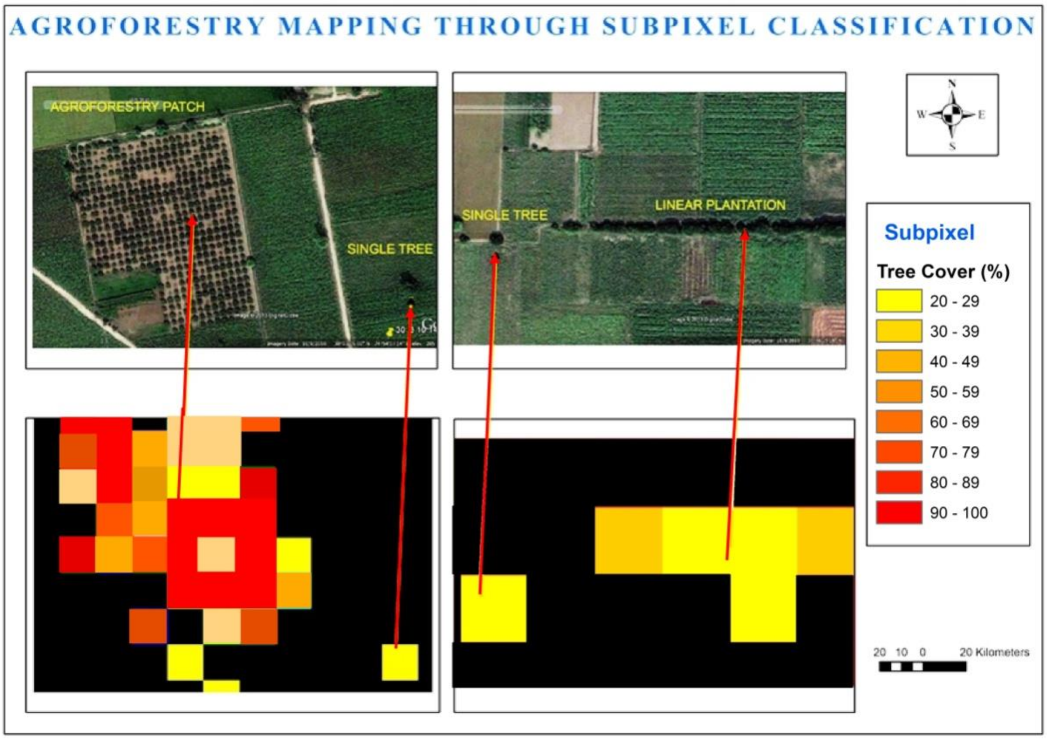

Figure 3: Single tree, linear plantation and block plantations identified through sub-pixel

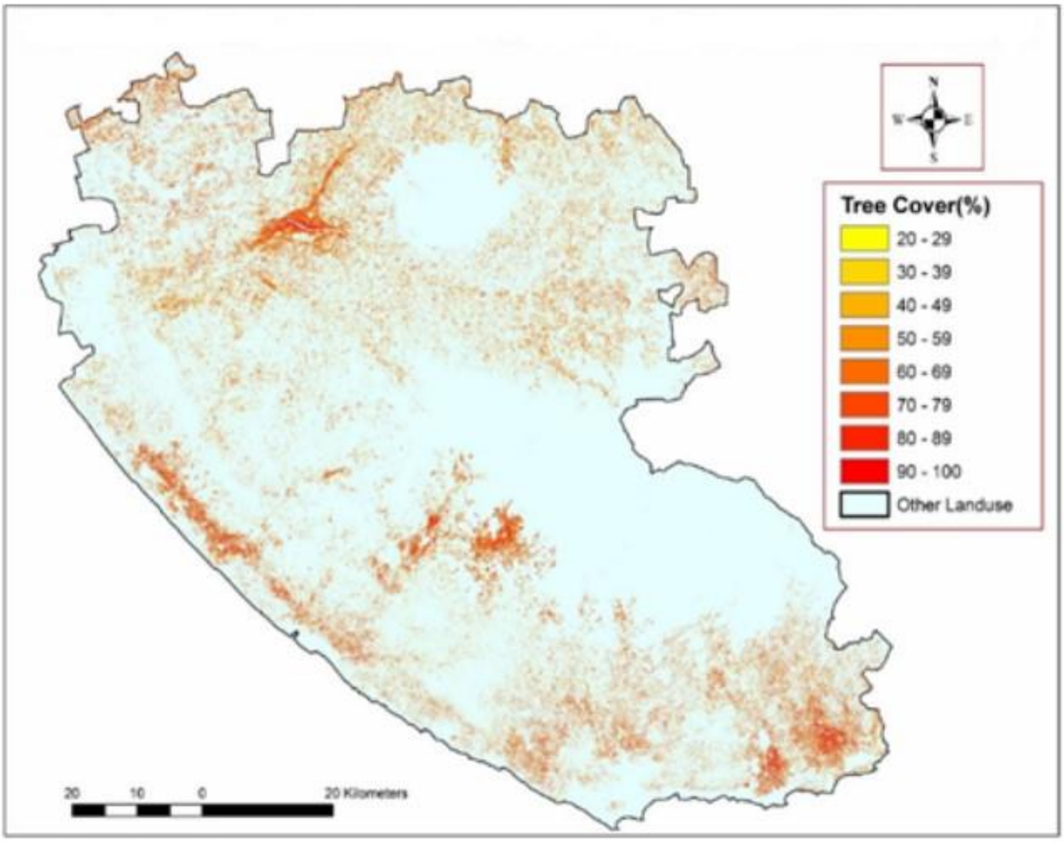

Figure 4: Manilkara zapota based agroforestry in Juagarh delineated by sub-pixel classifier

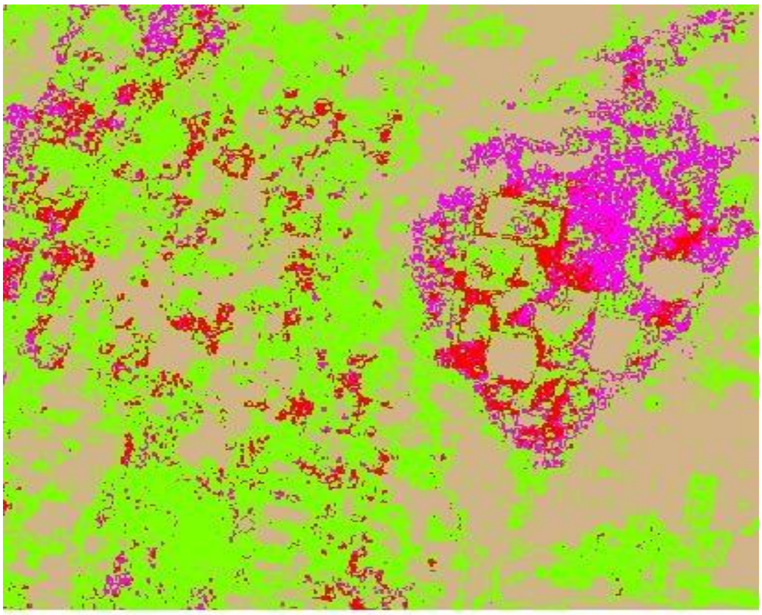

Figure 5: Bambusa and T. arjuna species identified through LISS-IV data

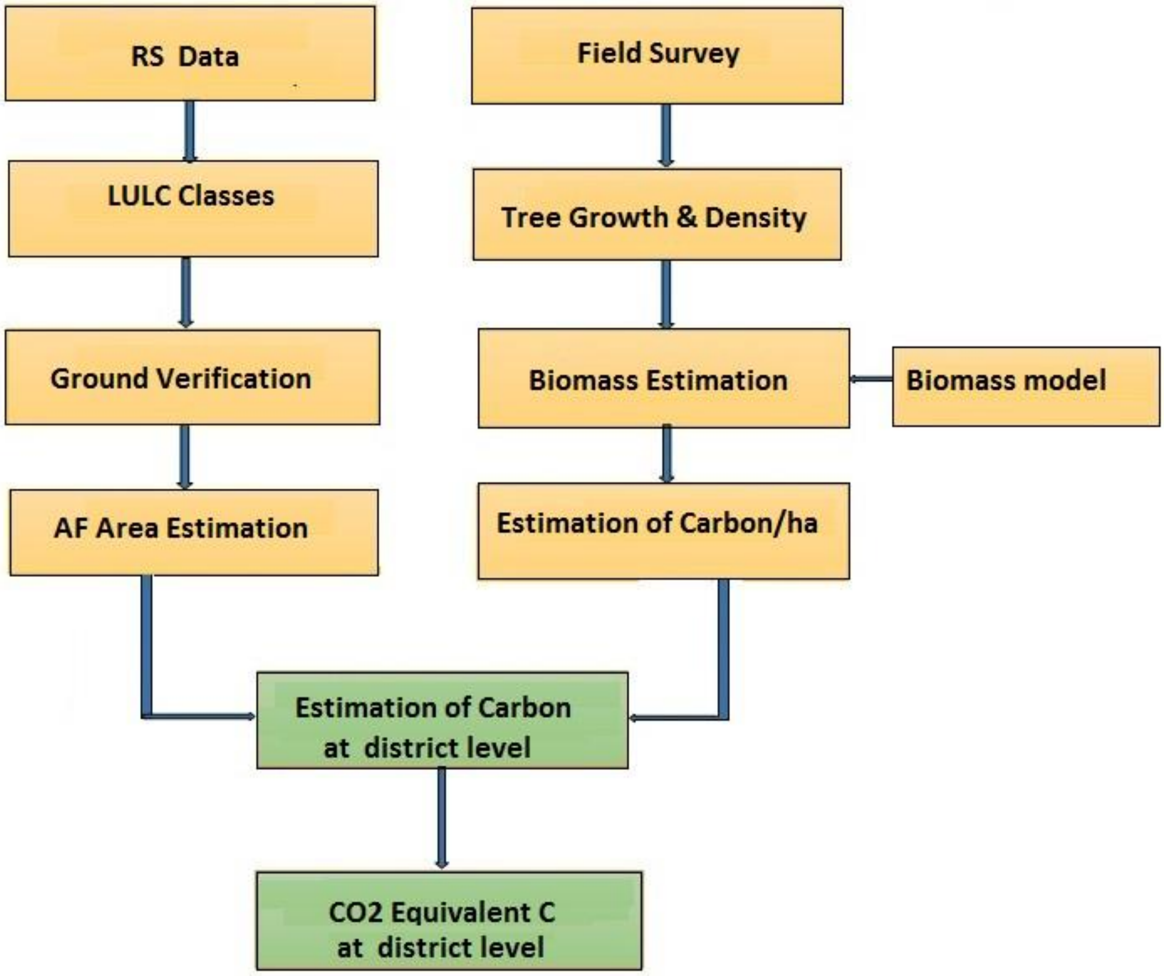

Figure 6: Methodology for estimating carbon sequestration at district level

Table 1: Land uses & land covers in Saharanpur and Yamunanagar districts without forest (2007)

Land uses/ land covers	**Yamunanagar**		**Saharanpur**	
	Area (in ha)	Area (%)#	Area (in ha)	Area (%)#
Agroforestry	31914.77	18.4	40746.06	11.3
Cropland	80981.92	46.8	140631.00	38.8
Water/water bodies	1470.20	0.8	8889.34	2.5
Builtups/ Sand	20805.15	12.0	25158.60	6.9
Fallow /wasteland	8257.03	4.8	43772.30	12.1
Plantation	12605.93	7.3	71539.20	19.8
Total Area	**156035.00**		**330736.50**	

- percentage of total geographical area (Rizvi et al., 2009; Rizvi et al., 2011)

MIR Spectroscopy and Hyper-Spectral Imaging for Mapping Soil Types

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Abstract
The wellbeing of soils is crucial for securing food production worldwide. The soil health concept has been introduced due to an evolving understanding that soil is not just a growing medium for crops but that it provides a foundation for other essential ecosystem services. Hence, understanding of the spatial distribution and dynamic changes of soil properties are the basis for sustainable land management. Assessment of soil properties is crucial for sustainable agricultural production. Traditional methods of soil analysis require more time and resources. New light-based techniques such as Midinfrared (MIR) provide rapid, non-destructive, reproducible, and cost-effective analysis of soils. Further, spectral reflectance data obtained from MIR can be used successfully with satellite imagery for rapid assessment of soil quality over large areas. This approach is opening up new opportunities for rapid assessment of soils.

Keywords: Alfisol, Mid-infrared (MIR) Spectroscopy, soil health assessment, reflectance spectroscopy

Introduction

The soil is recognized as one of the most valuable, life supporting natural resources since it produces food that is basic to man's existence. A clear and intimate knowledge of the kind of soils and the extent of their distribution are essential pre-requisites in developing rational land use plans for agriculture, forestry, irrigation, drainage etc., and for maximizing agricultural production to meet the ever-increasing needs for food, fiber etc. The need for sustainable intensification of agricultural production has ushered in a growing awareness of soil health and a requirement to identify with some certainty how changes to land management will affect soil. From an agricultural perspective, the active management of soil health needs to balance the production of a healthy and profitable crop with environmental protection and improvement. However, the extreme spatial and temporal heterogeneity of soils, and the complexity of biological, physical and chemical interactions therein, makes predicting management effects on soil health challenging.

A comprehensive understanding of the spatial distribution and dynamic changes of soil properties are the basis for sustainable land management. A proper understanding of variability of soil chemical properties over an area is important for identifying the soil nutrients related production constraints. The suggestions for remedial measures and execution of appropriate nutrient management strategies are also based on the good knowledge of variation in soil nutrients.

It is technically possible to perform a wide range of wet chemistry laboratory analyses of soils and derive a soil fertility assessment of soil properties. Wide range of wet chemistry methods are well established for assessment of soil. However, most of such required analyses based on wet chemistry are time consuming, labour intensive and costly which in practice, make it un-economic to map the soil properties of a field with the required spatial and/or temporal resolution. Such conventional assessments of soil capacity to perform specific production, engineering, or environmental functions rely on local calibration of observations on soil functional capacity to measured soil properties. According to Dent and Young (1981) soil analyses are expensive and dense sampling is required to adequately characterize spatial variability of an area, making broad-scale quantitative evaluation difficult.

New, rapid methods to quantify soil properties and variability are needed for the development of risk-based systems of soil interpretations that are designed to quantify prediction uncertainty so that users may be able to employ such information in decision-making (Dewayne Mays, 1996; McKenzie et al., 2000). Diffuse reflectance spectroscopy is now routinely used for the rapid nondestructive characterization of a wide range of materials (Davies and Giangiacomo, 2000).

Spectral signatures:

Every earth object react with spectrum of light differently based on its properties giving spectral signatures in different wave bands. Spectral signature of materials are defined by their reflectance or absorbance, as a function of wavelength in the electromagnetic spectrum. Under controlled conditions, the signatures result from electronic transitions of atoms and vibrational stretching and bending of structural groups of atoms that form molecules or crystals. Fundamental features in reflectance spectra occur at energy levels that allow molecules to rise to higher vibrational states. For example, the fundamental features related to various components of soil organic matter generally occur in the mid- to thermal-infrared range (2.5-25 µm.), but their overtones (at one half, one third, one fourth etc. of the wavelength of the fundamental feature) occur in the near-infrared (0.7–1.0 µm.) and short-wave infrared (1.0–2.5 µm.) regions. Such features governed by the various soil composition is useful for assessment of the soil properties. Such soil reflectance is a cumulative property which derives from inherent spectral behavior of the heterogeneous combination of mineral, organic matter and fluid matter that comprises mineral soils. Spectral curves that were resembled resemblance with determined soil properties, especially organic matter and iron-oxide content are described in figure 1. The discriminating features of the five curves are shape and the presence or absence of absorption bands. The strategy here will be to discuss observed relationships between soil properties and spectral reflectance with reference to the five characteristic spectra (Stoner and Baumgardner, 1981).

Mid-infrared (MIR) Spectroscopy for soil assessment

Mid-infrared spectroscopy is used for soil characterisation and analytical technique, can be used extensively for a fingerprint spectrum (identification) of soil properties. Midinfrared (MIR) diffuse reflection spectroscopy is rapid, non-destructive, reproducible, and cost-effective soil analytical methods. World Agroforestry has successfully created network of MIR laboratories in Africa for rapid assessment of the soil health through AfSIS.

World Agroforestry is working on the MIR technology and established a soil spectral laboratory at Indian Institute of Soil Science (IISS), Bhopal, India. Alpha-FT-MIR spectrometer is installed in the spectral laboratory at IISS, Bhopal (Fig. 2) and is fully functional. Soil samples parenting to different soil groups are being collected from different parts of India and being analysed in the spectral laboratory (Fig. 3)

The comparison of the results of soil sample analysis using wet chemistry methods and MIR techniques showed the good correlation (Table 1) among two techniques.

Hyper-spectral imaging for mapping soils

Soil properties can be predicted from soil spectral reflectance data such as MIR and in a second step can be combined successfully with information from satellite imagery for rapid assessment of soil quality over large areas. This approach is opening up new opportunities for rapid assessment of soils. Further, spatial representation of soil fertility of an area based on high resolution and hyper-spectral remote sensing satellite imageries can be developed.

Hyperspectral sensors typically collect data in hundreds of narrow, contiguous wavelengths so that for each pixel in an image, a reflectance spectrum can be derived that is dependent upon the composition and structure of materials. Many substances have a unique spectral signature that can be used for identification. Moreover, the hundreds of channels allow the detection or identification of more than one material in a pixel.

The difference between multispectral and hyperspectral is the far greater spectral resolution of the latter achieved by splitting the reflected solar irradiance into many more channels. Hyperspectral data allows the identification of many materials even in mixed pixels (Fig. 4). In addition, the data can be used to estimate abundance of materials based upon the depth of absorption features.

Hyperspectral data gives great opportunities for assessment of various soil properties. Various components present in the soil can be precisely identified and their species can be quantified. These components produce distinct absorption spectra.

Some of the examples of assessment of soils includes, different types of clays can be identified spectroscopically to their characteristic absorption bands around 2.2 μm. Kaolinite shows a doublet band, montmorillonite a single band, and illite have additional bands at 2.35 and 2.45 μm that can be used for identification of the minerals in the soil (Fig. 4). Similarly other important features like organic matter, iron content, carbonates content of the soils may be identified at specific wave bands.

The average spectral reflectance of some selected soils from different parts of India is shown in figure 5. It may be noted that the reflectance characteristics varies across soil types. The darker Vertisols of Karnataka show minimum soil reflectance at all wavelengths compared the lighter Inceptisols of Uttar Pradesh (soils of Agra region) and Aridisols of Rajasthan (soils of Jodhpur region); deep red Alfisols of lateritic origin show inter-mediate reflectance values. Such distinct variations in spectral reflectance show promise of distinguishing major soil orders across large landscapes (Das et. al, 2015)

Conclusions and Way Forward

Midinfrared spectroscopy can provide rapid and cost-effective prediction of several physical and chemical soil properties. MIR based spectral approach can be effective tool for soil assessments using a small amount of soil samples and also reduce time required for soil related studies. The rapid nature of the measurement allows soil variability to be frequently sampled and assessed than with conventional approaches and thereby facilitates soil health and environmental monitoring.

Further, the MIR spectral information may be linked with remote sensing data for soil information estimation with improved spatial prediction of various soil properties at large areal extents. The information generated can also be combined with other geo-referenced soils information derived for different sources.

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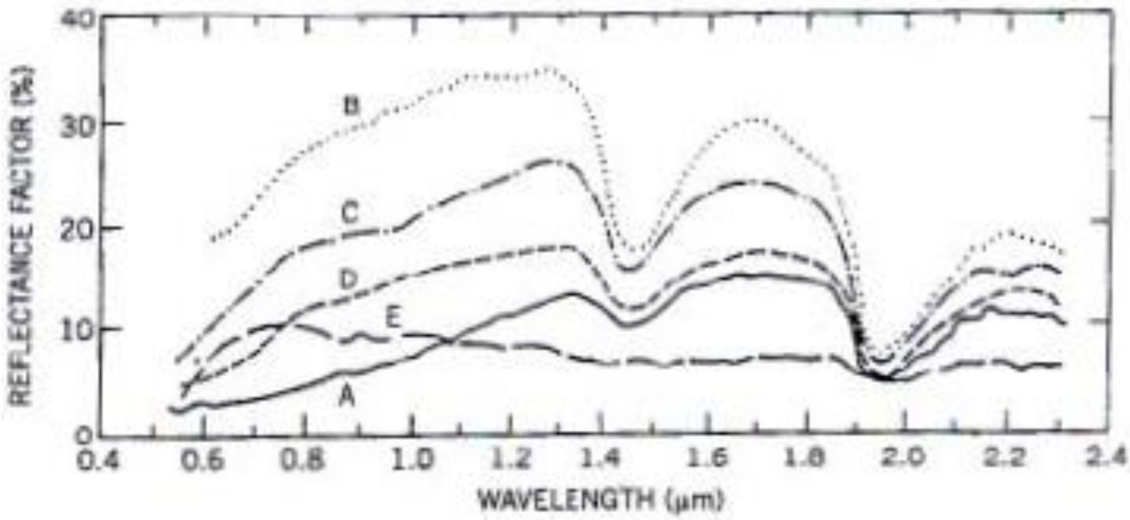

Figure 1: The characteristic soil bidirectional reflectance spectra (Source: Stoner and Baumgardner, 1981).
Curve A: soils having high (>2 %) organic-matter content and fine texture.
Curve B: soils having low (<2 %) organic-matter content and low (<1%) iron-oxide content.
Curve C: soils having low (<2 %) organic-matter content and medium (1 to 4 %) iron-oxide content.
Curve D: soils having high organic-matter content (>2 %), low iron-oxide content (<1 %), and moderately coarse texture.

Figure 2. Alpha-FT-MIR spectrometer installed at IISS, Bhopal

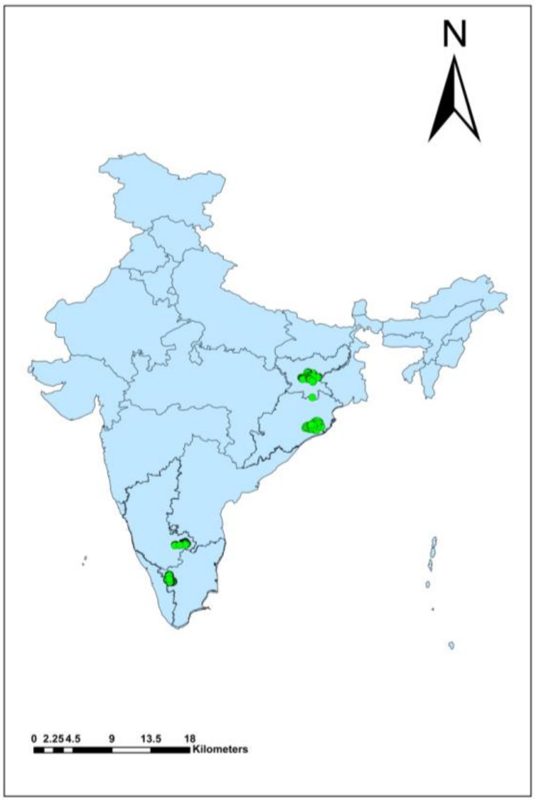

Figure 3. Location map of geo-referenced Alfisols sampling points

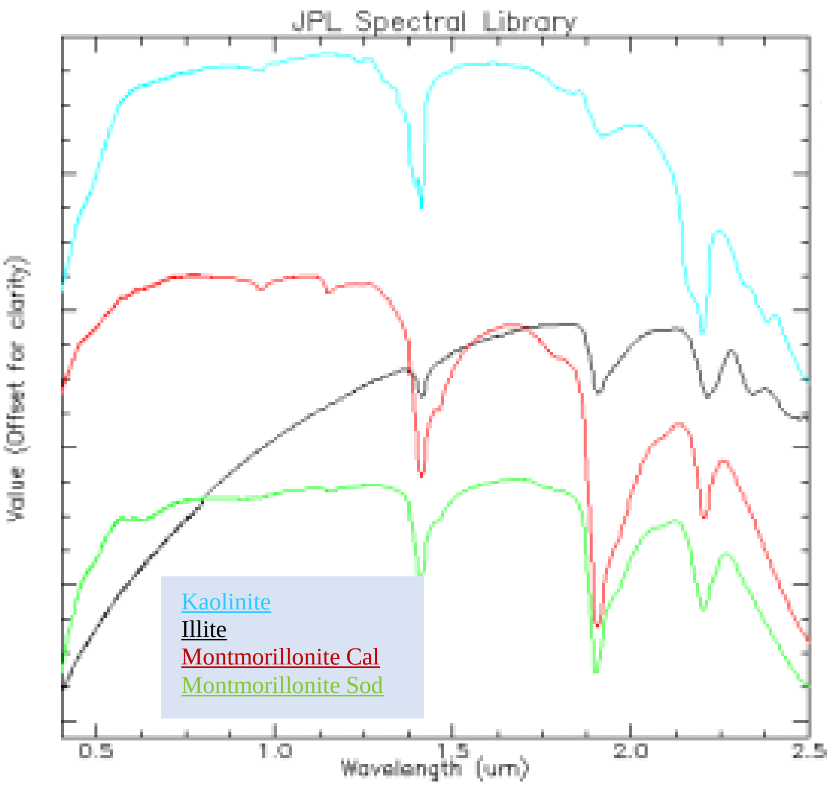

Figure 4. Spectral features of different types of clay mineral

Table 1. Statistical comparison of wet chemistry and MIR techniques using partial least square (PLS) regression method and validation prediction co-efficient of different soil properties for Alfisols from Jharkhand and Orissa states of India

Soil property	Calibration (with 80% sample)			Validation (20% sample)		
	R^2	RMSE	Mean Absolute Errors (MAE)	R^2	RMSE	MAE
pH	0.82	0.34	0.27	0.79	0.44	0.33
SOC (%)	0.83	0.11	0.09	0.82	0.11	0.08
Clay (%)	0.85	2.55	2.05	0.79	3.07	2.45
Silt (%)	0.73	3.18	2.59	0.71	3.59	2.84
Sand (%)	0.83	4.31	3.50	0.80	4.62	3.70

Developing Value Chain in Agroforestry: Consortium of Industrial Agroforestry- A New Initiative

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Abstract
India is one among the few tropical countries which has been reporting a progressive increase in the forest cover over the past two decades. India being a major consumer of wood and wood products, the role of agroforestry as a viable land use system is gaining significant attention owing to its contribution towards meeting domestic and industrial wood requirements. Growing demand coupled with legal issues in wood supply from Government owned forests have resulted in a total mismatch between demand and supply of wood and wood products. Tamil Nadu Agricultural University (TNAU) conceived and implemented "a value chain model" and created sustainability in industrial wood generation and supply in Tamil Nadu by involving a wide range of stakeholders. In order to strengthen the value chain and to promote agroforestry based on the objectives envisaged in National Agroforestry Policy (2014), the University established a "Consortium of Industrial Agroforestry" (CIAF) by linking stakeholders and addresses the issues related to production, processing and consumption in agroforestry. Keeping in line with the guidelines provided in the National Agroforestry Policy (2014), the consortium has successfully established decentralized institutions for supply of quality planting materials to the farmers besides facilitating organized plantation developers, harvesting and marketing institutions. Consortium activities have paved way for creating the much needed database in tree cultivation, development of price supportive mechanism for important farm grown industrial wood species and reduced the risks faced by tree growers through innovative approaches like tree insurance and value addition technologies. This consortium mode value chain model in agroforestry holds great potential for adoption and replication across India which would help to create self-reliance in raw material security besides augmenting the country's tree cover.

Keywords: Agroforestry, industrial wood, value chain model, consortium approach

Introduction

Forests in India have played a significant role in meeting the domestic and industrial wood requirements before the enactment of Forest Conservation Act, 1980 and the National Forest Policy 1988. Owing to policy and legal implications, there has been a paradigm shift in the forest management strategy of the country with more emphasis on conservation oriented management which resulted in restricted supply of wood from natural forests (Parthiban *et al.*, 2014). India being one of the major consumers in the Asia Pacific region, it is estimated that the country would need 152 million m^3 of wood by 2020. (FAO, 2009). This demand has been estimated for 12 organized wood based industries and does not include the fuelwood demand of the country which is also on the rise.

In 2010, world's agricultural lands occupied 4889 Mha, an increase of 7% (311 Mha) since 1970 (FAOSTAT, 2013) whereas agricultural land area has decreased by 53 Mha since 2000

(Karlheim Knickel, 1990). Increasing wood demand coupled with changes in land use pattern have necessitated significant interest towards agroforestry, a land use system which is being practiced across the country in various forms since time immemorial.

Though agroforestry is an age old practice as an important form of subsistence farming, in the recent past, it is valued as a commercial and profitable land use system across the world. Approximately, 1.2 billion people (20 percent of the world's population) depend directly on agroforestry products and services in rural and urban areas of developing countries (Leakey and Sanchez, 1997). Agroforestry systems are superior to other land uses at the global, regional, watershed and farm scales since they optimize tradeoffs between increased food production, poverty alleviation and environmental conservation (Izac and Sanchez, 2000).

The current area under agroforestry is of the order of 400 Mha, of which 300 Mha are "arable lands" and 100 Mha are "forest lands" (Robert Zomer *et al.*, 1999; Xu, 1999). It is estimated that an additional 630 Mha of croplands and grasslands could be converted into agroforestry, primarily in the tropics (IPCC, 1996b). FAO has also emphasized that agroforestry must be integrated in the Clean Development Mechanism (CDM) to broaden the scope of agroforestry. In India, several traditional agroforestry systems are successfully established with the tree-crop combination of *Acacia nilotica* with Paddy (Bargali *et al.,* 2009); mango and teak with wheat and rice in Kumaun region (Parihar *et al.,* 2015). Similarly, home garden based agroforestry has evidenced as a successful land use system in Central Himalayas (Vibhuti *et al.,* 2018) which attest the significance of agroforestry in India.

Recognizing the growing importance of agroforestry, the Indian Government directed the wood based industries to generate their own raw material in the National Forest Policy of 1988 (Anon, 1988). However, policy directives were not taken seriously by many wood based industries barring a few exceptions. Growing demand for wood and wood products, increasing interest in agroforestry and legal issues in wood supply from Government owned forests ushered in a total mismatch between demand and supply of wood and wood products (Parthiban and Cinthia, 2017).

Under such circumstances, Tamil Nadu Agricultural University (TNAU) conceived and implemented "a value chain model" to create sustainability in raw material generation and supply in Tamil Nadu by involving a wide range of stakeholders. This model of Industrial Agroforestry was implemented between 2008 and 2014 which witnessed successful establishment of over 70,000 ha of organized plantations in Tamil Nadu. (Parthiban, 2014). To sustain the positive impacts generated by this value chain model an institutional mechanism, called "Consortium of Industrial Agroforestry" (CIAF), was established by the university which is first of its kind in the country and addresses the issues related to production, processing and consumption in Agroforestry. This manuscript discusses the genesis, organizational structure, activities and achievements of CIAF which could act as a model for the rest of the country for adoption with necessary modifications for promoting and furthering the Government's objectives in agroforestry sector of the country.

Agroforestry – Constraints and Interventions

The wood based industries in the state of Tamil Nadu have been interacted for the current supply chain pattern. Based on the interactions and the consultations with the industries, tree growing farmers, non-governmental organization involved in promotion of agroforestry and other stake holders, Forest College and Research Institute of Tamil Nadu Agricultural University has identified several constraints towards promotion and popularization of commercial agroforestry model. These constraints have been grouped into three levels *viz.*, production related constraints, processing associated constraints and the consumption related constraints which are depicted in the figure 1.

Interventions through Value Chain Approach

The constraints identified and indicated above have been resolved through strong research and development coupled with the associated supply chain process. The entire PCS based industrial agroforestry has been value added through technological support resulting in massive industrial agroforestry development in the state of Tamil Nadu in association with several wood based industries. The interventions have been done through technology development, organizational linkage and facilitating market support system in association with respective wood based industries.

Conceptualization of Consortium of Industrial Agroforestry

National Forest Policy of 1988 directed wood based industries to generate their own raw material resources rather than depending on the forest department for their wood requirements. However, the policy guidelines were not taken seriously by most of the wood based industries except a few paper industries. Subsequently, Government of India announced an exclusive Agroforestry policy in 2014, which identified ten strategies to promote agroforestry in the country. To address all the issues envisaged in the National policies, TNAU pioneered by establishing a "CONSORTIUM OF INDUSTRIAL AGROFORESTRY" on 21st March 2015 which has successfully linked various stakeholders in the Industrial Agroforestry value chain and has been carrying out multifarious activities for the past three years in Tamil Nadu.

Objectives and Activities of the Consortium

The consortium aims to create sustainable and value added agroforestry initiatives with the following objectives:

- Network and establish linkages with all stakeholders to augment the Production to Consumption System (PCS) in Industrial Agroforestry.
- Promote effective collaboration among public agencies, private industries and organizations engaged in Industrial Agroforestry.
- Develop suitable research and development mechanism for industrial agroforestry in consultation with the consortium partners.
- Ensure self reliance in raw material supply and augment associated socio-economic and environmental issues.
- Formulate and recommend policy guidelines for promotion of Industrial Agroforestry.

Activities and Achievements of the Consortium

CIAF primarily aims to resolve the issues in production to consumption system in agroforestry through systematic Research and Development mechanism. This approach has made several stakeholders across the country enroll as members of the consortium whose present strength is 235. The details of the members are furnished in Figure 2.

a. Institutions for Production of Quality Planting Materials

The CIAF has created 12 decentralized institutions *viz.* nurseries and clonal production centres who mass multiply over 18 million plants annually which ensures availability of quality planting material in a decentralized manner as envisaged in National Agroforestry policy.

b. Organized Plantation Developers

One of the major problems faced by farmers and tree growers is the shortage of labour coupled with timely plantation establishment. This practical constraint was resolved by organizing capacity building programmes to the consortium members on modern plantation development technologies which ultimately helped them evolve as an organized plantation developers across Tamil Nadu. Eleven such plantation developers groomed by CIAF have been responsible for establishing over 5000 acres of agroforestry plantations annually. The list of these institutions along with the annual area of plantations established is furnished in Table 1.

Plantation developers of the consortium ensure availability of skilled labour for manual planting as well as machines for mechanized planting which has created significant positive impact among farmers/tree growers of Tamil Nadu.

c. Harvesting and Marketing Institutions

The major problem faced by farmers and tree growers include harvesting, transportation and marketing of farm grown trees. In most cases, particularly in Tamil Nadu, harvesting of trees for multifarious uses was restricted to a specific group of communities who usually practiced manual felling with axe. Manual felling results in considerable quantum of wood wastage leading to respective loss of due economic returns coupled with the absence of decentralization of felling institutions which hindered the expansion of forestry/agroforestry plantations. To resolve this issue and to reduce logging related wood loss, the consortium conceived the idea of creating felling institutions from among its members. These felling institutions were provided with necessary capacity building regarding the principles and practices of modern logging techniques including hands on training in the operation of the latest machineries available. Besides improving the harvest efficiency and reduction of human drudgery, these institutions have also enabled decentralized availability of felling groups which harvest over 1 lakh tonnes of industrial wood per annum in Tamil Nadu. Many of these groups also undertake transportation and marketing of harvested wood thereby providing the farmers with economic returns at the farm itself. The details of felling institutions and their annual capacity are furnished in Table 1.

d. Organized Wood Based Industries for Marketing of Industrial Wood

Success of agroforestry has been widely questioned for lack of marketing facilities which is cited to be the key reason. To overcome this constraint, the CIAF has identified potential wood based industries and has created market base for a wide range of farm grown trees. The major industries and their wood requirement are furnished in Table 2. These industries are linked in the consortium and facilitate the marketing issues in tree cultivation.

e. Development of Price Supportive Mechanism

Unlike agriculture and horticulture, there has been a lack of price supportive mechanism for farm grown trees. Till the recent past, wood based industries seldom indicated the price of wood (species wise) and hence tree growing farmers were never aware of the pricing pattern for wood growing in their farmlands. Surveys conducted by the consortium indicated the absence of a price supportive mechanism which was a major hindrance hampering the expansion of agroforestry in Tamil Nadu. This issue was earnestly addressed by establishing a price support system in the "organized contract farming mode" for farm grown trees. Wood price for various industrial wood species has been fixed based on mutual consultations besides taking a cue from the prevailing local wood market prices. Post adoption of price supportive system in Tamil Nadu, studies conducted by CIAF and wood based industries have indicated quantum increase in area under tree husbandry through agroforestry.

f. Value Addition Technologies

CIAF is also keen on creating a viable system for enhancing value addition of plantation and industrial wood residues. It is estimated that from 1 ha of organized *Casuarina* plantation, around 5 tonnes of plantation residues are produced. In *Eucalyptus*, for every ton of wood harvested, nearly 200 - 300 kg of wood bark residue is produced. In timber, plywood and matchwood industries, over 30-40% of the wood received by the industries is pronounced as waste in the form of sawdust, chips, wood shavings etc. which has good potential for value addition. These residues are value added in the form of briquettes, pellets, charcoal and activated carbon .

g. Mechanism for Tree Insurance

The CIAF has linked with one of the public sector insurance companies' *viz.* United India Insurance, the second largest general insurance company in India. Based on mutual consultations and brainstorming, the consortium conceived and developed an "Insurance mechanism" for seven important farm grown trees viz., Casuarina, *Melia dubia*, Eucalyptus, *Ailanthus excelsa, Leucaena leucocephala, Gmelina arborea* and *Dalbergia sissoo*. (Parthiban, 2016). This insurance scheme provides the farmers, tree growers and captive plantation owners with the much needed relief against the risks faced by them against possible losses due to biotic and abiotic factors.

h. Framework for Implementing Agroforestry Policy in Tamil Nadu

Consortium of Industrial Agroforestry conducts annual workshops by inviting the enrolled members and special invitees which serves as a platform for brining all the stakeholders in the industrial agroforestry value chain. These annual workshops aid in evaluating the progress made as well as to share the stakeholders' experiences and constraints faced. Based on the outcome of the annual workshop, the CIAF prioritizes researchable issues for the subsequent year. The consortium also organized an exclusive workshop to prioritize the strategies and guidelines provided in the National Agroforestry Policy in order to develop a framework for adopting and implementing an exclusive Agroforestry policy for Tamil Nadu and the recommendations of the workshop were submitted to the Government of Tamil Nadu for adoption and implementation.

i. Development of Unit Cost for Bankable Project

The CIAF has developed unit cost for four major tree species *viz. Melia dubia* (Malabar Neem), *Casuarina*, Kapok and *Ailanthus excelsa* (Indian Tree of Heaven) in consultation with the members of consortium and the details were forwarded to National Bank for Agricultural and Rural Development (NABARD) and insurance agency for approval and implementation to extend institutional credit and insurance for agroforestry.

j. Creation of Database

Development of a sound database on the extent and distribution of farm grown tree species (districtwise and specieswise data), intercrops suitable for cultivation, monthly market prices are also being undertaken by the consortium which is being shared among the members of consortium.

k. Research Initiatives

The CIAF also conducts a wide range of research initiatives to resolve the issues in Production to Consumption System. One of the major research initiatives is to inventorize and domesticate new tree species amenable for agroforestry. The consortium has prioritized 30 tree species suitable for agroforestry and efforts are being taken to develop High Yielding Short Rotation clones/varieties (HYSR), designing Multi-Functional Agroforestry Models (MFAM) and ensure adoption of new, emerging technologies by the farmers and stakeholders. The HYSR clones already developed and promoted through agroforestry are furnished in Table 3.

l. Impact of CIAF Activities

The activities of the CIAF have created significant impact in terms of increase in area under agroforestry coupled with improvement in productivity and profitability. It is estimated that these agroforestry initiatives have created 300 man days/ha of employment and augmented productivity to the tune of over 25m^3/ha/annum from the baseline level of less than 10m^3/ha/annum. It is also estimated that one ton of wood is equivalent to 0.5 tonnes of carbon sequestered and thus expansion of agroforestry in Tamil Nadu through CIAF's initiatives will help to reduce the carbon load in the atmosphere and help address the growing concerns on climate change besides opening up a new vista of carbon trading for the farmers of the state in future.

Way Forward

The consortium activities are spearheaded by TNAU whose present reach has expanded outside Tamil Nadu to Karnataka, Kerala, Maharashtra, Telengana, Andhra Pradesh, Madhya Pradesh, Gujarat and Uttar Pradesh. In near future, the activities of CIAF are expected to extend to other states of the country as well. By 2023, the CIAF proposes to raise a corpus fund of Rs.1,00,00,000 (INR 10 million) for sustaining research and development activities.

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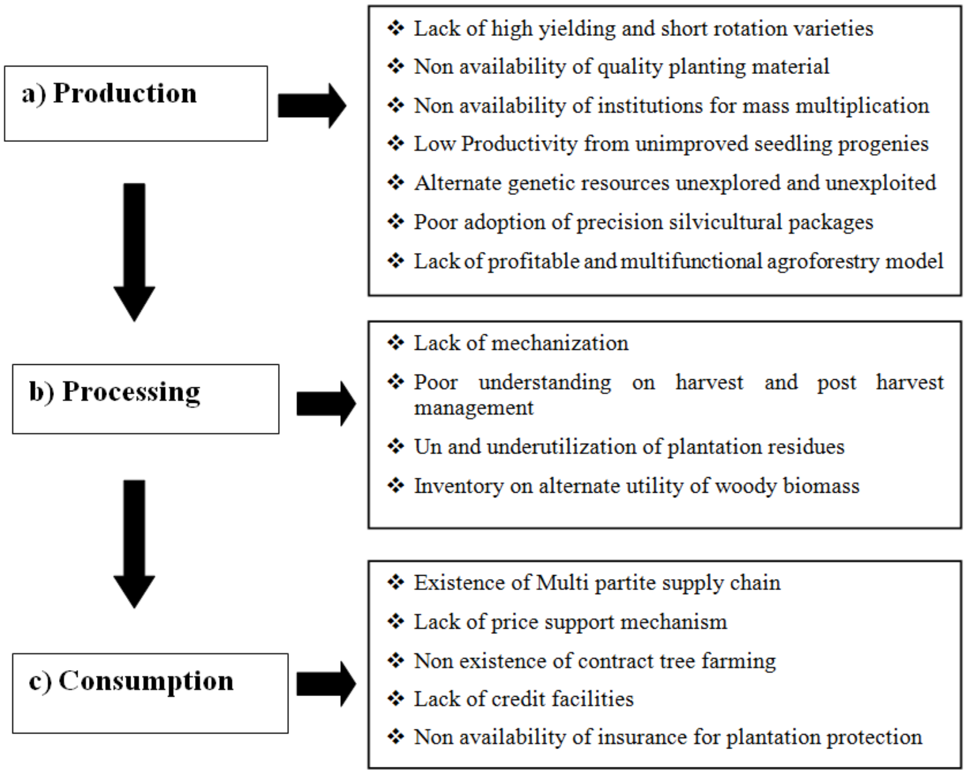

Figure 1: Constraints and Problems in Industrial Agroforestry

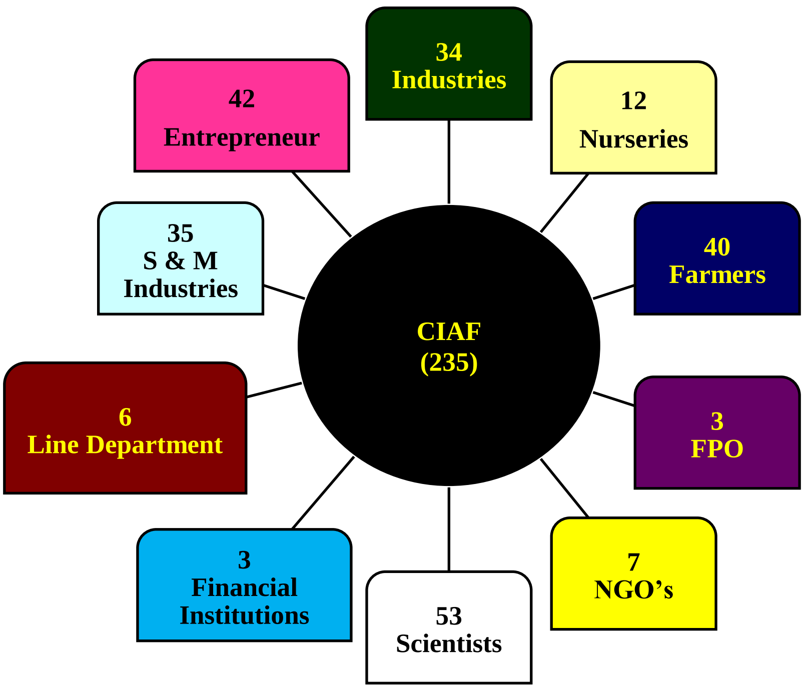

Figure 2. Composition of CIAF

Table 1. List of Plantation and Felling Institutions

Sl. No.	Plantation developers / Felling institutions	Area planted (acres) and wood harvested / year (tonnes)
A. List of plantation developers		
1.	Ever green Plantations, Manaparai, Trichy District	1000
2.	P.K.S. Developers, Namakkal District	1000
3.	Green Land Foundation , Thanjavur District	1000
4.	Agroforestry Producer Company, Coimbatore District	500
5.	Agrocorp, Hyderabad	100
6.	Siva Sakthi Farms, Sivagangai District	250
7.	Raja nursery, Cuddalore District	250
8.	Tree project, Theni District	250
9.	Sri Vaari Plantation, Villupuram District	250
10.	Chinnarosa Plantation Developer, Vellore District	100
11.	Priya nursery, Sivagangai District	1000
Total		**5700 acres**
B. List of felling institutions		
1.	Sathyamoorthy Felling Group, Thanjavore District	10,000
2.	Perumal Timber Mart, Anthiyur Erode District	40,000
3.	Thangavel Woods Traders, Sathyamangalam, Erode District	3000
4.	Agrocorp, Hyderabad	2500
5.	Saravanan Felling Group, Vellore District	500
6.	Forestry and Agroforestry Network, Coimbatore, Karur, Sivagangai Erode District	250
7.	Coimbatore District Agroforestry Producer Company, Coimbatore	50
8.	Bannari Traders, Sathyamangalam, Erode District	5000
9.	Manohar felling group, Erode District	15,000
10.	Evergreen plantations, Trichy District	25,000
Total		**1,01,300 tonnes**

Table 2. CIAF Linked Wood Based Industries

S.No.	Wood based industry	Species	Price
1.	Suresh Timbers, Elumalai, Madurai Dt.	Teak (30- 45 inches and above)	Rs. 20,000 – 25,000
2.		*Gmelina* (25 inches and above)	Rs. 8000 – 10,000
3.		*Leucaena leucocephala* (18 inches and above)	Rs. 5000 - 5500
4.	Tamil Nadu Newsprints and Papers Limited (TNPL), Kagithapuram, Seshasayee Paper and Boards Ltd., (SPB), Pallipalayam	*Casuarina* spp	Rs. 4200 (Debarked)
5.		*Eucalyptus* spp	Rs. 5500 - 6000
6.		*Leucaene leucocephala*	Rs. 4500
7.		*Melia dubia*	Rs. 4200 - 4400 (Debarked)
8.	Century Plyboards (I) Ltd, Chennai Ambiply Panels and Doors, Mettupalayam Maxbond Plywoods, Pollachi Asian Timbers, Pollachi Sri Ranga Ply Industries, Mettupalayam	*Eucalyptus* (18 inches and above)	Rs. 5500 - 6000
9.		*Melia dubia* (18 inches and above)	Rs. 7500 - 8500
10.	Vasan Match Works, Vellore Ideal Splints and Veneers , Coimbatore	*Ailanthus excelsa* (24 inches and above)	Rs. 5500
11.	Pavo Energy, Chennai K.G.Denim Limited, Coimbatore Senthil Group of Companies, Coimbatore	All Agroforestry tree species	Rs. 3500 - 4500
12.	Bharathi Package and Furniture, Coimbatore	*Melia dubia* *Albizia* sp. *Acrocarpus fraxinifolius*	Rs. 8000

Table 3. Average Productivity of HYSR Varieties

S.No.	Species	Variety	Productivity (tonnes / ha)
1.	Casuarina sp.	TNAU Casuarina MTP2	150
2.	Eucalyptus sp.	TNAU Eucalyptus MTP1	100
3.	*Melia dubia*	Malaivembu MTP1 (Plywood)	200
		Malaivembu MTP2 (Pulp and Plywood)	200-250
4.	*Leucaena leucocephala*	FCRILL15	100
5.	*Dalbergia sissoo*	DS18	150
6.	*Ailanthus excelsa*	MTPAE17	200
7.	*Neolamarckia cadamba*	FCRIAC13	100
8.	*Gmelina arborea*	FCRISS	450 – 500 kg / tree
9.	*Tectona grandis*	Syyaburry – MTPTK07	15 cft / tree

(Parthiban and Cinthia, 2017)

Fruit trees in Agroforestry for Nutritional Security and Enhanced Income in Arid and Semi-Arid Tropics of Africa and Asia

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Abstract
There are number of agroforestry systems based on fruit plants and almost all the systems are being used in one or other part of arid and semi arid tropics of Africa and Asia. These systems are not only provide fruits but also help in fulfilling the requirement of timber, food, fuel, fodder, generate employment opportunity, provide nutritional security, reduces GHGs, controls environment pollution, improves soil health and provide economic stability. Fruit based agroforestry has proven as an important tool for crop diversification. India's National Agricultural Policy, 2000 recommends agroforestry for sustainable agriculture and advocates bringing up agroforestry in areas currently under shifting cultivation. Task Force on Greening India, 2001 projected that additional 28 million ha area should be brought under plantation through agroforestry. For the purpose, 10 million ha of irrigated lands which are suffering from water logging, salinity and water erosion and another 18 million ha of rainfed lands have been ear marked for agroforestry development.

Keywords: Agroforestry, Economic Stability, Employment Generation, GHGs

Introduction

India has a long history of tree based farming system under diverse ecological conditions. Harappa civilization has indicated that the inhabitants were familiar with the species of date palm, pomegranate, lemon, melon, coconut etc. The agri-horticulture plantation was fostered by emperor Ashoka (274-237 BCE) with mango, jackfruit and grapes. The earliest evidences of fruit based agroforestry from India can also be found in the travelogue of Ibn Battuta (1325-1354 CE, Kumar *et al* 2012). Although, agroforestry is a traditional practice, but agroforestry research has proven that by incorporating agroforestry in planned way farmers/ planters can improve productivity, profitability and sustainability from their existing agriculture and could be a best solution to solve the problems of food, fuel, fodder, timber, unemployment, malnutrition, GHG's, environment pollution, soil health and so on.

The intervention of scientific community to harness full benefits of agroforestry land use and address global issues of land degradation and agricultural sustainability has led to horizontal (expansion of area) and vertical (innovative research) growth of agroforestry (Prasad *et al.* 2016). Global agriculture is facing diverse challenges and constraints due to growing demographic pressure, increasing needs of food, feed, pulp, fodder, fruits and timbers, degradation of natural resources and climate change (NRCAF, 2013 Vision 2050). It is assumed that diversification of land use system with agroforestry can address some or most of these challenges. Therefore, agroforestry has been receiving greater attention by researchers', policy makers and others for its ability to contribute significantly in economic growth, poverty alleviation and environmental quality. Agroforestry has been recognized as an important part of 'evergreen revolution' movement in the country. India is blessed with different types of agro-climatic conditions, so there is huge variation in agroforestry systems in their structural complexity and species diversity, their protective and productive attributes and their socioeconomic dimensions. They range from simple form of shifting cultivation to complex form of home- gardens; from sparse stands of trees on farmlands as in arid region of Rajasthan to high density complex multi-storied homesteads of Kerala; from systems in which trees play a predominantly ‘service’ role (shelter belts) to those in which they provide main saleable products (intercropping with plantation crops) (Dhyani *et al,* 2005). The common problems related to food insecurity in Asian and African countries are climate change and environmental stresses, poverty, increase in food prices, poor human health, poor market access, pest and diseases of crops and livestock, lack of education, unemployment, malnutrition, under nutrition, demographic pressure, land degradation, environment pollution and so on. There are number of agroforestry systems based on agricultural components used in the orchard and almost all the systems are being used in one or other part of Asian and African countries. These systems not only provide fruits but also help in fulfilling the requirement of timber, food, fuel, fodder, employment generation and provide economic stability. The present review could be useful to overcome above mentioned issues related to food insecurity by incorporating the fruit crops in traditional agriculture through diversification.

Fruit Based Agroforestry Systems

There are number of fruit based agroforestry systems, developed as per the local climate and need of the dwellers. They have been developed in almost all the region of India on the basis of either planting of trees, pastures, arable crops etc. in standing fruit orchards or by planting fruit trees in existing pasture or timber/ forest trees (Kumar and Chaturvedi, 2017). The evolved systems are as under:

Agri-horti System

Horticulture based production system is considered effective strategy for improving productivity, employment opportunities, economic condition and nutritional security. Several drought hardy fruit crops like *Capparis decidua, Salvadora oleoides, Cordia dichotoma, Cordia gharaf, Zizyphus nummularia var. rotundifolia, Z. mauritiana* are suitable for the area receiving rainfall <300 mm. Besides providing fruit these plant produce moisture laded nutritious leaves for animals. Several other fruit such as aonla (*Emblica officinalis*), pomegranate (*Punica granatum*), bael (*Aeglemarmelos),* date palm *(Phoenix dactylifera),* imli *(Tamarindus indica)* can be grown in the area having irrigation facilities. Agri-horti system comprising *Zizyphus* + mungbean provided fruit, fuel wood and round year employment even in below average rainfall year. Pomegranate has been found compatible with pearl millet, mung bean, Isabgol, sorghum and cumin in Jalore district of Rajasthan. Studies revealed that the yields of both jujube and the intercrops were higher than in monoculture (Singh 1997). Intercropping of guar, green gram and sesame with jujube (cv. Seb) increased the fruit yield to 14.8 from 5.2 kg tree−1. Cultivation of guar in this system gave additional advantage of 782 kg seed yield, which was higher than that obtained from green gram and cowpea in drought years. Agri-horti system under rainfed and irrigated conditions provide assured sustainability due to additional gains from under storey crops, better utilization of natural resources like water and soil, recycling of on-farm wastes, improving soil fertility, preventing soil erosion and land degradation. The system was found more remunerative particularly during juvenile stages of the horticultural crops. During juvenile phase of fruit tree, there are ample opportunities for raising annual, biennial and perennial crops which can meet diversified need of farmers.

Agri-horti-silvi System

This system is developed to manage the arid lands in judicious way In this system a combination of horticultural crops, silvicultural plantations and fodder crops has been suggested. It has been scientifically advised to adopt the planting of perennials as shelter belts in or around the field. This system is to provide more security, a symbiotic affinity which leads to the higher production of fruit, fodder, fuel and timber wood per unit area. Drought hardy fruit crops can survive and provide income to the farmers even under severe drought. Silvicultural plantations would check the drift of sand, provide forage, fuel and timber wood and would help in creating favourable micro-climatic conditions.

Under extreme arid condition (Yadav *et al.* 2013) agri-horti-silvi production system with green gram and guar as intercrops with 9 year old citrus (*Citrus aurentifolia*), mopane (*Colophospermum mopane*) and shisham (*Dalbergiasissoo*) were found very successful without any reduction in productivity.

Horti-pastoral System

It is a traditional farming system mainly adopted in dry areas. Under this system grasses are grown in the fruit orchard for rearing cattle. This system is also adopted as an alternative land use system in northern regions of India. Farmers in these areas grow fruit trees like guava, mango, citrus, pomegranate, jujube, Indian gooseberry, etc. and rear small cattle that graze on pastures. Now a day, hybrid varieties of fruit trees are being grown and people inhabiting these areas earn money from selling fruits, milk and other different products. In this system, the inter spaces between fruit trees are utilized for the cultivation of grasses and grass legume mixtures. In horti-pastoral system, fruit trees usually form the first tier whereas grasses are grown as ground storey crop. During dormant season of the fruit tree, the livestock are allowed to graze on the available pasture for a period of 3–4 months in a year depending on stocking rate. In rainfed conditions where animal husbandry is also a source of livelihood, this system is more suitable. In the integrated farming system model with a land holding of 7–8 ha, 10–15 % of land is allocated for this system. *Z. nummularia* (jharber) is an important top feed species commonly found in farmers' fields. During drought years when crops fail, this plant comes to the rescue of the farmers and provide them fodder, fuel wood and fruits. Adoption of horti-pastoral system in rainfed agriculture is economically viable, ecologically feasible and socially accepted to minimize the migration from rural areas for the hunt of jobs.

Horti-silvi-pastoral System

The concept of horti-silvi-pastoral system is based on both biological and socio-economic considerations. The former includes all the advantages of fruit and trees on the soil and environment, such as close and efficient nutrient cycle, maintenance of organic matter, prevention of runoff and soil erosion, regulation of microclimate, and above all adaptability of trees to soils that are incapable of sustaining annual crops. The socio-economic factors that substantiate the potential value of this production system are the burgeoning human and animal population pressure and lack of resources (Bhandari *et al.* 2014). The consumption of fruits in the daily diet of rural mass is almost negligible. Animal husbandry being major source of income, the availability of fodder in adequate quantity is important. Therefore, this system has great potential to provide a sustainable land use system. In this system, the selection of fruit trees would depend upon the agro-climatic conditions and availability of irrigation facilities. Recognizing the importance of trees as top feed during lean periods, it is useful to know the potential feed species along with their palatability and nutritive value. As far as possible, multipurpose species such as *A. tortilis, P. cineraria, S. oleoides, Z. nummularia, Acacia senegal, Albizia lebbeck, Anogeissus rotundifolia, A. pendula, Calligonum polygonoides, Azadirachta india, Grewia tenax, Gymnosporia spinosa, P. juliflora and T. undulate* would be an ideal choice under the given conditions. To provide balanced nutritive fodder to the animals, both grasses and legumes in the pasture are advocated. Based on the edaphic factors suitable grasses are *L. sindicus, Panicum antidotale, Saccharum bengalensis, C. ciliaris* for sand dunes and sandy plains; *D. annulatum, Heteropogon contortus* for sandy loam and sandy clay loam soils; *Sehima nervosum, D. annulatum* for sand stones and rocky sites; *C. ciliaris, C. setigerus* for well drained sandy alluvial soils; and *Sporobolus marginatus, Chloris virgata* for low lying saline soils. The horti-silvi-pastoral system can produce more biomass per unit area, which also meets the basic requirement of fruit, fuel and fodder for the rural masses of the region. This system will not only provide the judicious use of available land resources but will also generate additional employment opportunities for rural people.

How Fruit Trees in Agroforestry Systems Are Useful In Solving The Problems

Efficient Land Use

The horticulture based production systems can be practiced both in rainfed and irrigated conditions for enhanced productivity, profitability and sustainability. These systems are also useful for those marginal and degraded lands where arable farming is either not possible or uneconomical. Adopting horti-pastoral or horti-silvi- pastoral system can ameliorate these lands in a long term due to soil conservation and improvement in fertility levels. Windbreak effect due to live fences and tree plantation leading to better soil moisture retention and reduced transpiration will be an additional advantage.

Improves Productivity

In agroforestry, the potentially higher productivity could be due to the capture of more growth resources e. g. light or water or due to improved soil fertility. Several studies in different parts of the country suggested that agroforestry is more profitable to farmers than agriculture or forestry for a particular area of land. National Research Centre for Agroforestry has been working since 1989 on agri-silvi- horticulture system which included 4 varieties of aonla viz., Chakaiya, Kanchan, Krishna and NA 7 as fruit trees, *Leucaena* as multipurpose tree and blackgram as intercrop in rainfed areas. The *Leucaena* was planted on both sides of the fruit trees at 2 m distance. The aonla was planted at 10 m x 6 m and 5 m x 6 m spacing but 10 m x 6 m spacing was proved an ideal spacing among these and it was considered for calculating the yield and economics of the system. The cost of cultivation in first year which includes planting of fruit trees and *Leucaena* as multipurpose trees and cultivation of crop was Rs 8,666/ha but during next year the cost of cultivation was reduced and it was again increased with subsequent increase in the cost of input during different years. The gross income from the system was less during initial year but when fruiting started in aonla, the gross income was increased and it went up to Rs 60,712/ha at age of 13 years. Similarly the net income was positive in all the years except at first, third and six years when aonla had no fruiting/or less fruiting. In age of 13 years, the B: C ratio from the system was 3.28 and on discounted rate it was 2.61 which indicated that aonla based agroforestry system is a profitable enterprise in marginal lands under rainfed conditions.

Increases Soil Fertility

Ecologically sound agroforestry systems such as intercropping and mixed arable-livestock systems can increase the sustainability of agricultural production while reducing on-site and off-site consequences and lead to sustainable agriculture. Alternate land-use systems such as agroforestry, agro-horticultural, agro-pastoral and agro-silvipasture are more effective for soil organic matter restoration (Manna, *et al.* 2003) and to improve the fertility.

Fodder Supply

The fodder scarcity could be reduced through fodder cultivation on farm lands and through silvipasture/hortipasture on farm/community wastelands. Assuming availability of another 10 percent of community wastelands for silvipasture/hortipasture, the additional fodder production (@ 2.0 t/ha /yr *i.e*. at 40 % of research yield) would be 11.99 million tonnes in the immediate future.

Socio-Economic Issues

Adoption of horticulture based production systems can improve the socio-economic conditions of resource deficient farming community. These will provide an assured source of livelihood as perennial component will generate farm produce even during low rainfall or drought conditions. Many of these underutilized fruit species play an important role in the social economy and livelihoods of tribal, small, marginal and landless farmers. Produce of trees provides additional income to these farmers and substantial livelihood support in addition to the nutritional security to the children and women. Organized production and processing for value addition of products would further enhance income of small and marginal farmers and also help in on-farm conservation of valuable germplasm (Malik *et al.* 2013). Increased biomass availability will help in integration of livestock in to the farming system. Most of the perennial components also provide fodder for huge animal population under adverse conditions.

Emploment Opportunity

These production systems will certainly open an opportunity for additional employment for rural youth during most of the months compared to arable farming, which is exclusively dependent on rains and confined to a limited period. These systems involve collection of fodder from grass and top feed tree component, raising nurseries, grafting of fruit trees, training, application of agronomical and plant protection measures, irrigation, grading, marketing, pruning, and managing farm produce for compost preparation or recycling in soil. There is a tremendous potential for employment generation with improved agroforestry systems including fruit trees to the tune of 943 million mandays per annum (NRCAF, 2007: Perspective Plan Vision 2025).

Nutritional Security

The rural masses do not have adequate fruits and vegetables in their diet. With large scale plantation of horticultural crops in their farm under integrated system, the inhabitants of region will certainly get nutrition in the form of vegetables and fruits.

Biodiversity Conservation

Over exploitation of natural resources is a major challenge for sustainable production and livelihood security. Agroforestry with components like timber trees, fruit trees, agricultural crops, grasses, livestock etc. provides all kinds of life support. Trees in agroforestry system act as a refuse to biodiversity after catastrophic events such as fire (Griffith, 2000). The traditional society of coastal belts and tropics of the country practicing home gardens and sacred groves help in bio- diversity conservation.

Carbon Sequestration

Intervention of fruit trees in agroforestry can be significant sink of atmospheric carbon (C) due to their fast growth and high productivity. In fruit based agroforestry system, tree components are managed, often intensively by pruning of minimizing competition and maximize complimentarily. The pruned materials are mostly non- timber products. Such materials are often returned to soil. Besides, the amount of biomass and therefore C that is harvested and exported from the system is relatively low in relation to the productivity of the tree. Therefore, unlike in tree plantations and other mono culture systems, an agroforestry model seems to have unique advantage in terms of C sequestration. The C storage capacity varied from region to region and also depends upon the growth and nature of tree species involved in the system.

Potential Use in Targeted Countries (Arid and Semi-Arid Tropics of Africa and Asia)
Most of the land in targeted countries is non-arable, undulated, hilly, non-fertile, eroded consequently production is poor which leads many problems like starvation, poverty, unemployment, poor economy and so on; by adapting different agroforestry systems one can reduce such problems upto some extent as these systems improves productivity, enhance fertility, generate employment opportunity, provides nutritional security and capable to solve socio-economic issues.

Way Forward / Conclusion
The critical food security factors that need urgent analysis backed by effective management mechanisms include the rapid rate of population growth rate; agricultural policies and governance; management of agricultural land; water resources management; technological possibilities; the contribution of women; food security early warning systems; protecting the environment while ensuring food security; and providing appropriate support for pastoralists and livestock production. The fruit trees based agroforestry system has a big potential to contribute positively towards the reduction of poverty and food insecurity if accorded the right support. Taking into account the fragile and variable environmental conditions of most of the countries, modern industrialised agriculture should be de-emphasised and the priority accorded sustainable and integrated farming systems. In present scenario when the population (human and animal), unemployment, malnutrition is increasing, land is shrinking and soil fertility is going down and down, climate is changing, environment is polluting and food security is threatening- fruit based agroforestry systems could be a best solution to fight against such problems as these systems not only provides food, fruit, fodder but also provides employment, income, conserve the soil and its fertility, conserve biodiversity and helps in carbon sequestration and mitigation.

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Mini Clonal Technology and Value Addition of Plantation Residues

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Abstract
The growing importance on promotion of plantation and agroforestry in India demand production of quality planting material to satisfy the demands of tree growing farmers and wood based industries. As of now, most plantation activities in the country are carried out through seed based seedling production which exhibited wide variations in productivity and adoptability. Under such circumstances the current mini clonal technology has been developed for wide range of pulpwood, plywood and timber species which exhibits greater potential of adoption across regions towards mass multiplication of wide range of species. The rapid multiplication coupled with increased rooting efficiency and elimination of epigenetic variation attracts this technology as a most promising in forestry and agroforestry promotion.

The growing energy demand coupled with alarming concerns on impacts due to fossil fuel encouraged the use of renewable energy which is safe and environmentally viable. Wide range of renewable energy sources has been deployed in the country but among them the potential of biomass based energy generation is very well witnessed. Among the biomass resources the significance of value added briquettes and pellets are very important due to their fuel efficiency, combusability and low ash content. This has attracted development of value addition technology for plantation residues and extends greater scope of application and replication across the regions.

Keywords: Mini Clonal Technology, Tree Crops

Introduction

Forestry in general and agroforestry in particular is gaining significant attention across the world due to their productive, protective and ameliorative functions. In India, forestry has been playing a significant role in contributing towards productivity and the associated socio economic development till the recent past. The policy and legal issues have restricted the regular reserve forests for production function which resulted in limited availability of wood and wood products for the domestic and industrial utility. This has widened the gap between the demand and supply both domestic and industrial wood. It has attracted agroforestry across the country and currently the agroforestry contributes nearly 60% of the timber requirements of the country. This besides, agroforestry contributes towards domestic and industrial wood requirement. The agroforestry received attention due to higher productivity of over 20m^3/ha/annum compared to 0.5 m^3/ha/annum of the natural forest productivity. The higher productivity was achieved due to strong breeding and improvement programme coupled with the exploitation of improved genetic resources through clonal technology. The clonal technology has been emerging as a strong attraction and alternate to traditional seed based propagation technology (Parthiban *et al*, 2014). The use of Clonal technology and the associated productivity improvement has been witnessed in many tree species (Nanda 1970, Zobel and Talbert, 1984, Leaky 1987, Park, *et al* 1995 and BRACELPA, 1999).

Brazilian Forestry has been pioneer in the development of Clonal technology primarily concentrated on Eucalyptus. Originally the Clonal propagation was viewed as a method to improve plantation productivity and uniformity, disease resistance and coppicing ability (Campinhos and Ikemori, 1983). The objectives over the years have been changed towards wood volume and wood quality (Ken Mcnabb *et al*, 2002). Coppicing was no longer an objective as the rate of Clonal selection and improvement has been so fast which resulted in identification and incorporation of new clones in the successive rotation. This has been witnessed by the current author and the author was trained in the recent Clonal technology practiced in Brazil for Eucalyptus. This technology has been named as mini Clonal technology and has been moderated and deployed for mass multiplication of most of the industrial wood species like *Casuarina, Melia dubia, Anthocephalus cadam, Dalbergia sissoo, Khaya senagalensis* etc. The technology deployed for the above mentioned species have been discussed in this chapter.

Clonal selection programme

The first stage in Clonal propagation is selection of a clone. It is the selection of the individual trees based on its morphogenic superiority from the existing plantations. The individual trees are selected based on growth attributes, tree morphology, tree health and the apical dominance. In general, trees are selected as early in 3 years after planting and for many species selection in half rotation age are practiced. The clonal selection also depends on the species, objectives of management and also the end utility coupled with the commercial value.

Once the trees are selected, the trees are cut at base preferably at 15 cm above the ground level and are allowed to coppice. These coppice shoots are harvested and treated with rooting hormone and ramets are multiplied for field testing and evaluation. Simultaneously, the harvested wood is fragmented into wood samples and is analyzed for physical, chemical, mechanical and anatomical properties. The wood properties viz., cellulose content, lignin content, kappa number, specific gravity and fibre length are characterized for screening the superior most wood quality clone. Based on the field productivity coupled with wood quality, the selected clones are finally screened and are deployed for mass multiplication through mini Clonal technology.

Clonal Multiplication Process

The clones identified in the above process are multiplied through the mini clonal technology towards mass multiplication of domestic and industrial wood species. The Clonal materials are first established through micro propagation under controlled light and temperature condition. The shoots produced were rooted under invitro conditions and they are planted in mother Clonal garden. The general Clonal multiplication process follow is depicted in Fig 1.

Construction of Sand Bed Trough

The clones screened have to be planted in the sand bed trough for mass multiplication. The sand bed trough can be of various sizes viz., 10 x 1 x 0.6 m or 5 x 1 x 0.6 m or 3 x 1 x 0.6 m depending on the annual planting material requirement and the associated management technologies. The trough of the required sizes can be constructed using cement concretes or fabricated through GI sheets. Once the bed size is designed and established, the bottom of the trough is filled with 20 mm stones upto the height 20 to 25 cm from the base upwards. Then the portion above stone filling should be filled with fine sewed river sand. The trough should be facility for proper drainage at both the ends. The trough can be covered with 100 micron UV stabilized poly ethylene film on the top and covered with insect proof mesh along the sides in order to protect the plants from pest and diseases. The design of a trough is furnished in Fig 2. The bed should be properly connected with drip lines to facilitate irrigation and fertilization.

Planting and management of clones

Once the trough is established, the prioritized clones are planted for mass multiplication. The ramets are planted at an espacement of 10 cm x 10 cm (between rows and between plants) so as to cover 100 plants/m^2. So in 10 m^2 plot, about 1000 plants can be planted. The design of Clonal planting in the sand bed trough is furnished in fig 3.

Irrigation

After planting, the clones have to be irrigated at an interval of every one hour in order to activate the cell division and induce new micro shoots for early harvest.

Fertigation

The mini clonal garden should be maintained with irrigation at an interval of every one hour and supplemented with the following nutrients.

- Urea – 300-400 /m^2 area
- SSP – 150-175 /m^2 area
- KCL – 175-250 /m^2 area
- Micro nutrient mixture – 100 /m^2 area

The nutrients can be applied twice or thrice depending on the rate of growth of plants and the species involved in the multiplication process.

Clonal Management

The plants are allowed to grow upto 30-60 days by applying the required nutrient composition. After 60 days, the plants are pruned at required size preferably at half of the plant to induce new shoots.

Harvesting of Apical Shoot Cuttings

With continuous irrigation and nutrient management, the cut end stem will start producing new shoots from 8-10 days onwards and after 15-20 days the apical shoot cuttings can be collected and treated with 2% carbendazim solution. After each and every harvest the irrigation and fertilizer should be continued daily to induce next cycle shoots.

Mini cutting Treatment

The apical shoot tip cuttings do not require basal hormone treatment for root initiation due to active cell divisions and the presence of balanced hormonal regulation. These shoot tip cuttings form new apical meristems and the leading growing tip does not originate from the lateral buds. Similarly the roots tend to grow straight down from the base of the cutting as opposed to growing from the side of the stem. This resulted in rapid growth and development coupled with vigorous and quality planting material.

Planting of Apical Shoot Cuttings

The newly induced shoots were separated from the plants and are planted in 90 cc root trainers filled with decomposed coir pith without any external hormonal treatment. The rooting started in 15 days and 25 days old rooted plants are ready for hardening. Some species require hormonal treatment for which IBA at 1500 – 3000 ppm powder formulation can be applied before planting in the root trainer.

Green House Conditions

The root trainers are kept under greenhouse conditions with a temperature regime of 32 – 35°C and a relative humidity of 85-95%. Periodical watering once in every 30 minutes will ensure early, easy and uniform rooting process.

No. of cycles of shoot Harvest
Through this intensive mini garden management, at least one harvest per month is possible. For every harvest, a minimum of 5 shoots per plant is ensured for most species barring few exceptions.

Acclimatization and Hardening
The rooted plants are hardened in a shade house condition with 50% shading for 7-15 days and maintained with adequate irrigations. After hardening chamber, the plants are lifted to open nursery for 30 days. Watering is done 2 times a day and the fertilizer of all 19 (N:P:K) can be applied at the rate of 5g/plant. During this hardening process, application of carbendazim (2g/l) or triazophos (2ml/lr) is recommended based on the incidence of diseases and pests.

Advantages of Mini Clonal Technology
- ❖ Rooting ability of mini clonal technology is High
- ❖ Propagules expressed variability due to epigenetic or somatic variations in the existing clonal technology is avoided through the mini clonal technology.
- ❖ This technology can produce more number of cuttings per year and per unit area
- ❖ It can be maintained upto 5 years
- ❖ It does not require rooting hormone.
- ❖ This technology has shown great potential for offering technical and economic advantages.
- ❖ Increased uniformity and greatly reduced topophysis effects
- ❖ Compared to existing clonal technology, the mini clonal technology have improved rooting potential, rooting speed, quality root systems as well as reduced cost
- ❖ Cuttings can be taken from 60 days onwards and after that once in every 15-20 days against the periodic collection in the existing technology

Limitations
- ❖ Initial high cost of establishment
- ❖ Intensive care and management
- ❖ Requirement of skilled labour
- ❖ Continued research and development support

Value Addition of Plantation Residues - Briquetting

Introduction
The energy consumption in India is steadily increasing over years but there is no concomitant increase in biomass availability. In India, about 46% of the total energy consumption is estimated to be met from various biomass residues *viz.*, agriculture residues, animal dung, forest waste, fire wood etc. (Ravindranath and Hall, 1995). The major portion of the agriculture residues produced in the country is used for domestic utility (Tripathi *et al.*, 1998) and the direct burning of agriculture residues in domestic as well as industrial application is very inefficient due to wide range of biomass sizes and varying water content coupled with more ash content. More over transportation, storage and handling and other logistic issues also create problems in their sustainable utilization. Hence forests in general and the forest biomass in particular played significant role in energy generation due to their sustainable availability and the associated positive factors like low ash content and increases burning efficiency coupled with their role in environmental amelioration. This created the scope of large scale demonstration and establishment of energy plantations in the country thereby helped to resolve the issues on energy unavailability. These forest biomasses were utilized directly both for domestic and industrial consumption which resulted in inefficient energy conversion coupled

with the associated environmental issues due to the smoke and the ash that emanated from direct burning of forest residues. This besides the huge volume of biomass residues (other than the major woody biomass) *viz.*, twigs, branches, leaves, saw dust, bark etc., have been so far under or unutilized for want of suitable conversion technology and the associated operation and logistic issues. Similarly the growing area under agroforestry has also produced huge volume of plantation residues which are left unutilized. To resolve these issues, there is a current research team has carried out systematic research to transform the plantation residues into value added briquettes / Pellets which are furnished below.

Significance of Wood Based Biomass Energy

Wood fuel plays an important role in the economy of rural people. It provides local income and employment. About 70% of the rural population in India is dependent on wood energy. It is also used by the medium and metropolitan group to meet their day today energy needs. In India, wood fuel contributes to the extent of 69.2% of the rural energy needs and 35.5% of the urban sector. The consumption of wood fuel is estimated to be around 300 million tons per annum. Wood fuel is more sustainable than fossil based fuels like coal, peat, oil or bituminous rock. No doubt the combustion of wood emits CO_2, but the reforestation or regrowth of these forests capture it back. The use of cogeneration technology has made a carbon neutral. Hence the wood as direct energy and wood converted into various fuel forms have contributed significantly the energy needs of the country and requires enough attention for their promotion, popularization and rationale utilization to have clean environment.

Biomass Residues Availability for Briquetting

Essentially the residues from agriculture sector, forest biomass, saw dust from timber mill can be successfully briquetted. The agriculture residues which do not host collection and drying problem are also suitable for briquetting but not as a direct raw material but as a blended material. The suitability of raw material for briquette production rely on several factors but the prominent characteristics are moisture content, ash content, flow characteristics and particle size. Moisture content is preferred in the range between 10 and 15 and the ash content up to 4%. The particle size of the raw material must be uniform and the preferred size ranged between 6 and 8 mm which provide uniform flow in screw conveyors which facilitate easy briquetting and avoid blockage. In India, wide range of raw materials viz., saw dust, groundnut shell, cotton stalks, maize stalks, rice husk, and tamarind shell. Coir pith, coffee husk, mustard stalk, sunflower stalk, baggasse, wood chips etc., are used either singly or in combinations. The raw material suitable for briquetting is classified into three categories viz., fine granulated, coarse granulated and stalky biomass. However, the use of agroforestry residues for value addition into briquettes is of recent origin and the processes involved are presented.

Constraints faced by the briquetting industry

- ❖ The spectare of raw material unavailability
- ❖ Sporadic availability of raw material
- ❖ Wide variation in biomass
- ❖ Availability of higher volume of raw material with uncertain quality
- ❖ Seasonal availability
- ❖ Collection, transportation and other logistics
- ❖ Higher moisture content
- ❖ Availability of soil and other inert materials in the agriculture biomass
- ❖ Unorganized marketing and trade resulting in poor supply chain

Scope of Briquetting

The constraints listed above are not exhaustive but only indicative which thus extent adequate scope for briquetting in order to create self-reliance in energy sector through value addition process. The briquetting technology will help to convert the diverse biomass into a value added quality products thereby create considerable scope for establishment of value addition industries in rural and urban centers. These establishments will help to create adequate income and employment generation activities thereby help to auger the socio economic status of the rural dwellers. Above all, white smoke coupled with low ash content in the briquettes will create clean and sustainable environment and help to achieve the policy requirements of the country.

Briquetting Enterprise and the Processing Technology

a) Machineries

Briquette production is recognized as a business enterprise which predominantly uses wood residues. Most of the briquetting units in the state of Tamil Nadu, India utilizes around 70% of wood based saw dust and 30% of agro residues for all types of briquette production. The briquetting enterprise will require the following machineries viz., cutting, pulverizing machine or hammer mill grinder, drier, briquetting press. The schematic diagram of a briquetting plant setup at the host institute is depicted in figure 4.

b) Processing Technology

The briquetting process involved are drying (reduction in moisture content), size reduction (change in surface area to volume ratio) and densification (change in density).

i) Drying

It is a method of removing moisture content of biomass. The heat generation of biomass is dependent on the moisture content, therefore drying of biomass is essential for enhancing its calorific value. It has been observed that only about 9% of energy value of biomass are lost in reducing the moisture content from 30 to 9%. But if it is not reduced the decrease in calorific value is about 26%. The optimum moisture content of the raw material suitable for briquetting is between 7 and 10% (Hasan Yumak *et al*. 2010).

ii) Size Reduction

Size reduction of biomass is done to convert it to a convenient transportable, storable and usable form. These processes include tree cutting (removing stems and branches from tree), log cutting to convenient size for use and log cutting to small billet form for use.

iii) Densification

This process is to increase the bulk density of biomass for efficient and convenient transportation and handling. It also reduces the requirement of bulk storage space. The physical dimensions and the combustion characteristics of the fuel become homogeneous and uniform due to the availability of required particle size, porosity and density which result in efficient energy conversion.

The densification processes are broadly three types:

i. **Binderless Densification Technique**

   In this method, no external binders are added for compacting the material however the process is done at high temperature (85 – 105^{o}C) and at high pressure (1500 kg / cm^2).

ii. **Densification With Binders**
In this method, the pressure requirement is low but the binding materials such as tar, molasses, resins, wax, or other biological binding materials like tamarind and cashew shell are used along with the biomass to enhance densification process.

iii. **Pyrolysis**
In this method, the biomass is first carbonized and the charcoal obtained is powdered and then compacted in required size and shape.

The flow of industrial process involved in briquetting technology is depicted below in the Figure 5.

Thermo-Chemical Analysis of Briquettes Parameters

The current study on Casuarina needles, Eucalyptus plantation residues, Jaropha (TBO) fruit husk, match wood residues and plantation residues of *Melia dubia* were successfully converted into briquettes and the thermo-chemical study findings are furnished in Table 1.

Utility and Other Benefits

The forest biomass based briquette production technology has significant utility and made tremendous impact in terms of value addition of underutilized biomass (nearly 5 to 8 tonnes of green biomass) into value added briquettes thereby help to create adequate socio economic and environmental impact. The state of Tamil Nadu, India is currently housed with nearly 0.1 million ha Casurina plantation which will result in the availability of 0.5 to 0.8 million tons of green biomass distributed in 24 districts of the state. Hence establishment of decentralized value addition units may result in efficient utilization of biomass residues and their conversion into briquettes will result in meeting the energy requirements of the country.

Benefits of the Briquetting

- Utilized as domestic and industrial fuel for energy supply
- The bulk density is increased from 80-200 kg/m^3 to 600-800 kg/m^3
- The specific density will range from 1,100 – 1,200 kg/m^3
- Increased heating efficiency
- It produces white smoke and low ash and hence environmentally safe fuel

Way Forward

The mini clonal technology established for few industrial wood species will have the replication potential across wide range of species and varieties. The technology extends greater scope of mass multiplication of elite varieties with minimal space, time and money. The technology is adoptable to wide range of commercially important tree species across the world. Similarly the value addition technology needs to be established across different countries and continents thereby help to convert unutilized biomass into a value added briquettes. This will also ensure clean and green energy generation and satisfy the demands of clean development mechanism.

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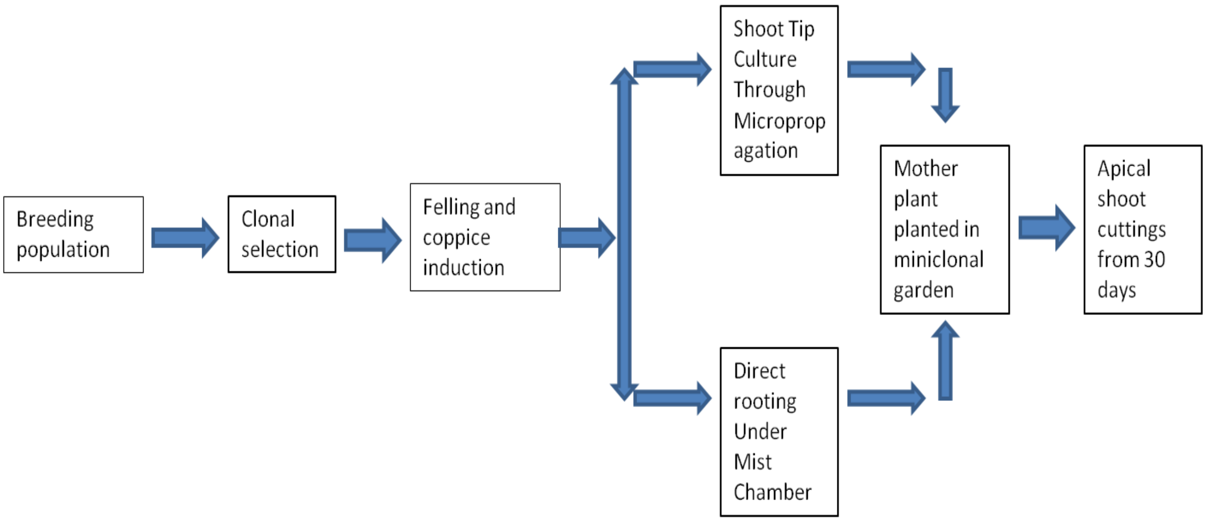

Figure 1: Mini Clonal Technology Protocol

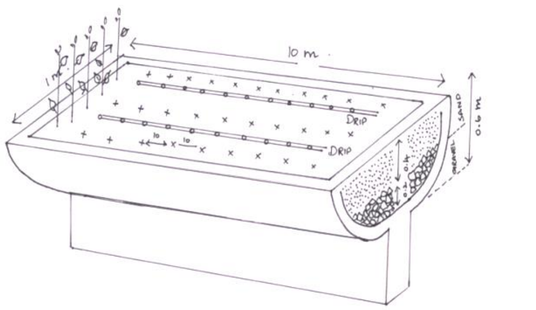

Figure 2: Design of a Sand Bed Trough - 10 m x 1 m x 0.6 m

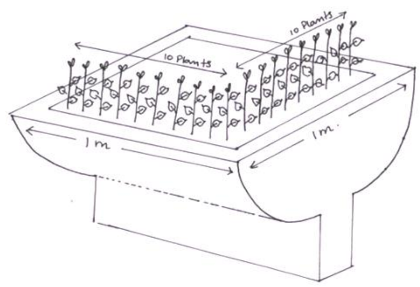

Figure 3: Design of clonal planting in sand bed trough

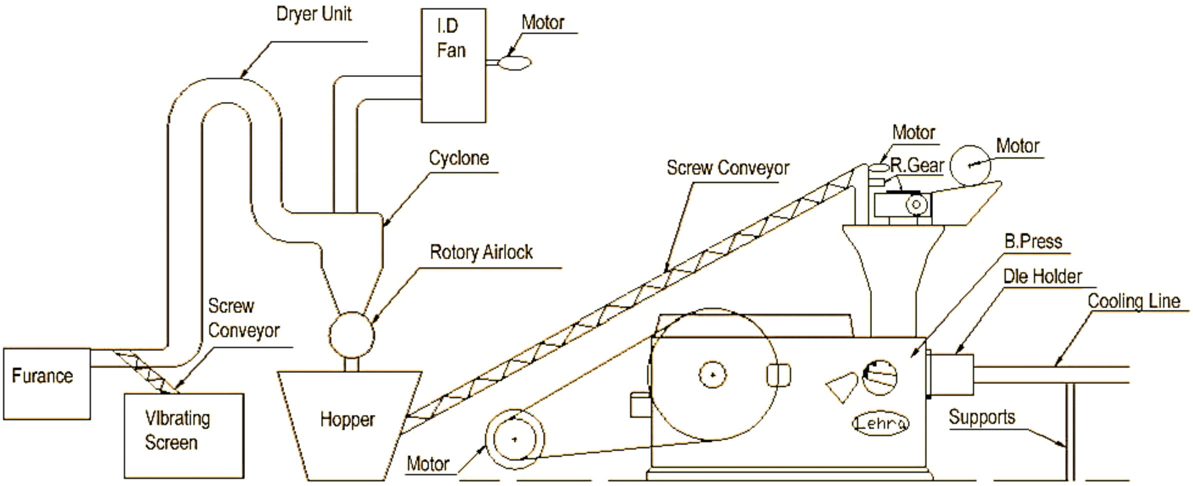

Figure 4: Schematic Diagram of Briquetting Plant

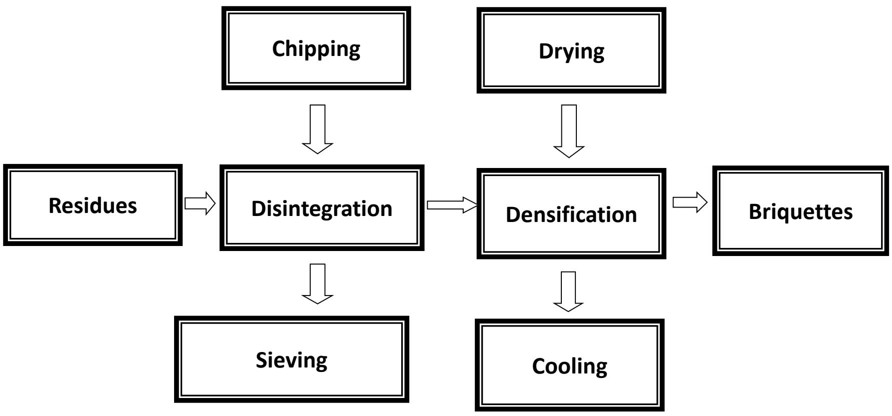

Figure 5. Briquetting process

Table 1. Briquetting quality of various tree residues

Sl.No	Raw materials	Volatile matter %	Ash content %	Heating value MJ.kg-1 (DB)	MC %	Calorific value K.cal/kg
1	Casuarina needles	15.53	7.77	31.54	5.06	4950
2	Eucalyptus plantation residues	12.87	3.96	32.87	7.42	4426
3	Jatropha (TBO) fruit husk	17.82	9.90	30.78	4.15	2968
4	Matchwood industrial residues	14.42	4.81	32.56	4.48	4714
5	*Melia dubia* plantation residues	15.00	8.00	31.46	5.01	3650

Agroforestry and Livelihood Opportunities from Natural Resins and Gums (NRGS) including Lac

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Abstract
Natural resins and gums (NRGs) are the most important non timber forest products (NTFP) widely traded in national and international market. In India about 400 million people earn their livelihood by getting employment in collection and processing of NTFP. However, the production base of NTFP has been declining due to unscientific over tapping of existing trees in forests. Integration of gum/resin-yielding trees in agroforestry systems offers great potential for utilization of available resources and increasing productivity of NRGs on sustainable basis besides providing livelihood support options and ensuring ecological stability of the land use. This article is an attempt to showcase current status of NRGs in India, research and development initiatives, how NRGs yielding trees can be integrated in agroforestry and the future prospects.

Keywords: Agroforestry models, Bundelkhand, gum karaya, gum Arabic, IINRG, NTFPs.

Introduction
Natural resins and gums are the most important non timber forest products (NTFP) widely traded in national and international market. According to International Trade Centre (ITC) statistics, the world trade aggregation of lac, natural gums, resins, gum-resins and balsams during 2015 was about 1220.16 million US dollars (Yogi *et al*; 2018). Out of this, the world export was about 436.70 million US dollars. Major suppliers of NRGs contributing about 92 % share in international market are France (31.2%), India (15.6%), USA (8.3%), Germany (7.1%), UK (6.1%), Thailand (5.9%), Brazil (4.5%), Singapore (2.7%), Ethiopia (2.6%), Greece (2.5%), Italy (2.2%), Netherlands (1.4%), China (1.1%) and Malaysia (1.0%). Rest of the 7.6% NRGs are supplied from 83 countries across the world.

Similarly, the world import aggregation of lac, natural gums, resins, gum-resins and balsams during 2015 was about 783.45 million US dollars. Major importers of NRGs contributing about 80% share in the international market are India (17.0 %), France (13.6 %), United States of America (11.2 %), Germany (5.2 %), China (4.7 %), Italy (3.9 %), Netherlands (3.4 %), United Kingdom (3.3 %), Portugal (2.8%), Russian Federation (2.6%), Singapore (2.5%), Saudi Arabia (2.4%), Spain (2.3%), Brazil (2.1%), Ireland (2.0%), Japan (1.6%), Switzerland (1.4%), and Thailand (1.3%). Rests of the 16.6% demand of NRGs aroused from the 115 countries across the world.In modern times applications of gums and resins have expanded world over in many industries such as paper, textile, petroleum, pharmaceutical, cosmetics, food, varnishes, lacquers and soap.

Forest produce based industries contribute to 1.2% of India's Gross Domestic Product (Economic Survey, Ministry of Finance, 2011). In India, there are around 1.73 lakh villages located in and around forests (MoEF, 2006). According to some estimates about 350- 400 million people (MoEF, 2009) are dependent on forest and earn their livelihood from NTFPs. About 70% of the NTFP collection in India takes place in the tribal belt of the country (Mitchell *et al.*, 2003). Around 55% of employment in forestry sector is attributed to this sector alone (Joshi, 2003). In India the bulk of commercially important gums in the country come from the

Central Indian Forests consisting of states like Madhya Pradesh, Chhattisgarh, Andhra Pradesh, Odisha, Jharkhand and Bihar. The gum producing areas are the Western Ghats, Eastern Ghats, and surrounding areas. Though there are more than 30 commercially important gum and resin species available in India, the number of important trees with substantial production is rather small. Among the various kinds of gums, the important species are gum *karaya* (*Sterculia urens* Roxb.),, gum dhawara (*Anogeissus latifolia* Roxb.), tamarind gum (*Tamarindus indica* L.), and gum arabic (*Acacia senegal*). Among resins, the important ones are pine resin (*P. roxburghii* Sarg.*)*, Sal resin (*Shorea robusta*), Salai (*Boswellia serrata*), black dammer (*Canarium strictum*) and Guggul (*Commiphora weightii*). Besides, NRGs of commercial importance like lac (*Kerria lacca* Kerr), *guar* gum (*Cyamopsis tetragonoloba* L.), *char /piyar* gum (*Buchanania lanzan* Spreng.) and *babool* gum (*Acacia nilotica* L.) are also produced. India holds monopoly in international trade over some of the NRGs such as lac, gum *karaya* and *guar* gum.

The gums and resins trade in India faces declining trend in the production base of the produce due to ruthless tapping and unorganized harvesting approaches. However, the demand for NRGs has been continuously increasing in the world market since 1990's. Integration of NRGs yielding trees in agroforestry land use may help in increasing production base of gums and resins, and provide a new option of livelihood support to small holders at the edge of climatic vulnerability. Besides, the gum and resin based agroforests will also contribute in mitigating enhanced CO_2 in atmosphere. This article is an attempt to showcase the potential of agroforestry land use for producing gums and resins for livelihood support.

Natural Resins and Gums: Current Status

NTFPs based on their chemical composition may be classified in three categories namely natural resins, natural gums and gum resins. Natural resins are solid or semi-solid materials, usually a complex mixture of organic compounds called terpenoides, which are insoluble in water but soluble in certain organic solvents. Resins are secretion of several plants, particularly coniferous trees. Resins are used in the production of varnishes, adhesives and food glazing agents. These are also used as raw material for synthesis of incense and perfume. This group of natural resins includes lac secreted by an insect *K. lacca* (Kerr) and plant originated products like rosin, copal and dammer. Solidified resin from which the volatile terpene components have been removed by distillation is known as rosin.

Natural gums are polysaccharides of natural origin, capable of causing a high viscosity in the solution. Most often these gums are found as exudates from woody elements of plants or in seed coatings. In the food industry these are used as thickening, gelling and emulsifying agents and stabilizers. These are also used as adhesives, binding agents, crystal inhibitors, clarifying agents, encapsulating agents, flocculating, foam stabilizers, swelling agents, *etc.* Natural gums can be classified according to their origin. Firstly, tree exudates *e.g.* gum *arabic*, gum *ghatti*, gum *tragacanth*, gum *karaya*, *guar* gum, locust bean gum, *chicle* gum, *dammar*, *mastic* gum, psyllium gum and spruce gum. Secondly, originated from seaweeds *e.g.* agar and *carrageenan* and thirdly, produced by bacterial fermentation *e.g. gellan* gum and *xanthum* gum. They can also be classified as uncharged or ionic polymers (polyelectrolyte). Gum-resins are the natural mixtures of gums and resins in variable proportions therefore possess properties of both the groups. They contain traces of essential oils and are partly soluble in water. They have a penetrating and characteristic odour and taste and obtained from the plants. Olibanum/ *salai* gum (*Boswellia serrata*), guggal *(Commiphora wightii)*, myrrh, asafoetida, *etc*. are the major gum resins of importance.

1. Resins

A. Resin from insect source

Lac: Lac is a natural resin secreted mainly by Indian lac insect, *K. lacca* (Kerr) which thrives on the tender twigs of specific host trees *viz.*, *palas* (*Butea monosperma*), *ber* (*Ziziphus mauritiana*), *kusum* (*Schleichera oleosa*), *Flemingia semialata*, *Ficus spp*. *etc*. *Rangeeni* and *kusmi* are the two strains of lac insect which are classified based on preference of the insect for specific host plants. Raw lac is the source of three valuable products *i.e.* resin, dye and wax. Lac is mainly produced in India, Thailand, Indonesia, parts of China, Myanmar, Philippines, Vietnam, Cambodia *etc.* and India is the largest producer of lac in the world. In India, lac cultivation is an important source of income for livelihood of the forest and sub-forest dwellers of Jharkhand, Chhattisgarh, Madhya Pradesh, West Bengal, Maharashtra, Odisha and parts of Uttar Pradesh, Andhra Pradesh, Gujarat and NEH region. Lac production is highly labour intensive process and provides employment to both men and women dwelling in forest and sub-forest areas of these states. It is a highly remunerative crop, paying high economic returns to the farmers. The cultivation of lac on a large number of hosts of different kinds, its collection by numerous small growers, variations in the yield depending on the type and size of the host, cultivation practices and climatic conditions are the major factors influencing the estimation of lac production. On the basis of survey in the markets of different lac producing districts, the estimated national production of sticklac during 2015-16 was approximately 18,746 tons comprising *rangeeni* (7,597 tons) and *kusmi* (11,149 tons) sticklac. Among the lac growing states, Jharkhand state ranks 1st followed by Chhattisgarh, Madhya Pradesh, Maharashtra and Odisha. These five states contribute around 93% of the national lac production. Contribution of Jharkhand in national lac production is about 53% followed by Chhattisgarh (17%), Madhya Pradesh (12%), Maharashtra (8%) and Odisha (3%). Among the different cropping season crops, *jethwi* crop is ranked 1st with the contribution of 32% followed by *aghani* (27%), *baisakhi* (24%) and *katki* (17%) in total lac production (Yogi *et al*., 2018).

B. Resin from plant source

Pine resin: Rosin is a natural product of pine resins (*Pinus roxburghii* Sarg.). Rosin and its derivatives have been used as paper-sizing agents, emulsifiers, surface coatings, chewing gums, tackifiers in adhesives, insulating materials, and additives for printing inks. Recently, it was also evaluated for application in the pharmaceutical as microencapsulating materials (Lee & Hong, 2002; Tang, 2003). Pine resins are secretion of plants, particularly coniferous trees. These are used in the production of varnishes, adhesives, and food glazing agents. Extensive *chir* pine forests are found in the Himalayas between an elevation of 1000 to 1900 m. *Chir* pine yields commercially important oleo-resin which forms the raw material for rosin and turpentine oil industry in India. *Chir* pine is widely tapped for resin on commercial basis, particularly in the hills of Himachal Pradesh, Uttarakhand, Jammu & Kashmir and north-eastern states. The northern hill states annually produce around 8,000 to 9,000 tons of raw rosin extracted from pine trees.

Major share of resin production comes from Himachal Pradesh and Uttarakhand. The production of resin in the states during the year 2013-14 was about 8000 tons and about 85 % of this raw material is processed in the Rosin and Turpentine oil Factories (RTFs). Indonesia also supplies rosin to Indian industries but China is the major supplier of imported product. Indonesian rosin costs around the same as the Chinese product. Both China and Indonesia have captured more than 50% of the Indian market. The annual requirement of rosin in the country is 40,000-50,000 tons. World production of turpentine is approximately 3.3 lakh tons from all sources; almost 1.0 lakh tons (30%) is estimated to be gum turpentine, and the bulk of the remainder is sulphate turpentine. Total annual production of rosin is about 1.0 million tons world-wide. Of this, it is estimated that almost 60%, is gum rosin; most of the remainder, about 35% is tall oil rosin and the rest is wood rosin.

Copal: Copals are derived from species of *Bursera*, *Protium* (*Burseraceae*), and *Hymenaea*. The adhesive property of copal makes it a potential coating material. More than 99% of the copal in India is supplied from Indonesia (96.83%) and Philippines (3.06%) during 2015-16. A very little portion of the total imported quantity was exported to Thailand (90.21%) and Canada (9.79%) during 2014-15.

Dammar batu: Damar is tapped from the *sal* tree *(Shorea robusta)*, although some is still collected from the ground in fossilized form. Annual production of Dammar batu in India is about 80-100 tons. It is used as painting and incense material. During 2015-16, more than 95% of this resin in India was supplied from Indonesia (58.60%) and Thailand (38.77%). A very little portion of the total imported quantity was exported to Japan (58.05%), Jordan (33.74%), Canada (7.29%) and Vietnam SOC Rep (0.46%).

2. Natural gums

The gum tapping is mainly done in the schedule areas where tribal populations exist. The collection charges to the collectors at collection centres are paid by the purchaser at the rate fixed by the Govt. After making the payment of the collection charges to the collectors and the difference amount of sale rate and collection rate in the District Union, the purchasers are allowed to transport the collected gums wherever they desire. In India, mainly *karaya* gum (*S. urens*), *dhawada* gum (*A. latifolia*), *prosopis* gum (*P. juliflflora*), *khair* gum (*Acacia catechu*), *babool*/*babul* gum (*A. nilotica*), *Jhingan* (*Lannea coromandelica*), *palas* (*B. monosperma*), *char* (*B. lanzan*) and *guggul* gum (*C. wightii*) are produced. Exudate gums possess a unique combination of functionalities and properties that can never be matched by any other alternative synthetic polymers, which makes their complete substitution impossible. Importantly, these biopolymers are ecofriendly as they are biodegradable. About 81 % of gum production in the country is contributed by Maharashtra (26.9 %), Madhya Pradesh (18.8 %), Jharkhand (13.5 %), Telengana (12.8 %), and Chhattisgarh (8.9 %). Rest of the 19 % comes from Gujarat (4.4 %), Andhra Pradesh (4.2%) and other minor gum producing states (10.5%). In parts of the Jaipur, Ajmer and Jodhpur districts *A. senegal* is common. *A. catechu* forests are common in the south-eastern regions. *e.g.* Baran, Jhalawar, Kota, Tonk , Chittorgarh and Alwar.

Gum *karaya* (*Sterculia urens*): Gum *karaya* is the dry exudate of *S. urens* and *S. villosa*. It is also collected from *S. urceolata* and *S. foetida* in Indonesia, *S. setigera* in Africa and from *S. caudata* in Australia (Gautami and Bhat 1992). It is also known by the name Indian tragacanth, as it resembles gum tragacanth produced by *Astragalus spp.* Gum *karaya* is one of the least soluble gums used for many industries viz. pharmaceutical, food, paper, textiles, cosmetic industry, superior grades in ice-creams, Inks, rubber, linoleum, oil clothes, paper coatings, polishes, lower grades in varnishes, *etc*, engraving processes and in oil drilling operations, in dental compounds and colostomy rings. Acting as mucilage it is also used as a bulk laxative as a binder, emulsifier and stabilizer in food industry. In India its overall production has decreased from 6838 tons in 1975–1976 to 100.35 tons in 2015-16. During this period the price increased from Rs 7.4/kg to Rs110/kg. During 2015-16, a Minimum Support Price (MSP) of Rs 10800 per 100 kg for *karaya* gum was declared by Pricing Cell, Ministry of tribal affairs, Govt. of India. The gum producing forest divisions in the Chhattisgarh are Bilaspur (Mugeli, Dindori, Ratanpur, Takhatpur, Lormi), Raipur, E. Surguja (Balarampur), Marvahi (Kota), S. Surguja, Raigarh (Khamariya,), Dharmajaygarh, Rajnandgaon, Mahasamund, Dhamtari, Korea, Sukma, Bijapur, Dantewada and W. Bhanupratapur. In Jharkhand, the *karaya* gum is produced in the Latehar (Garu, Mahuadar, Herhanj, Balumath, Barwadih, Lesliganj, Chhipadohar and Richughutu), Chatra (Lawalang, Pratappur and Kanti), Garhwa (Ramkanda and Bhandaria), Daltonganj (Panki and Chhatarpur) and West Singhbhum (Chakradharpur).

***Dhawda* gum/ *Gum Ghatti* (*A. latifolia*):** *Dhawda* gum is the dry exudate of A. latifolia. It has a glassy fracture and occurs in rounded tears which are normally less than 1 cm in diameter. It often occurs in larger vermiform masses. *Dhawda* gum is used as an emulsifier and stabilizer in beverages and butter containing table syrups; flavour fixative for specific applications; as a binder in long-fibered light weight papers; as an emulsifier of petroleum and non petroleum waxes to form liquid and wax paste emulsions; to prepare uniform and discrete prills of cross-linked polystyrene; used as drilling mud conditioner and the acidizing of oil wells and also used in powdered explosives to improve resistance to water damage. *Dhawda* gum is produced in the states of Chhattisgarh, Gujarat, Jharkhand, Madhya Pradesh,
Maharashtra and Andhra Pradesh. In India total production of *dhawda* gum increased from 2.7 tons in 2011-12 to 194.00 tons in 2015-16. The collection rate for *dhawada* gum for the year 2015-16 was around Rs 600-800/kg for Grade-I, Rs 200-300/kg for Grade-II, Rs 100-150/kg for Grade-III.

Gum *arabic* (*Acacia senegal*) : Gum arabic, also known as Acacia gum, is a natural gum made of the hardened sap of various species of the Acacia tree. Gum *arabic* is predominantly collected from two species of Acacia, namely *A. senegal* and *Vachellia (Acacia) seyal*. Producers harvest the gum commercially from wild trees, mostly in Sudan (80%). The uses of gum *arabic* are linked to its two main characteristics *i.e.* its high solubility in water and its low viscosity. This gives gum *arabic* eminent qualities as an emulsifier, stabilizer, thickener or adhesive of a non-toxic nature and its low calorific value and high soluble fibre, which are of major importance in nutrition and dietary applications. Pharmaceutical drugs and cosmetics also use the gum as a binder, emulsifying agent, and a suspending or viscosity increasing agent. *A. senegal*, commonly known as to produce gum acacia is a deciduous shrub, growing up to 15 m tall and usually branching out from the ground. Gum production is excellent on poor soils and higher in stressed trees .Gum exudes from the duct of the inner bark and is tapped in the hot season (May-June) when the trees are under stress and annual gum production in India is about 5-10 tons. Tapping begins when trees are 4-5 years old. It commences after leaf fall and ceases during the colder months of the dry season. Annual yields stand at 188-2856 g for young trees and 379-6754 g for older trees (7-15 years). Production of gum *arabic* is concentrated within a 520,000 Km2 radius of central Sudan, commonly known as the gum belt (FAO, 2014). The three main producing countries are Sudan, Nigeria, Cameroon and Chad which cover about 82% of the global export market of the gum *arabic*.

There is high demand of gum *arabic* from and in India. About 4000 tons of gum *arabic* exported to Nepal (53.02 %), Bangladesh Pr (37.58 %) and China P Rp (2.61 %) during 2015-16. About 93 % gum *arabic* supplied to these top 3 destinations. It was noted that Nepal emerged as major importer for gum Arabic in 2015-16. In the international market, price of gum *arabic* ranged from Rs 500-600/kg for Grade-I, Rs 100- 300/kg for Grade-II, Rs 50-100/kg for Grade-III. The international market for gum *arabic* is subject to different trends and fluctuations, determined by an increasing demand, variable capacity of African producer countries to stabilize the supply, variability of quality and prices and use of substitutes by importing countries, which can negatively affect the gum *arabic* market demand. During 2015-16, gum *arabic* is exported across the globe in 38 countries. Sudan, Nigeria, Cameroon and Chad have supplied 82 % raw gum *arabic* and rest 18 % was supplied from Mali, France, Senegal, Benin, U Arab Emts, Ethiopia, Tanzania Rep and others. India is second only to the US in consumption of Gum Arabic (NGARA, 2004).

3. Natural gum-resins

Under this category, *asafoetida*, *salai* gum and *myrrh* are the major gum resins. About 1100 tons of the gum resins exported from the country earned Rs 657 million foreign exchange.

Asafoetida (*Hing*): Asafoetida (*Ferula anthrax* and *F. foetida*) is a popular spice used in daily food by Indians. It was found to contain mainly ferulic acid, umbellic acid and ketonic substance known as umbelliferone. Powder of Asafoetida is used as carminative and also used in fainting, flatulent colic and chronic bronchitis as well as it is used to treat asthma in adults (Kokate *et al* 2002). New pharmacological investigations indicate possible anti-inflammatory, anti-diabetic and anti-bacterial effects (Kandziora *et al.*, 2015). In India, asafetida is supplied from Afghanistan (90.44%) and Uzbekistan (7.32%). On other hand, UAE (27.25%), USA (14.78%), Saudi Arab (7.33%) and Singapore (7.01%) are the major export destination of Asafetida.

***Sal*ai gum:** *Salai* gum (*Boswellia serrata*) *Frankincense*, also known as *Olibanum*, is an aromatic oleogum resin obtained as pale yellow to red tears from the bark of trees belonging to the genera *Boswellia* of the *Burseraceae* family thriving in arid regions of Africa and southern Arabia. There are 43 different reported species in India, Arabian Peninsula and North Africa. It is an important component in cosmetic industry and it is widely marketed as a food supplement (Khan, *et al*., 2014). The smoke is also a powerful insect deterrent and thus served as a prophylactic to prevent the bites of malaria carrying mosquitoes.

B. serrata is a deciduous middle sized tree, which is mostly concentrated in tropical areas; parts of Asia and Africa. In India, it occurs in dry hilly forests of Rajasthan, Madhya Pradesh, Gujarat, Bihar, Assam, Odisha as well as central penisular regions of Andhra Pradesh, Assam *etc.* This gum is tapped from the incision made on the trunk of the tree which is then stored in specially made bamboo basket and converted into different grades of material according to flavor, color, shape and size. Harvesting frankincense is a time consuming process that begins in December, reaching a peak from March to May (Marshall, 2003). The trees start producing resin when they are about 8 to 10 years old (Michie *et al*., 1991). In India, olibanum is supplied from U Arab Emts (57.53%), Somalia 23.43%), Yemen Republic (12.43%) and Ethiopia (5.53%). Trinidad (26.66%), Germany (12.69%), Mauritius (7.63%), Morocco (7.42%), Mexico (7.35%) and USA (6.61%) are the major export destinations.

Myrrh: *Myrrh* comes from a small, thorny tree *Commiphora myrrha,* cultivated since ancient times in the Arabian Peninsula. The growers make a small cut in the bark, from where the resin would leak out. It is then collected and stored for about three months until it hardens into fragrant globules. *Myrrh* is used raw or crushed and mixed with oil to make perfume. Myrrh oil, which is steam distilled directly from the *myrrh* resin, has an aroma that is woody, earthy and a bit balsamic. Also, *myrrh* is occasionally used as a flavoring agent. Somalia and Ethiopia are by far the largest producers of the substance. In India, *myrrh* is supplied from U Arab Emts (61.48%), Somalia (24.07%) and Kenya (6.96%). Turkey (47.21%), Iraq (47.21%) and UK (3.62%) are the major export destinations of *myrrh.*

Integration of Natural Resins and Gums Yielding Trees in Agroforestry

Agroforestry is the integration of trees into farming systems for producing various marketable food and non-food products. Besides, agroforestry offer great potential of sequestering atmospheric carbon and an almost zero cost approach for restoration of badly degraded land through nitrogen-fixing trees and shrubs. The tree products viz. fodder, wood, fuel, fruits, nuts, resins, gums, extractives, medicines, etc makes agroforestry the best land use system in the era of changing climate. This is the reason why agroforestry has been widely promoted in tropical countries. In India, the area under agroforestry is likely to increase substantially in the near future. There are many gums yielding tree species which can be planted as woody components along with crops in an agroforestry model. The associated crop and trees can vary from region to region and such agroforestry models will be highly beneficial to the resource poor farmers in providing livelihood security.

The agroforestry models can be developed by planting selected tree species for the given agro-climatic condition. Trees can be planted on boundary of the field or as rows inside the field. The distance between row to row and tree to tree in a row depends on growth behaviour of tree species and associated crops. Generally row to row distance should be such that agricultural operations can be performed without any hindrance. To reduce harm full effects of trees on associated crops, tree pruning must be conducted. The associated crops should be selected on the basis of selected tree species and its growth behaviour so that both components (woody and annual crop) offer minimum competition to each other. Gum and resin yielding tree species should be planted after getting complete information on produce quality and its market.

Among four major agroforestry systems based on the nature of woody perennial and annual components, agri-siliviculture system with different gum and resin yielding trees, fruit trees and agricultural crops in different combinations can be practised. As far as possible, wider spacing is advised to allow optimum sun light in the inter spaces and minimize reduction of annual crop yield. Choice of the annual crop will depend upon the farmer’s interest and the local edapho-climatic conditions. In areas where soil quality is poor (degraded, sloppy, less soil depth, rocky out growth, low nutrient status), block planting of gum and resin yielding trees is recommended with 6 x 6 m spacing. In this system, intercropping of agricultural and fodder crops can be taken during the first 2 – 3 years.

In arid and semi-arid regions of India, integration of *Acacia senegal* in traditional grazing grounds such as *orens* and *gochars,* systematically raised silvopastoral systems and other agroforestry landuse, for production of gum Arabic can be a profitable proposition. It will not only provide alternative livelihood options to local people but also increase economic viability of the land use. The area covered under forest, barren and uncultivable pastures, and community grazing land can be used for commercial plantation of *A. senegal.* In central India bundelkhand region typically represents semi-arid climate and is prone to frequent drought. Most of the terrain is undulating with rocky and gravely surface. Cultivation of gum Arabic can provide an alternative livelihood option to the poverty stricken farming community.

For development of gum and resin based agroforestry models, selection of tree species which produce gums and resin is first requisite. The tree species identified for different climatic region are given below:

i) Arid and Semi-Arid: *Acacia nilotica, Acacia catechu, Acacia senegal, Anogeissus latifolia, Bauhinia retusa, Bombax ceiba, Boswellia serrata, Butea monosperma, Commiphora mukul, Shorea robusta, Sterculia urens.*
ii) Sub Humid: *Acacia catechu, Bombax ceiba, Canarium stritum, Dipterocarpus turpinatus, Garcinia morella, Hopea odorata, Shorea robusta.*

iii) Humid Tropics: *Bombax ceiba, Canarium stritum, Cochlospermum religiosum, Dipterocarpus turpinatus, Garcinia morella, Hopea odorata, Kingiodendron pinnatum, Lannea coromandelica, Pinus wallichiana, Sterculia urens, Veteria indica*

iv) Sub-Tropical: *Acacia nilotica, Acacia catechu Acacia senegal, Anogeissus latifolia, Bauhinia retusa, Bombax ceiba, Boswellia serrata, Butea monosperma, Cochlospermum religiosum, Commiphora mukul, Garcinia morella, Hopea odorata, Kingiodendron pinnatum, Lannea coromandelica, Pinus roxburghii, Sterculia urens*

v) Temperate: *Butea monosperma, Dipterocarpus turpinatus, Garcinia morella, Kingiodendron pinnatum, Pinus roxburghii, Veteria indica*

vi) Moist: *Dipterocarpus turpinatus, Kingiodendron pinnatum, Pinus roxburghii, Pinus wallichiana, Veteria indica*

Research and Development

Realizing the strategic importance of Natural Resins, Gums and gum-resins, India has been on forefront in research and development. The beginning was made in 1920 when the then Imperial Government of India constituted the Lindsay-Harlow Committee (1920) to look into all aspects of the country's lac trade and its development. On the suggestions of this committee, lac merchants organized themselves into the Indian Lac Association for Research, under the aegis of which, the foundation stone of the Indian Lac Research Institute (ILRI) was laid in 1924 at Ranchi. Subsequently, on the recommendations of the Royal Commission on Agriculture, the Indian Lac Cess Committee (ILCC) was constituted, which took over the reins of the ILRI in 1931. As a result of reorganization of agricultural research and education in the country after independence, the ICAR took over the administrative control of the ILRI in April 1966.Since then, it has contributed immensely towards all-round development of lac in the country. Recognizing the importance of other natural resins and gums, which are cultivated and collected in the Indian subcontinent, and are of tremendous industrial importance in divergent industries and export markets, the ICAR revised the mandate of ILRI and renamed it as Indian Institute of Natural Resins and Gums in 2007. All natural gums and resins were brought under its scope in revised research mandate of the Institute. Subsequently, new Network Project on Network Project on Harvesting, Processing and Value Addition of NRGs was launched in 2009 with 10 centres. In 2014 the institute has started another network project on Conservation of Lac Insect Genetic Resources with eight centres. Since 2009 the Institute is recognized as National Lac Insect Germplasm Centre (NATLIGEC).

To strengthen production and trade of NRGs, many central and state agencies are catering needs of different stakeholders. Some of them are: Department of Industrial Policy and Promotion, Ministry of Commerce and Industry, Government of India; Shellac and Forest Products Export Promotion Council (SHEFXIL), Kolkata; Directorate of Economics and Statistics, Ministry of Agriculture and Farmers Welfare, Government of India; The Tribal Cooperative Marketing Development Federation of India Limited (TRIFED), Ministry of Tribal Affairs (MOTA), Government of India; Girijan Co-operative Corporation Limited (GCCL), Visakhapatnam, Government of Andhra Pradesh; Kovel Foundation, Visakhapatnam, Andhra Pradesh; Sahayog Community Coordination Network, Visakhapatnam, Andhra Pradesh; The Jharkhand State Co-operative Lac Marketing & Procurement Federation Ltd.(JASCOLAMPF), Ranchi, Government of Jharkhand; State Agriculture Marketing Board (JHAMFCOFED), Ranchi, Government of Jharkhand; Chhattisgarh Minor Forest Product Federation Ltd.(CGMFP), Raipur, Government of Chhattisgarh; Madhya Pradesh State Minor Forest Product Federation Ltd. (MPMFP), Bhopal, Government of Madhya Pradesh; Gujarat State Forest Development Corporation (GSFDC), Vadodara, Gujarat; Forest Department, Government of Himachal Pradesh; Forest Department, Government of Uttarakhand; and

Forest Department, Government of Maharashtra. Besides, various NRG based processors, traders, exporters, importers, progressive farmers, forest dwellers, and Non - Government Organizations (NGOs) are also playing key roles.

Research initiatives under ICAR-Network Project on harvesting, processing and value addition of NRGs at 10 different centres and Conservation of Lac Insect Genetic Resources at eight centres spread across the country addresses research issues of major NRGs including lac produced in India. At ICAR-Central Agroforestry Research Institute, Jhansi (CAFRI); which is one of the co-ordinating centres in the network project on Natural Resin and Gums headquartered at Indian Institute of Natural Resin and Gums, Ranchi; efforts are being made to develop suitable agroforestry models based on gums and resins yielding trees. Under this project the major thrust is given to gum production techniques on naturally growing *Butea monosperma* trees (palas) and development of agroforestry models based on gum yielding trees viz., *Acacia nilotica, A. senegal* and *Anogeissus pendula* in Bundelkhand region of Central India. In Bundelkhand region of Central India, *Butea* trees occur naturally and widely distributed on farmer's fields, degraded land, common grazing areas and forests. Studies at ICAR-CAFRI have revealed that on average, 10-15 trees/ha of *Butea monosperma* are available on farmer's field and used by local tribe (Saharia) for collecting gum-butea called *kamarkas* (Prasad et al., 2016a). Yield of gum-butea greatly depends on tree growth factors and incisions made on bark of the stem.

Butea tree is also a host for lac insect and offers great potential for lac cultivation, besides yielding gum. Hence, studies were conducted to assess effect of lac production on gum yield and vice versa in *Butea monosperma* at ICAR-CAFRI, Jhansi. The results revealed that, on an average, settlement of lac insect was slightly better on trees inoculated with lac insect than those trees where production of both lac and gum was taken. On average, gum exudation caused reduction in lac insect settlement which was reflected in lac yield. The trees where both lac and gum production was taken yielded less lac than trees having inoculated with only lac insect. It was concluded that simultaneous production of gum and lac from Butea trees yields more gum but less lac. For tapping of gum from the existing trees in the agroforestry system, improved tapping techniques and use of gum inducer (ethephon) are being experimented to obtain more gum yields. Results of studies conducted to assess whether type of incision on bark had any effect on yield of gum-butea revealed that out of four types of cuts *viz.* knotching, vertical cuts, slant cuts and horizontal cuts on bark of the stem, maximum gum-butea was obtained with knotching and minimum with slant cuts (Prasad et al., 2016b). On use of ethephon for inducing gummosis in *Butea monosperma* (Lam.) in Bundelkhand region, it has been observed that the yield of gum-butea was significantly increased by application of ethephon (Prasad et al., 2014); however, varying doses of ethephon had no effect on gum yield. On an average, maximum amount of gum-butea was obtained when ethephon was sprayed on surface on tree stem before knotching. The studies on use of ethephon to induce gummosis in *Anogeissus pendula* 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 the least (37.5g/tree) (Prasad et al., 2018a). The exuded gum had variety of forms viz. globular, tear shaped or irregular masses and good quality. Use of ethephon did not show any negative effect on tree health. In view of negligible gum oozing from *A. pendula* in nature, application of ethephon @ 1170mg/tree in the month of October has been suggested for enhancing gummosis and gum yield.

Research initiatives for developing agroforestry models revealed that after seven years of planting of various agroforestry models, survival and growth of planted gum yielding trees and horticultural plants was more in models developed at research farm than the models on farmer's field. Out of the two gum yielding tree species, better performance has been shown by *A. nilotica* than *A. senegal* on farm, however on farmers field reverse was true (Figure 1). Among horticultural species *E. officinalis* had shown maximum growth while *C. carandus* the least. The main reason for poor survival and growth of planted species on farmers' field was uncontrolled grazing due to practice of *anna pratha*. In *anna pratha* the cattle are let loose, which openly graze and trembles growing saplings planted on farmers' fields. The planted seedlings require to be protected from moving cattle in beginning for 2-3 years.

A. senegal performed better in semi- arid region of Bundelkhand than arid region of western Rajasthan wherein after 12 years of age plants reported to attain height of about 3.0m on rocky and gravely soil. *Acacia nilotica* planted at farm has started exuding gum after 4 years whereas, gummosis in *A. senegal* was observed after 5 Year. On farmer's field, no gummosis was observed either in *A. nilotica* or *A. Senegal* up to 6 years of plantation. In agri-silvi-horti models established at CAFRI, oozing of gum in *A. senegal* has been observed after five years and gum yield varied from 26.1 to 134.7 with mean of 58.7 g/ tree. The number of gum tears varied from 3 to 7 per tree. The yield of gum Arabic is likely to increase in future as the trees grow in age. Despite constraint of *anna pratha* in Bundelkhand, the farmers of the region are getting attracted toward Gum arabic (*A. senegal*) based agroforestry models developed at CAFRI Jhansi (Prasad et al., 2018b), and many farmers have planted *Acacia senegal* on their fields. The Institute is helping farmers and providing seedlings free of cost. In last five years about 10000 seedlings of gum Arabic (*A. senegal*) have been planted in parasai, chhatpur, bachouni (Jhansi in U.P.) shivrampur, dabar and garkundar (Tikamgarh in M.P) villages on farmers's field mainly as boundary plantation. The farmers preferred this species as it act as live fence besides yielding gum Arabic (Prasad et al., 2018c).

Policy Interventions

To provide fair prices of NTFPs which differ widely state to state and to prevent exploitation of the poor tribals; the government has taken initiatives under the scheme for NWFPs to introduce Minimum Support Price (MSP). A Pricing Cell was constituted in pursuant to the Ministry of Tribal Affairs, Government of India and notified vide TRIFED, to recommend MSP for Minor Forest Produce under the scheme "Mechanism for marketing of Minor Forest Produce through MSP and development of Value Chain for MFP". To determine fair and remunerative MSP for lac and gum *karaya* the deliberations of the Pricing Cell with State Procurement Agencies (SPAs) and federations were conducted. Computation of cost of production of gum *karaya* and lac for MSP was furnished by ICAR-Indian Institute of Natural Resins & Gums (ICAR-IINRG), Ranchi. Minimum Support Price of gum *karaya* was *announced* during 2014-15 for procuring it from gum pickers in three grades. Similarly, minimum support price of lac for the year 2014-15 was announced at the rate of Rs 210 and Rs 290/ kg for *rangeeni* and *kusumi* lac, respectively. During year 2015-16 the Pricing Cell recommended enhancing the current MSP by 10 % and recommended a MSP of Rs 230 and Rs 320/kg for *rangeeni* and *kusumi* lac, respectively.

Future Prospects

The role of NRGs in enhancement of livelihood of local populations is undisputable. Besides, the trees and plantations for production of NRGs have ecological implications in terms of carbon credit. The NRGs stand very high when it comes to safety to human beings and environment in the realm of applications. Thus, strengthening production of NRGs would yields multi-fold benefits. The R & D needs to focus on following areas:

- Development of multi-species man-made forest/agroforest and agroforestry models in large targeted areas for production of lac, plant resins, gums for sustainable income.
- Educating and empowering rural community for harnessing NTFP/ NRGs resource bases on sustainable basis.
- Creating support systems for marketing the produce, value-addition, credit, insurance, etc. to help resource-constrained farmers.
- Formulation of pro-producer policies for sustainable output and income to the beneficiaries.
- Development and promotion of application areas for sustained growth.

Development and implementation of such mission-mode programme to develop NRG production base in the country along with support system would be a great contribution to the economically deprived population dependent on NTFP in particular and the society at large.

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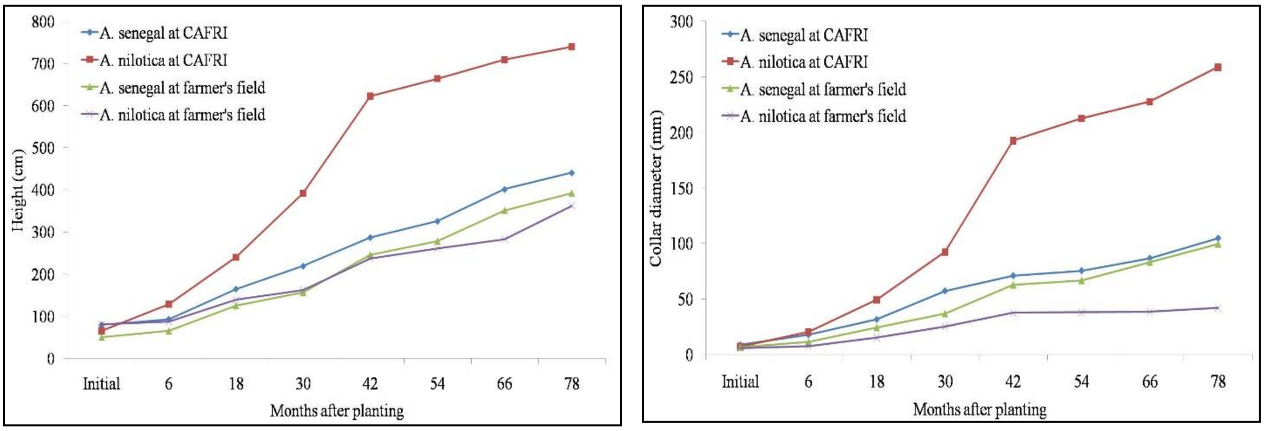

Figure 1: Comparative performance of gum-yielding trees (Acacia senegal and Acacia nilotica) at research farm and farmer's fields

Agroforestry Education, Research, Extension and Value addition - Contribution of Forest College and Research Institute, Tamil Nadu Agricultural University

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Abstract:

The forests in the country have played a significant role in ecological stability, food security and economic prosperity. The forest has provided all wood and non wood products till the recent past to meet the domestic and industrial requirement. However, the legal and `policy issues coupled with environmental conservation and as per the directives from Honorable Supreme Court have declined the supply of wood and wood products from the natural forest. This besides, the country has witnessed growing wood demand to the tune of 152 mill. m^3 per annum against the actual supply of less than 90 mill. m^3. This has resulted in paradigm shift in forest management in the country and necessitated intensive promotion of agroforestry. The National Agroforestry Policy 2014 has also directed the role of wood based industries in agroforestry development. Against this backdrop, the Forest College and Research Institute, TNAU is involved in creating professional man power requirement to cater the needs of forest management and augmenting the intensive promotion of agroforestry to become self reliance in raw material security besides creating Professionalism in Forestry.

Keywords: Forestry Education, Research, Extension, Tree Improvement, Clonal Forestry, Multifunctional Agroforestry, Precision Silviculture, Natural Dye, Value addition.

Introduction

Realizing the pivotal role the forests play in the economic prosperity and ecological stability of a country, Tamil Nadu Agricultural University started as early as in 1973 a full – fledged department of Forestry as a forerunner to a College of Forestry. Though mandated then to carry out research in agroforestry, plantation forestry and exotic forestry the department also assumed the onus of offering a course in Agroforestry to the B.Sc. (Agri.) and B.Sc. (Hort.) degree programmes, with drift of time and the concomitant multiplication of problems encountered by the State Forest Departments, Tree Growing Farmers and Wood based industries, the need for enlarging the education and research base was keenly felt.

To sub-serve these needs a forest research Station encompassing an area of 200 ha was started in February 1976 as an adjunct to the Department of Forestry in the sylvan surroundings of a reserve forest at Mettupalayam. The station has since been elevated to the status of Forest College and Research Institute in 1990. The Forest College and Research Institute (FC & RI) is located at Mettupalayam in the sylvan surroundings of Jakanari Reserve Forest, about 40 km north of Tamil Nadu Agricultural University (TNAU) main campus, Coimbatore. It is situated over a sprawling expanse of 200 ha of reserved forest, located of the foothills of Nilgiris on the Kothagiri road. The college is perched at an altitude of 300 m with a longitude of 11.19'N, latitude of 77.56' and enjoys an annual rainfall of 830 mm. The mean maximum and minimum temperature are 32.2°C and 23.2°C respectively. The Institute hails with the triple mandate of teaching, research and outreach activities

Forestry Education

Realizing the pivotal role the forest play in the economic viability and ecological stability of a country, the TNAU started a full fledged department of forestry as early as in 1973 with a mandate of carrying out research in the areas of tree improvement and agroforestry with the march of time coupled with proliferation of problems encountered by tree growing farmers and wood based industries, a forestry research station was started as an adjunct to the department in 1976 at Mettupalayam in the sylvan surroundings of the Nilgiris. Subsequently based on the recommendations of National Commission on Agriculture 1976 and directed by Indian Council of Agricultural Research, TNAU started professional forestry education in the year 1985 to create the professional manpower requirement to cater to the needs of forest management, conservation and promotion of agroforestry. Subsequently as directed in the National Forest Policy (1988), the institute has mandated Post Graduate Education and research activities. Currently this institute offers Under Graduate, Post Graduate and Ph.D program in faculty of Forestry incorporating the State-of-the-act recent developments in forestry sector. The forestry education offered at TNAU has witnessed successful creation of professional foresters, researchers, entrepreneurs and teachers and are serving across the country in all forestry and agroforestry developmental activities.

Forestry Research

The paradigm shift in forest management and the associated developmental process in agroforestry have ushered in a total mismatch between demand and supply of wood and wood products. It is estimated that the country would need 65 million m^3 short rotation species and another 85 million m^3 of long rotation species to meet the demands of domestic and industrial sector. The country has also witnessed several constraints in forestry and agroforestry promotion which has been characterized into production, processing and consumption related issues.

I. Varietal Development

Progress in the tree breeding and selection over the period resulted in development and commercialization of tree varieties of economic importance. Further, to provide the growers a wide range of choices, many varieties were developed and commercialized. Commercial cultivation of the new varieties has been enhanced through supply of seedlings by tripartite agreement with industry and farmers. Through the years the tree breeding programme in FC&RI has aimed to satisfy both the needs of farmers who grow trees in diverse agro-climatic conditions and the industries. Breeding work will continue to focus on the identification of superior varieties that will address the requirement of the wood -based industries in the country.

II. National DUS test centre and Varietal Registration

Protection of Plant Varieties and Farmers Right Authority, New Delhi, Government of India has identified this institute as National DUS Test centre for Neem, Karanj and Jatropha. The DUS test guidelines and descriptors developed by this institute for the above mentioned species in order to register the varieties was accepted by the authority and released in the Government of India Gazette in the name of Plant Variety Journal of India (Vol. 10 No. 2 February 05, 2016). Based on the above notification, Forest College and Research Institute, Mettupalayam is acting as a Nodal Centre for registration of varieties in Neem, Karanj and Jatropha.

III. Production Technologies

(i) Precision Silvicultural Technology

The concept of Precision Silviculture is being introduced first time by Forest College and Research Institute, Mettupalayam, the technique involves canopy, stem and root engineering system so as to get the maximum yield with optimal inputs of both for short rotation and long rotation tree species. Utilising this system commercial tree farming model is devised for fast growing tree species that enables to get maximum economic returns per unit area by the farmers.

(ii) Optimal Tree Density

Tree density is the one of the critical factors in yield gap assessment. Traditionally casuarinas are grown at a higher density levels of 8000 – 10000 plants/ ha which resulted in the yield realization of less than 80 tonnes / ha after 4-5 years. To resolve this issue, an optimal tree density of 4400 – 5000 plants / ha has been standardized using clone based industrial agroforestry model. Through this density, the Casuarina MTP 2 variety has recorded an average yield of 150 tonnes / ha and a maximum yield of 220 tonnes / ha in a short span of 3 years.

(iii) Irrigation and Fertigation Technology

Precision tree farming techniques are developed using drip irrigation system for fast growing indigenous tree species. The techniques are standardized in a way that a maximum of 40 - 50 tons of wood per acre can be harvested with the rotation of 1.5 to 2 years. Accordingly, this high productive system was standardized for species namely, *Neolamarkia cadamba, Melia dubia, Ailanthus excelsa, Dalbergia sissoo.* The techniques are standardized in a way that a maximum of 40 - 50 tons of wood per acre can be harvested with the rotation of 1.5 to 2 years. Maximum yield in trees with shortest rotation were realized by the farmers and now this technology is popular among farmers as a commercial tree farming model. This technology is adopted for an area of over 2000 acres by farmers of Tamil Nadu, Karnataka and parts of Andhra Pradesh.

(vi) Mini clonal technology for trees

A mini clonal technology has been developed for Casuarina and *Melia* which is one of the pioneering attempts in the country for these species. Under this technology, the superior clonal plants were planted in a mini clonal garden and are provided with regular irrigation and fertilization in order to enhance shoot multiplication.

(v) Seed Ball and Cube Technology

A detailed research on making productive seed balls was carried out *in Vagai, Karuvel Poovarasu* and *Pungam* species. Physiological changes at cell level by dormancy breaking treatment and seed priming, the seed vigour increases substantially and enables the seeds to perform well under wide range of environmental conditions. A media was developed to optimum bulk density, porosity and nutrient availability, which are very important for higher germination of seeds. The shape is also altered to cuboid shape instead of seed ball, since it is more supportive to facilitate seed germination and root anchorage.

IV. Processing and Value Addition Technologies

(i) Briquetting Technology

The Casuarina clonal plantation need to be pruned twice the year and during the three year of plantation activities it is expected that 1-2 tonnes of plantation residues in the form of needles are to be available which are currently either unutilized or underutilized. The plantation residues have been successfully value added into briquettes. The economic analysis of plantation residue based briquetting technology has indicated the economic superiority of the system compared to the existing saw dust based technology.

(ii) Tamarind seed processing and seed gum products

Tamarind seed and pod processing equipments were established for post-harvest handling of tamarind seeds for exploiting gum utility. The tamarind processing unit is housed with dehuller, roaster, decorticator and pulversier. Techniques were standardised for extraction of tamarind gum from seed powder. Utilising the gumming property of the seed powder, edible product were developed by replacing commercial pectin. Market acceptable fruit jellies were developed using tamarind seed gum

(iii) Herbal Handwash from *Sapindus emarginatus.*

Sapindus emarginatus belongs to the family Sapindaceae and genus Sapindus is a medium-sized deciduous tree found in South India. *Sapindus emarginatus* consists of various compounds viz., flavonoids, triterpenoids, glycosides, carbohydrates, fatty acids, phenols, fixed oil, and saponin. Due to the presence of saponins, soapnut is well known for its detergent and insecticidal properties. Hence, hand wash using soapnut pulp extracts with potential antibacterial and antifungal properties has been formulated. In future, skin allergic test has to be carried out to market the product.

(iv) Value added product from Syzygium cumuni fruit pulp

Syzygium cumunii (Naval) fruit is one of the Non-Timber Forest Products from the forest known for its edible value. The fruits are highly perishable in nature. *Syzygium cumuni* is a fast-growing, attractive, compact, evergreen tree with a dense, frondose crown belongs to the Myrtaceae family. Both the seeds and the fruits are diuretic and have important carminative and astringent properties. The seeds also reduce blood sugar levels and are useful in the treatment of diabetes. The ripe fruit is astringent and is used as an effective treatment for diabetes. They cannot be stored for more than 3 to 4 days under room temperature.

(v) Preservation and Conservation Technologies

(i) Ex situ conservation of Forest Genetic Resources

As a part of conservation measures and academic interest, 76 indigenous tree species from 30 families were collected and assembled in the form of arboretum. This arboretum will be a source of information and knowledge for the students of the campus and the public besides ensuring the ex situ conservation of the assembled species.

(ii) Genetic Resources – Prioritizing the species

The Institute has prioritized varieties development as its major objectives and hence prioritized wide range of species for improvement program. The prioritized species are furnished in Table 3.

(iii) Superior progenies for higher Bixin

Forest College and Research Institute, Mettupalayam has developed dye extraction from the genetic resources of *Bixa* characterized for higher bixin content. Based on the bixin content nine superior genetic resources were screened for adoption and promotional activities.

(iv) Pollution Abatement – Tree Species

The Institute focuses on Trees and Pollution Abatement for the past five years to develop bio floating techniques for water pollution control and screening of tree species for urban air pollution abatement. To achieve the goal of this theme area, nearly 25 tree species have been tested and the tree species namely *Terminalia arjuna, Millingtonia hortensis, Hibiscus tiliaceus and Melia dubia* are screened for water pollution control. Also a mobile van based Air quality monitoring facility worth of 80 lakhs have been created and being utilized for monitoring real time ambient air quality. Based on the air quality data obtained, trees suitable for specific air pollutant will be screened and a good action plan will be developed for air pollution abatement in urban areas as the levels of pollution in the ambient air due to traffic is increasing at an alarming rate.

(v) Land Management Systems - Multifunctional Agroforestry

Agroforestry research has been triggered to develop land management systems that integrate agricultural crops with forest trees. Three agroforestry systems viz., Agrisilviculture, silvipastoral and agrisilvi-pastoral systems have been developed through All India Coordinated Research Project. Various tree species like Silk Cotton, Jatropha, Pungam, Simarouba, Teak, Ailanthus, Silver oak and eucalyptus based agroforestry systems were developed with judicial mixture of compatible intercrops like cowpea, Blackgram and forage crops like Cenchrus sp. and medicinal plants like Thulasi and recommended for various agro-climatic zones of Tamil Nadu for adoption.The promotion of Multifunctional Agroforestry has been done to generate both wood and food from the same unit of land to auger the productivity and profitability.

Extension Interventions

TNAU has conceived a value chain based research and resolved the constraints through technological, organizational and marketing innovations and interventions.

The development of High Yielding Short Rotation clones, mini clonal technology precision silvicultural technology, multi functional agroforestry, industrial agroforestry and value addition technology are the major technological innovations which attracted several farmers and wood based industries towards tree husbandry in the farm lands.

Forestry College and Research Institute, Mettupalayam through its Academic Interventions has produced 115 IFS officers, 80 Range Officers, 90 Scientists and more than 10 Entreprenuers for catering the administrative and to meet the demand for the wood based Industries. The varieties developed by this Institute have spread over an area of 60,000 acres across the State. This besides the technologies evolved has enhanced the per capita yield of pulp wood, match wood and timber wood in the region. The Extension technologies and the Economics department are able to forecast price and demonstrate the varieties and technologies in the farmer’s field. And also the Institute have impressed the tree growers for profitable tree farming.

Consortium of Industrial Agroforestry

To sustain and strengthen the developmental and promotional activities along with continuing the linkages among stakeholders, the Institute has conceived and established an innovative institutional mechanism called **Consortium of Industrial Agroforestry. This** consortium has enrolled 230 members which included members from wood based industries, potential farmers, scientists, line departments, NGO’s, producer companies, small and medium scale industries and they are involved in resolving the issues from the entire production to consumption system. This besides the consortium also ensures availability of quality planting materials, mechanized plantation development, organized and mechanized felling and assured buyback from wide range of wood based industries.

Agroforestry Business Incubator

The Institute has now mandated to translate technologies into commercial product which resulted in establishment of India’s first Agroforestry Business Incubator. This incubator is involved in commercialization of technologies, creating startups and entrepreneurs besides developing human resources for managing and establishing forest based industries.

The Institute every year conducts farmers training programme on seedling production, plantation development and value addition technology to benefit various stake holders which resulted in promotion of tree husbandry across the state and development of decentralized nursery planning process for quality seedling production

The faculty of this institute periodically transfers the technology through radio and TV programme on regular basis with respect to species of commercial importance and other forestry technologies to augment the productivity. Active participation in the State and District level exhibitions paves way for an efficient technology transfer among the farmers and various stake holders.

Way Forward

In a holistic approach, the forestry and agroforestry education and research will be involved in producing professional manpower and to establish improved plantation technology to ensure self reliance in raw materials and combat the climate change associated risk and uncertainties. Doubling the farmer's income and sustainable technology development through validated Multifunctional Agroforestry Models is the need of the hour

Table 1. Tree Varieties released and their special features

Name of Tree	Variety	Year of Release	Duration Years	Special Features
Casuarina	MTP CA1	2008	3	Yield potential: 100 t/ha. Pulp yield: > 48 %
Casuarina	MTP2	2011	2 and half to 3	Hybrid clone. Yield potential 150 t/ha. Amenable for both pulp and pole industry.
Melia dubia (Malai Vembu)	MTP 1	2012	5-6	Veneer recovery: > 58 % and high quality
Eucalyptus	MTP 1	2013	-	Clone type. Pulp yield: > 48 %. Suitable for dry land agro -forestry
Melia Dubia (Malai Vembu)	MTP 2	2018	1 and half	Clonal variety. Yield: 100 t/ha. Pulp yield: > 50 %. Suitable for both pulp and ply wood production
Jetropha:	FCRI HC 21 (INGR 09037)	-	-	-
Jetropha:	FCRI HC 32 (INGR 09036)	-	-	-

Table 2. Precision Silvicultural Technology

Sl.No	Type of Management	Nature of Management	Adoption rate
1	Canopy engineering	Maintaining optimum canopy density regulated through pruning, spacing and thinning	More than 90 per cent adaptation rate by the farmers is visualized in the filed
2	Stem engineering	Enhancing internodal length and promoting intercalary meristem development for obtaining highest diameter increment	More than 60 per cent adaptation rate by the farmers in the filed
3	Root engineering	Promoting feeder roots spread and density though manipulating water regime and interval of irrigation using drip irrigation system	More than 80 per cent adaptation and yield regulation is achieved by the farmers

Table 3. Prioritized tree species

S.No.	Genetic resources	Name of the Genus/Species
1.	Timber	Teak *Tectona grandis*
		Albizia lebbeck
		Gmelina arborea
2.	Pulp and Paper	*Eucalyptus tereticornis, Eucalyptus camaldulensis*
		Casuarina equisetifolia, Casuarina junghuhniana
		Acacia hybrids (*Acacia auriculiformis* x *Acacia mangium*)
3.	Plywood	*Melia dubia*
		Anthocephalus cadamba
		Toona ciliata
4.	Matchwood	*Ailanthus excelsa*
		Populus deltoides
5.	Dendro Biomass	*Leucaena leucocephala*
		Dalbergia sissoo
6.	Alternate Industrial Wood Species	*Acrocarpus fraxinifolius*
		Chukrassia tubularis
		Lannea coromendalica
7.	NTFP	*Bixa Orellana*
		Ceiba pentandra
8.	Gum	*Tamarindus indica*
9.	Biofuel	Jatrobha, Pongam, Mahua, Simarouba, Neem

Mettupalayam Agroforestry Business Incubation Forum (MAFBIF) and Visit to the Agroforestry Business Incubation Facility

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Abstract

The demand for wood and wood products in India is increasing at an alarming rate but there is no concomitant plantation development to satisfy the demands barring few exceptions like pulp and plywood. The legal and policy restriction coupled with directives from honorable Supreme Court have restricted the felling operations thus results in decline in wood supply. It is also directed that the wood based industries should derive their own raw material resources by establishing suitable linkages with farmers and other stakeholders. This besides wide range of forestry products like energy, composite wood, value added products like briquettes, pellets, activated charcoal, carbon, medicinal products, gums, resins, oils, etc., are also in huge demand which necessitated suitable value addition and technology development.

All these activities underscore the need for skill development from production to consumption system in forestry and agroforestry sector in order to treat forestry as a commercial and business enterprise. However as on date, there is no institutional mechanism to cater to the needs of skill and expertise development and the associated forestry based entrepreneurship development. Against this backdrop the Forest College and Research Institute of Tamil Nadu Agricultural University has conceived an innovative idea of forestry based business incubation and established India's first Agroforestry Business Incubator and involved in entrepreneurship development. The establishments, activities and achievements of this innovative and pioneer institutional mechanism are discussed in this paper.

Introduction

India is one of the major consumers of wood in the Asia Pacific Region, although the country produces several tropical hardwood species domestically to meet the growing wood demand. The indigenous production was sufficient to meet most domestic timber demand till 1980s. However with the enactment of Forest Conservation Act (1980) and subsequent enunciation of National Forest Policy (1988), the Country's forest has been recognized more towards conservation than timber production. This has resulted in decline of domestic production and increased the gap between demand and supply. Due to growing population, urbanization and rapid industrial development, the demand for wood both from short and long rotation species has increased drastically.

India is one of the robust countries with multifarious industrial establishments and the demand for wood requirement will be nearly 152 million m^3 by the year 2020 (FAO, 2009). However the actual supply is very low of nearly 40 – 60 million m^3. Simultaneously the demand for value added products in the form of composite wood, energy, medicinal products, gums, resins, tannins etc., are also on rise for various domestic and industrial utility. The country has also witnessed huge unemployment for the educated and uneducated youths. This besides the landless laborers and farmers are also looking for alternate revenue generation system to cater to the needs of their livelihood.

Under such circumstance there is a need and demand to establish institutional mechanism to create income and employment activities in decentralized approaches. The existing human resources both skilled and unskilled need to be trained towards multifarious innovative technologies to create self reliance in income and employment activities besides augmenting the domestic production of goods and services. Several institutions and establish have already been established in sectors like engineering and contributed significantly towards entrepreneurship and business incubation developments. Similarly the concept of incubation establishment has been developed in agriculture and horticulture sectors to promote the respective technology based business promotion. However such incubation development for entrepreneurship development in forestry and agroforestry sector has not been witnessed so far in Indian subcontinent. Against this backdrop the Forest College and Research Institute has conceived and established an India's First Agroforestry Business Incubator to develop business opportunities through innovative forestry and agroforestry technologies through entrepreneurship development.

Rationale for Business Incubation

Forestry and agroforestry has been practiced since time immemorial for domestic wood production besides extending other ecosystem services like soil and water conservation, environmental amelioration, biodiversity production and maintenance of ecosystem stability. Though forestry and agroforestry has contributed significantly to meet the raw material requirement of various wood based industries like timber, pulp and paper, plywood, veneer, match splints, sports goods, agricultural implements etc their contribution towards entrepreneurship development has not been witnessed so far. The existing forest policies and acts have restricted raw material supply to the above wood based industries and directed these industries to develop their own raw material resources.

Similarly forest have provided wide range of Non-Timber Forest Product like food, fiber, fodder, fuel, gums, resin, floss, beedi leaf, medicinal products etc., and extended livelihood options to the forest dwellers and dependence. However these developments and existing support system have not created business entrepreneurs, startup companies, skill development and technology updation to the stakeholders. This has facilitate forestry as a livelihood system but not as a business enterprise. Under such circumstances the forest business incubator established at Forest College and Research Institute is a timely intervention which is involved in creation of skilled entrepreneurs and a new startups towards creating forestry and agroforestry as a business enterprise besides resolving the problems and constraints from the entire production to consumption system in forestry and agroforestry development.

Incubation Strategy and Business Model

The forest business incubator strategy is designed to cater the managerial and financial needs of forest business operation by prioritizing industry based agroforestry as a major thematic area and mandated production, processing and consumption led business operation. It has identified the following business and support services in order to strengthen the existing entrepreneurs and to create new startup business enterprise.

The wood based industries has been linked for skill development, mentoring support along with facilitating market support system to the entrepreneurs. This business incubator has mandated to involve various stakeholders like individuals, student entrepreneurs, startups, entrepreneurs with new idea and innovations, individuals seeking business opportunities and wood based industries. The various supporting services extended by the incubator to various stakeholders are provided in the Figure 1.

Technology Available for Entrepreneurship Development

Technology 1: Mini Clonal Technology

Targeted Species	Technology Transfer	Market potential
• Melia MTP 1 & 2 • Casuarina MTP 1 & 2, • Eucalyptus MTP 1 • Dalbergia DS18 • Teak MTPTK 07 • Kadam AC 13 • Kumil GA 7	The technology is transferred through capacity building programme at clonal complex of business incubator. It is done through in plant training for a period ranged between 5 and 7 days. The men and women's self-help group, student entrepreneurs and existing consortium nurseries have been trained	Tie up with TNPL, SPB, Ambi ply, and Sharon ply, Suresh timbers through the pulp wood, ply wood, timber and biomass contract farming system. The annual demand for seedlings for industrial plantation establishment is estimated at 50 million.

Technology 2: Forest biomass value addition through briquette/ pelleting technology

Target raw material	Technology Transfer	Market Potential
• Debarked wood from pulpwood plantation • Other plantation and agricultural residues • Industrial residues like saw dust, wood shaving, plywood waste, splints waste etc.,	The technology transfer is done through inhouse capacity building for the period ranged between 3 and 5 days followed by industrial visits.	It is estimated that Tamil Nadu alone requires about 25 lakh tones of fire woods to cater to the energy needs of both domestic and industrial sector. Hence any volume of briquettes produced could have excellent market potential. 23 industries / companies have already indicated to buy around 536 tonnes of briquettes/ day. Hence this enterprise will have sustained market potential.

Technology 3: Precision plantation development technology

Prioritized Species	Technology Transfer	Market potential
Timber Agroforestry • Teak • Mahagony Plywood Agroforestry • *Melia dubia* • Toon • Eucalyptus Pulpwood Agroforestry • Eucalyptus • Casuarina Energy Agroforestry	The enterprise on plantation development is created involving 10 – 15 workers as a plantation development team. These workers are trained for precision plantation technology through adoption of state-of-art-technology along	In Tamil Nadu annually 10000 ha of plantation is established in association with wood based industries. This needs organized plantation developers with updated scientific technologies. This besides the plantation development made by state forest department in the farmer's field will also be linked. This technology will be linked with the mini clonal production centre to ensure successful contract farming models of various wood based industries. This strategy will be extended outside the state through suitable incubators.

• Subabul Biofuel Agroforestry • Jatropha • Pungam • Madhuca	with adoption of mechanization	

Technology 4: Wood seasoning technology

Prioritized Species	Technology Transfer	Market potential
All lesser known and unutilized species	The identified entrepreneurs are trained with wood seasoning technology coupled with preservative application in the identified user industries. The agroforestry business incubator is also establishing seasoning facilities for inhouse training for transfer of technology and to develop new technology for lesser known species.	In Tamil Nadu, the volume of farm grown timber is increasing, but there is no facility for organized seasoning plant. Hence establishment of decentralized wood seasoning facility will have great market potential. It is estimated that for Tamil Nadu alone nearly 5 million m^3 of timber is needed and hence this technology would find great market potential. The existing consortium of industries registered with TNAU will be linked and create platform for market potential.

Technology 5: Forest biomass based activated charcoal/carbon generation

Prioritized Species	Technology Transfer	Market potential
All woody species	The technology transfer is in the process through consortium industries. The carbonization plant establishment is in the process at business incubator for in-house training	The activated charcoal/carbon has great market potential in following industries. • Filtration industries • Paints and varnishes • Pharmaceuticals • Food industries The existing activated carbon generation industry will be linked to buy activated charcoal and associated activated carbon. In Coimbatore district alone there is a demand of 1.5 lakhs tonnes of activated charcoal per annum.

New innovation

The institute is also involved in developing new technologies which are at various stages of development. These technologies are listed below:

- Wood antiques from new and alternate genetic resources
- Tall seedling production technology

- Tree burlapping technology
- Seed cube technology for large scale Afforestation and reforestation programme
- Cocoon craft technology

New technology development
The institute is also involved in wide range of product development towards catering to the needs of society and the industries. The technology development is in various stages of developmental process which will be mentored by the faculty for establishing full fledged technology towards commercializing them through the incubation centre.

- Natural Hand wash from soapnut
- Jamun based food additive products for anti diabetic utility
- Wine production from un and underutilized edible wild fruits
- Tamarind seed gum for industrial application
- Medicinal plant based product development
- Development of high Azardirachtin neem clones
- Development of bixin based natural dyes
- Pupal oil production technology
- Sericin production technology

Inventory and Documentary of ITKS and Product Development
The indigenous traditional knowledge available with the tribals and forest dwellers will be inventorized and documented in the Forestry Business Incubator. This indigenous traditional knowledge will be validated through suitable research and development. This will create a new product suitable for domestic and industrial utility. The products like anti-venom, herbal repellents, Neutracitical and Pharmaceutical products will be the major focus area of business development.

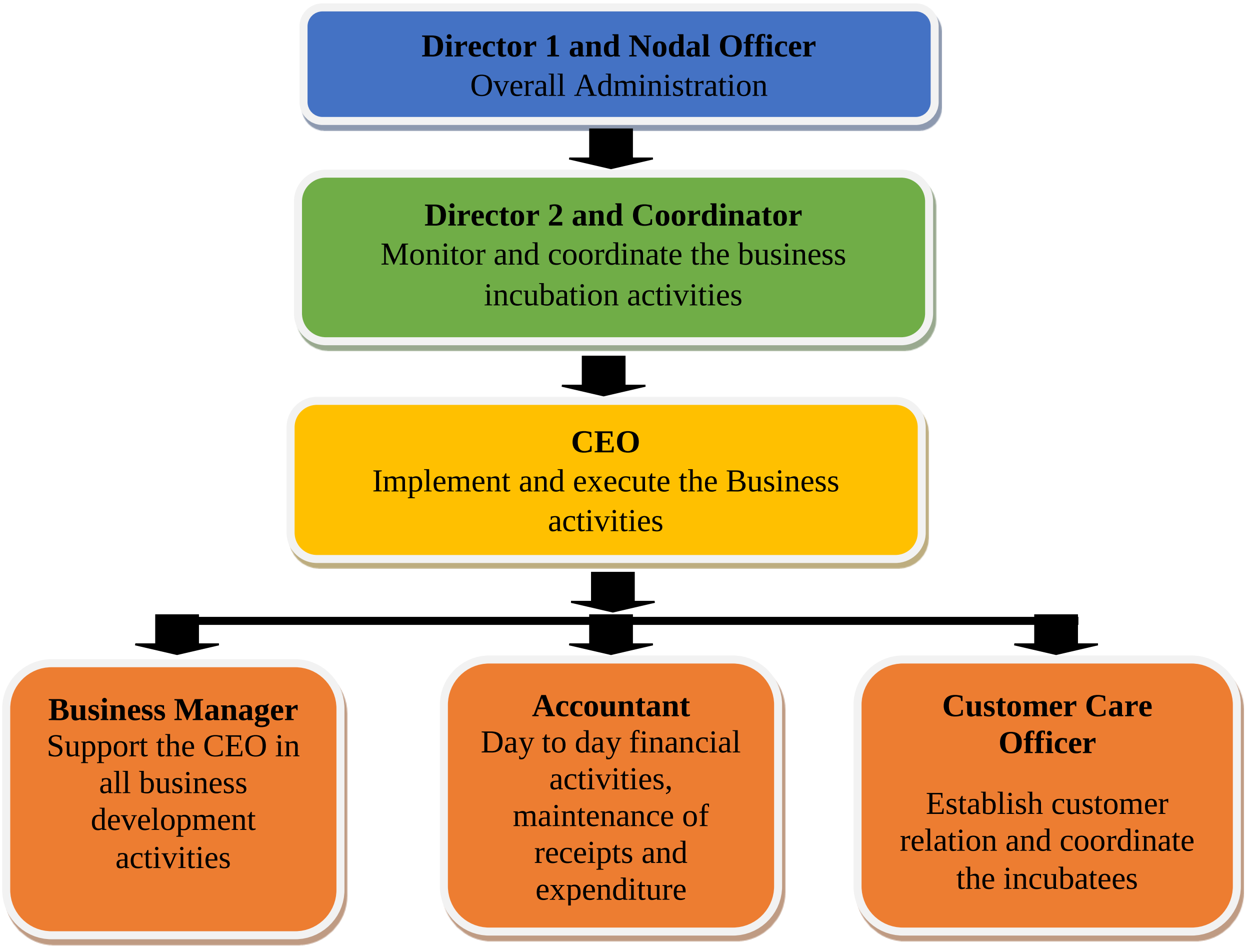
Establishment of India's First Agroforestry Business Incubator
The Mettupalayam Agro forestry Business Incubator (MAFBIF) is incorporated as Section 8 Company on 05.09.2018 registered under the Ministry of Corporate Affairs, Government of India and established at Forest College and research Institute, TNAU, Mettupalayam, Tamil Nadu.

Incubation Facility
A separate incubation facility in an area of 5050 sq. ft had been built with clean energy support system through solar power generation. This incubator has been established with following infrastructure facilities to develop skill and expertise on the entrepreneurs towards creation of startups, new business enterprise and strengthening the existing entrepreneurs.

- Central Clonal Multiplication Facility for mini clonal technology and mass multiplication
- Pulverizer/Chipper/Briquetting Unit for value addition enterprise
- Veneer peeling unit for new startup development
- Wood Seasoning Plant for new startup through lesser known species
- Oil Expeller Unit for biofuel enterprise
- Steam Distillation Unit for forestry based perfumery industry
- Carbonization Plant for value addition industries

Incubation administration

The incubation has established a standard administrative system with the following members for company administration supported by executives to implement the incubation activities. The administrative structure is furnished below:



Objectives and Targets

i. Leveraging the following established R & D activities establish forestry based start-ups.
   a) Miniclonal technology for industrial wood species (College to keep the source/pedigree of the clonal varieties released).
   b) Tree based biomass value addition through briquetting/pelleting technology.
   c) Wood seasoning technology (especially for secondary timbers from agroforestry).
   d) Dendro biomass based activated charcoal/carbon generation (from trees outside forests cover).
   e) Validating innovative technologies- wood antiques from new and alternate genetic resources, tall seedling production, tree burlapping technology, cocoon craft technology.
   f) Value added forestry products-natural hand wash, seed gum, natural dyes, pupal oil, sericin production etc.,

ii. Inventorising and documenting Indigenous traditional Knowledge (ITK)
   a) To collect, assess and incubate ITK from local tribal population like anti-venom, herbal repellents etc.,

iii. Training to farmers, tribal population, rural youths, educated and unemployed urban population in and around the region for enticing entrepreneurship opportunities in forestry.
iv. Atleast 25 small enterprises to e incubated in three years duration.

Activities and Achievements

i. Enrollment of incubatees

The Mettupalayam Agro Forestry Business Incubation Forum has promoted its establishment through the members of consortium operated by FC & RI and through other channels. This has attracted 32 members who have enrolled as potential Incubatees and the process of Incubator activities like commercialization, Technology validation, licensing process and other activities have already been initiated for the benefit of members of Agroforestry Business Incubation Forum.

The enrolled Incubatees represent corporate firms, Individual farmers, New Business Enterprises, Startup Companies, Aspiring Student Entrepreneurs, women entrepreneurs, self-help groups, Tribal Associations, NGOs, Farmer Producer Companies, etc. The list of members enrolled is furnished below.

S.No	Categories	Enrolled Incubatees
1.	Farmers and individual entrepreneurs	5
1.	Student entrepreneurs	5
2.	Startup companies	1
3.	Corporate firms	3
4.	Women entrepreneurs	4
5.	New Business enterprises	9
6.	Forest based Machinery designer	1
7.	Farmer Producer Companies	3
8.	Financial institutions	1
Total		**32**

ii. Awareness creation

The forest based business incubation facility established in Tamil Nadu has been promoted through various awareness programme involving wide range of stakeholders representing individual entrepreneurs, professional graduates from farm university, officials from state forest department, Scientists and faculties from ICAR, SAU and ICFRE Institutes. This besides, the potential farmers, landless laborers, women's self-help groups, tribal communities, school students, venture capitalist, member of Consortium of Industrial Agroforestry and financial institutions were also exposed to the establishments and the activities of agroforestry business incubator in order to create more awareness across the country.

The India's First Agroforestry Business Incubator was launched on 02.02.2019 by the Vice-Chancellor, TNAU along with the Regional Director, ICRAF, New Delhi in the presence of over 250 stakeholders representing various sectors from across the country. These promotional activities have received significant attraction and strengthen the activities of business incubator.

iii. Capacity building

Wide range of technology based capacity building programme has been carried out to transfer the technologies and to commercialize them towards creation of new entrepreneurs, startups and other business venture activities.

S.No	Name of the training programme	Number of programmes	Number of beneficiaries
1.	Mini clonal technology	5 Identified and incubated nurseries	50
2.	Briquetting technology	3 Identified individuals and entrepreneurs	15
3.	Essential oil extraction	2 Individuals and entrepreneurs	5
4.	Business incubation – Scope and opportunities	1 KVK Programme co-coordinators	35
		5 for forest department	300
		1 General stakeholders	250
		2 Farm Graduates	120
		1 Retired professionals	50
		1 Wood based industries	20
		2 College students	100
		1 School students	38
		1 Tribal communities	35
		1 Business management Students	45
5.	Over all business opportunities	2 for enrolled incubatees	32

iv. Technology commercialization

One of the mandated objectives of the business incubator is to commercialize the existing technologies towards creation of startups and new business enterprises. Accordingly two varieties viz., Melia dubia MTP 2 and Casuarina MTP 2 and the mini clonal technology have been commercialized through 11 business incubatees and clonal production centres have been created across the state of Tamil Nadu and Maharashtra. The list of technology commercialized and the new business enterprises established are furnished below.

List of Varieties / Technologies commercialized through Business incubatees

S.No	Name of the incubatee	Variety / Technology commercialized	License Fee (Rs.)	Validity (In Years)
1.	Kumar Hi-Tech Nursery Annur	*Melia dubia* MTP2 with Mini clonal technology	1 lakh	5
2.	National Associates Sathyamangalam	*Melia dubia* MTP2 with Mini clonal technology	1 lakh	5
3.	Covai Gain Naturals Coimbatore	*Melia dubia* MTP2 with Mini clonal technology	1 lakh	5
4.	Newgen Hi-Tech Nursery Walajapet	*Melia dubia* MTP2 with Mini clonal technology	1 lakh	5

5.	K3 Nursery Tindivanam	*Melia dubia* MTP2 with Mini clonal technology	1 lakh	5
6.	La Farme De Peter LLP Tirunelveli	Casuarina MTP2 with Mini clonal technology	1 lakh	5
7.	RPS Green Energy Ltd Badlagundu	*Melia dubia* MTP2 with Mini clonal technology	1 lakh	5
8.	Eccentric Organics Limited Trichy	*Melia dubia* MTP2 with Mini clonal technology	1 lakh	5
9.	Enhanced Bio-fuels and Technologies India Ltd Coimbatore	*Melia dubia* MTP2 with Mini clonal technology	1 lakh	5
10.	Tandulwadi Agro Produce Company Ltd, Parbhani, Maharashtra	*Melia dubia* MTP2 with Mini clonal technology	1 lakh	5
11.	Tandulwadi Agro Produce Company Ltd, Parbhani, Maharashtra	Casuarina MTP2 with Mini clonal technology	1 lakh	5

v. Technology validation

The agroforestry business incubator facilitates technology validation for the individuals / enterprises who have conceived and developed technologies on a pilot scale. Accordingly one of the registered incubatees M/s ARRGEE Aromatics, Karamadai of Mettupalayam has indicated that he has found an aromatic essential oil from curry leaves. He expressed interest towards process validation and quality test through GC-MS. Hence the mentoring team of Agroforestry Business Incubator has organized process validation test during 24.12.2018-31.12.2018 through steam distillation process. The aromatic essential oil extracted from three different curry leaf varieties is now under quality test through GC-MS. Now a Steam Distillation Unit has been established to conduct multiple trials using various types of raw material.

vi. Facilitation of student inventor

One of the student inventor viz., R. Jawahar has developed an innovative Seed Cube technology with the mentoring support from a scientist of FC&RI which has better rate of success in germination and is more efficient. The student inventor has been incubated in the business incubator and further technology validation and testing is continued. The Incubator is now in the process of technology commercialization in association with various stakeholders towards restoration, Afforestation and reforestation activities to translate student inventor into a business professional by creating a startup company.

vii. Other support services

The Business Incubators is also involved in product and process testing, validation, licensing of products and technologies of various incubatees and stakeholders. Accordingly wide range of products like honey, value added medicinal products, hand wash, etc are in the process of technology validation and licensing.

viii. Financial Support

One of the major activities of the Agroforestry business Incubator is to facilitate funding support to the startups, new enterprise, individuals, student entrepreneurs etc., through grant in aid and also through soft loans. Since the business incubator is at its early stage of establishment the sourcing of seed money is in the process through government sector, MSME projects, Corporate Social Responsibility (CSR) funds of wood based industries, venture capitalist, and angel investors. Once the seed money is established financial support will be extended to individuals and incubatees with innovative technologies and ideas for validation, testing, enterprise development, licensing and commercialization.

ix. Revenue generation

The Agroforestry business incubator is also involved in generation of revenue through its own sources by membership fees, technology license fee, product testing, incubation fee and royalty from the sale of products and technologies. During the last six months of implementation the Agroforestry business incubator is able to generate significant revenue which are furnished below.

S. No	Source of Revenue	Revenue Generated (Rupees In lakhs)
1.	Membership fee for business incubator	6.23
2.	Training	0.005
3.	Technology commercialization	11.00
4.	EMDs	0.12
5.	Interest on account	0.10558
Total		**17.46058**

Sustainability Plan

The Mettupalayam Agroforestry Business Incubator (MAFBIF) a pioneer institutional system established first time in the country to cater to the needs of business skill development in forestry sector. This innovative establishment is funded by the entrepreneurship development and innovation institute of government of Tamil Nadu initially for the period of three years. After three years this business incubator has to become self sustainable towards its managerial and financial capacities. Hence a detailed sustainability plan has been conceived and implemented during the process of implementation towards creating self reliance of this section 8 company. Increasing registration of more members, technology commercialization, technology validation, capacity building programme, product sales, royalty for the product and process, rental fee for incubation facility etc. are identified as the sustainable source of income for their incubation center. This besides the incubator is also facilitating establishment of corpus fund through the CSR funds of wood based industries and other involved in forestry and agroforestry development programme. The MSME sector of government of India and ATAL business incubator programme available at government of India will also be approach to sustain the agroforestry business incubation activities to benefit the human kind through skill and entrepreneurial development.

Way Forward

The business incubator is acting as a skill development institution for the graduating students, potential farmers, individuals with or without technology, startups, existing business establishment and wood based industries. The business incubator is mandated to create 10-15 successful business entrepreneurs per annum deploying forestry based innovations and technologies. The scientist involved in forestry research could use the facility for technology validation and commercialization. The graduating students from across disciplines will have a profound utility in order to become successful entrepreneurs. Above all the farmers and others who are looking for self employment opportunities will find this incubator as an excellent platform. However the incubator will have to go a long way to identify incubatees, develop and transfer new technologies, supporting the incubatees for all managerial and financial resources which demand concreter effort by both government and participating private sector institution, organizations and individuals. It is hoped that this business incubator will act as a model for other institutes and organizations both within and outside the country to replicate in order to create more entrepreneurs towards realizing forestry and Agroforestry as a commercial and business enterprise venture.

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Figure 1: Supporting services extended by the incubator to various stakeholders

Mobile Based App for Agroforestry Dissemination

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Abstract
Agroforestry represents a strategy to reverse land degradation and increase social-ecological resilience to climate shocks by diversifying farming systems. However, better information and tools are needed to optimize the selection and use of trees for different agro-ecologies. This is particularly the case for indigenous tree species that are often underutilized. Recent developments in Information and Communication Technologies (ICT) especially mobile based information dissemination holds good promise in providing timely information on various aspects. Such mobile based Agroforestry Apps help farmers to choose right kind of tree to produce timber, fruits, fuel wood, fodder, and medicinal products. Currently, farmers are not able to get correct information in absence of strong extension services. The mobile based Agroforestry App will fill the gap and will tremendously improve the ability of farmers to get full benefits of Agroforestry. The present paper gives a brief account of a smartphone application that allows farmers and extension workers to identify the right agroforestry tree species for their location or farm, including quality seedling sources and suggest appropriate tree crop combination.

Keywords: Agroforest App, Information and Communication Technologies (ICT) Agroforestry System App, Tree Species Suitability

Introduction

Agroforestry systems have been shown to assist smallholder farmers in adapting to climate change, particularly through improved water conservation and micro-climatic conditions, as well as enhanced soil quality. However, in order to realize these benefits, it is critical that the right trees are planted in the right place and that trees are selected that can supply the desired ecosystem services such as increase carbon storage. The trees on the agricultural landscapes will help to full fill the demand for food which is expected to increase in the coming years as the world's population is estimated to reach 9.2 billion by 2050. The increasing demand for the food has to be attained under existing and foreseeable constraints such as the stagnation of expansion of arable lands, scarcity of water resources, advancing environmental degradation, negative impacts of climate change, natural disasters etc. In such situation the agroforestry will be playing important role in food and nutritional security for the growing population.

In order to strengthen the farmer's efforts, timely information on Agroforestry is important. Although rich information on practicing agroforestry is available but dissemination channels are not easily accessible to the farmers. There are varieties of mobile applications, utilized over the globe for different segments, including farming, but the usage in Agroforestry is still limited. There are enormous opportunities for utilizing the smart phones as a part of Agroforestry practices. It will help to get easy access to information on Agroforestry practices. The Agroforestry System App will help farmers to choose right kind of tree to produce timber, fruits, fuel wood, fodder, and medicinal products to cater farmers need. Currently, farmers are not able to get correct information in time in absence of strong extension services. With the mobile based Agroforestry System App the user will be able to select suitable tree species based on desired products and environmental services by building on research conducted by the applicant and its partners including spatial databases of both naturally occurring and exotic agroforestry tree species. Such Applications will also facilitate crowd-sourcing capabilities, allowing users to upload information about trees at their location to a database that will in-turn inform mathematical models to improve current estimates of the distribution of important tree species and agroforestry tree species diversity. The mobile based Agroforestry Apps will fill the gap and will tremendously improve the ability of farmers to get full benefits of agroforestry.

Gap in Knowledge

Knowledge gaps remain in terms of the actual suitability of specific agroforestry tree species for specific locations that explicitly consider soil quality, health, environment and farmer's preference. Also, knowledge gaps remain about the distribution and diversity of existing agroforestry systems in the locality of the farmer. While illiteracy is not a major obstacle in terms of smartphone use in India, knowledge gaps remain in terms of ways to present information to farmers and involve smallholder who tend to be risk-averse in decision making processes, including in the selection of appropriate agroforestry tree species.

Studies reveal that mobile phones have a positive impact on sustainable poverty reduction and identify accessibility as the main challenge in harnessing the full potential (Bhavnani et al., 2008). The advantages of mobile phones include: affordability, wide ownership, voice communication, and instant and convenient service delivery. Due to these, there is explosion across the world in the number of mobile apps, facilitated by the evolution of mobile networks and by the increasing functions and falling prices of mobile handsets (World Bank, 2012). Considering vast benefits of the mobile apps Government of India has launched a number of web and mobile based applications for dissemination of information on agriculture related activities, free of cost, for the benefit of farmers and other stakeholders. Some of the examples of the Mobile based Apps for the agriculture are given in below table 1.

Table 1. Details of Mobile based Apps in India

Sr No	Name of App	Developed by	Source
1.	Kisan Suvidha	Ministry of Agriculture & Farmers Welfare, Govt. of India	http://mkisan.gov.in/download mobileapps.aspx
2.	Pusa Krishi	Ministry of Agriculture & Farmers Welfare, Govt. of India	http://mkisan.gov.in/mApp/Pusa-Krishi.apk
3.	Soil Health Card (SHC) Mobile App	Ministry of Agriculture & Farmers Welfare, Govt. of India	https://play.google.com/store/apps/details?id=com.nic.soilhealthcard&hl=en
4.	Crop Cutting Experiments-Agri Mobile App	Ministry of Agriculture and Farmers Welfare, Govt. of India	http://agri-insurance.gov.in/CCEAppVersions.aspx
5.	Bhuvan Hailstorm App	Ministry of Agriculture & Farmers Welfare, Govt. of India	https://play.google.com/store/apps/details?id=isro.nrsc.BhuvanHailstorm&hl=en; https://apps.mgov.gov.in/descp.do?appid=1029
6.	Krishi Video Advice mobile app	Developed by: MANAGE with NIC, Hyderabad	www.krishivideoadvise.gov.in; https://www.manage.gov.in/krishivideo.apk

Sr No	Name of App	Developed by	Source
7.	Plantix	PEAT, Germany	https://play.google.com/store/apps/details?id=com.peat.GartenBank&hl=en
8.	IFFCO Kisan Agriculture	IFFCO Kisan, a subsidiary of Indian Farmers' Fertilizer Cooperative Ltd	https://play.google.com/store/apps/details?id=com.IFFCOKisan&hl=en
9.	APEDA Farmer Connect	Agricultural and Processed Food Products Export Development Authority (APEDA)	https://play.google.com/store/apps/details?id=in.gov.apeda.apedaapp&hl=en
10.	Krishi Vigyan	Krishi Vigyan Kendra (KVK), Amadalavalasa, Andhra Pradesh	https://play.google.com/store/apps/details?id=com.krishi.krushivision&hl=en
11.	Havaamana Krishi	AICRP on Agrometeorology, Vijayapura Centre, University of Agricultural Sciences, Dharwad.	https://play.google.com/store/apps/details?id=com.uasd.havaamana&hl=en
12.	eNAM Mobile App	Small Farmers' Agribusiness Consortium (SFAC), Ministry of Agriculture & Farmers Welfare, Govt. of India	https://play.google.com/store/apps/details?id=in.gov.enam&hl=en
13.	AgriMarket	Ministry of Agriculture & Farmers Welfare, Govt. of India	https://apps.mgov.gov.in/descp.do?appid=989
14.	Digital Mandi India	Appkiddo	https://play.google.com/store/apps/details?id=com.appkiddo.smartfarmer&hl=en
15.	Loop	Digital Green	https://play.google.com/store/apps/details?id=loop.org.digitalgreen.loop&hl=en
16.	riceXpert	ICAR-National Rice Research Institute (NRRI), Cuttack	https://play.google.com/store/apps/details?id=com.icar.ricexpert&hl=en
17.	Mana Verusanaga App	Regional Agricultural Research Station, Tirupati, Acharya N.G.Ranga Agricultural University, Andhra Pradesh, India	https://play.google.com/store/apps/details?id=com.kishan.agri&hl=en
18.	Mobile App on Castor	ICAR - Indian Institute of Oilseeds Research (IIOR)	https://play.google.com/store/apps/details?id=in.org.icar_iior.icariiorcastor&hl=en
19.	Solapur Anar	ICAR - National Research Centre on Pomegranate (NRCP), Solapur	https://play.google.com/store/apps/details?id=com.icarnrcp.solapuranar&hl=en
20.	Cane Adviser	ICAR-Sugarcane Breeding Institute, Coimbatore, Tamil Nadu, India	https://play.google.com/store/apps/details?id=sugarcane.cdac.com.sugarcane&hl=enI
21.	Sugarcane Expert System	Tamil Nadu Agricultural University (TNAU), Coimbatore and C-DAC Hyderabad	https://play.google.com/store/apps/details?id=com.cdac.tnau_sugarcane_eng&hl=en

Sr No	Name of App	Developed by	Source
22.	Paddy Expert System	Tamil Nadu Agricultural University (TNAU), Coimbatore and C-DAC, Hyderabad	https://play.google.com/store/apps/details?id=com.cdac.tnau_paddy_eng&hl=en
23.	Coconut Expert System	Tamil Nadu Agricultural University (TNAU), Coimbatore and C-DAC, Hyderabad	https://play.google.com/store/apps/details?id=com.cdac.tnau_coconut_eng
24.	Pashu Poshan	National Dairy Development Board (NDDB)	https://play.google.com/store/apps/details?id=coop.nddb.pashu_poshan&hl=en
25.	Cattle Expert System	TNAU, Coimbatore and C-DAC, Hyderabad	https://play.google.com/store/apps/details?id=com.cdac.tnau_cattle_eng
26.	Dairy Telugu and Dairy Kannada	Jayalaxmi Agrotech	https://play.google.com/store/apps/details?id=com.agri.telugudairy&hl=enhttps://play.google.com/store/apps/details?id=com.agri.dairy&hl=en
27.	mKrishi Fisheries App	Tata Consultancy Services (TCS) Innovation Lab – Mumbai, in collaboration with ICAR- Central Marine Fisheries Research Institute and Indian National Centre for Ocean Information Services (INCOIS) Hyderabad.	https://play.google.com/store/apps/details?id=com.tcs.fish.mkrishi&hl=en
28.	Fisher Friendly Mobile Application (FEMA)	MS Swaminathan Research Foundation in partnership with Qualcomm and INCOIS	https://play.google.com/store/apps/details?id=com.mssrf.ffma&hl=en
29.	RML Farmer	RML AgTech	https://play.google.com/store/apps/details?id=com.rml.Activities&hl=en
30.	MyAgriGuru	Mahindra Agri Solutions, Mahindra and Mahindra	https://play.google.com/store/apps/details?id=com.myagriguru&hl=en
31.	Rythu Nestham	Rythu Nestham Foundation	https://play.google.com/store/apps/details?id=rutherford.apps.raithunestam&hl=en
32.	Kultivate	Gowthaman Ramasamy	https://play.google.com/store/apps/details?id=com.ionicframework.kultivate679690&hl=en
33.	FarmersGrid		https://play.google.com/store/apps/details?id=com.adish.farmersgrid&hl=en feedback@farmersgrid.com

There are many mobile based apps available for farmers for various crops and purposes. However, a comprehensive mobile based apps are very limited in number in India. ICRAF is working on various application of ICT in Agroforestry since long time. ICRAF had launched the Africa Tree Finder recently to fill the knowledge gap, allowing farmers and other stakeholders in East Africa to receive recommendations on suitable agroforestry tree species based on their specific location using spatial databases on the potential natural vegetation for these locations.

The Africa Tree Finder is easy-to-use App shows data on the distribution of indigenous tree species in different natural vegetation types, combined with information on the products and services that the tree species can provide. It is helpful tool for the community members, government agencies, private sector owners, and other land managers with the information need to select the best tree species for their landscapes. The overview screen shot of the Africa Tree finder is given in fig 1 and the App is available on www.vegetationmap4africa.org .

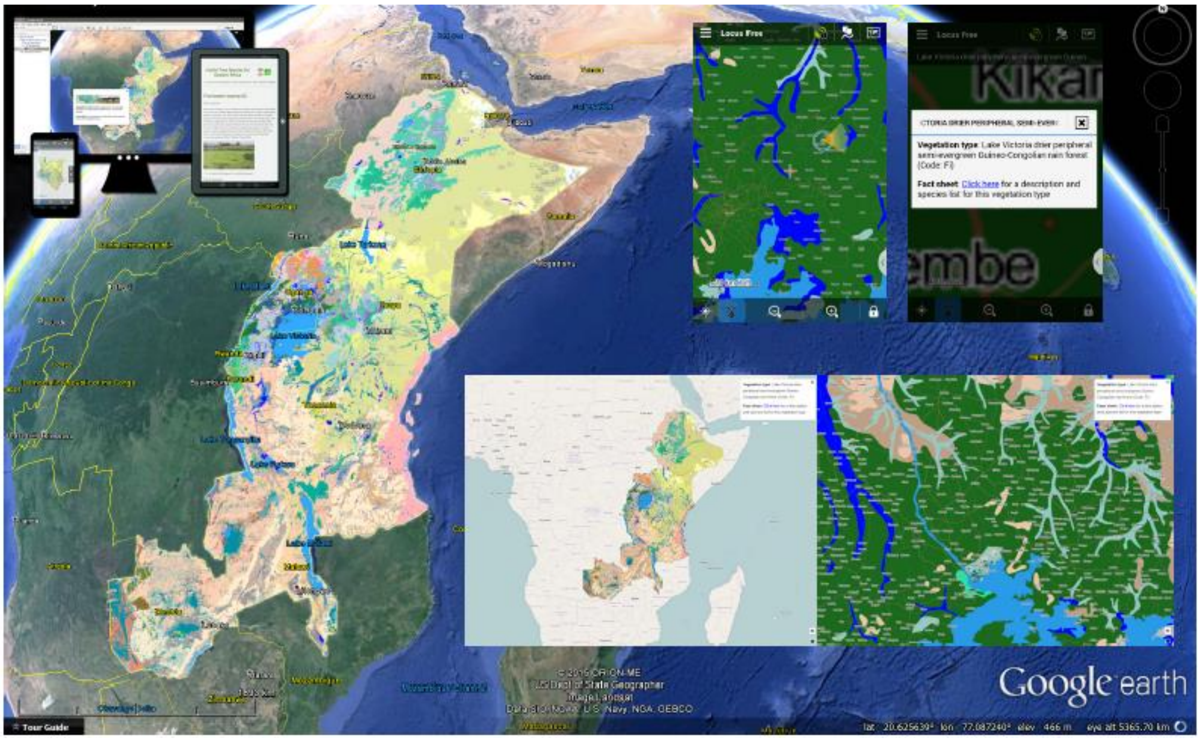

Figure 1. Overview of Africa Tree Finder

Agroforestry System App

As Agroforestry systems include both traditional and modern land-use systems where trees are managed together with crops and/or animal production systems in agricultural settings. They are dynamic, ecologically sound natural resource management systems that diversify and sustain production to increase social, economic and environmental benefits for farmers. Hence, management of both the components (trees and crops) are important to the farmers. World Agroforestry is working on Agroforestry System App for India that will help farmers to manage crop and trees on the farm on sustainable and economically more beneficial ways (Fig. 2). The main components/ modules of this interactive App are listed below. The App will be available on Web as well as Android (mobile) based platform and free for use to the community.

Modules/Components of Agroforestry System App

- Introduction: Information on the Agroforestry systems and benefits
- Registration: Facilitate farmer to register and use the App
- Farmer Inputs: Farmer can enter his farm resources that will be used for manipulating/interacting, and for providing recommendations and services on crops and Agroforestry species.
- Agroforestry: This will provide full package of practice of selected tree species to the farmer

- Quality Planting Material: Based on farmers location and choice of tree species the App will provide the nursery names along with full contact details and available sapling stock in the nursery.
- Processing, value addition and marketing for tree products: The module will guide farmer to produce tree based high value marketable products

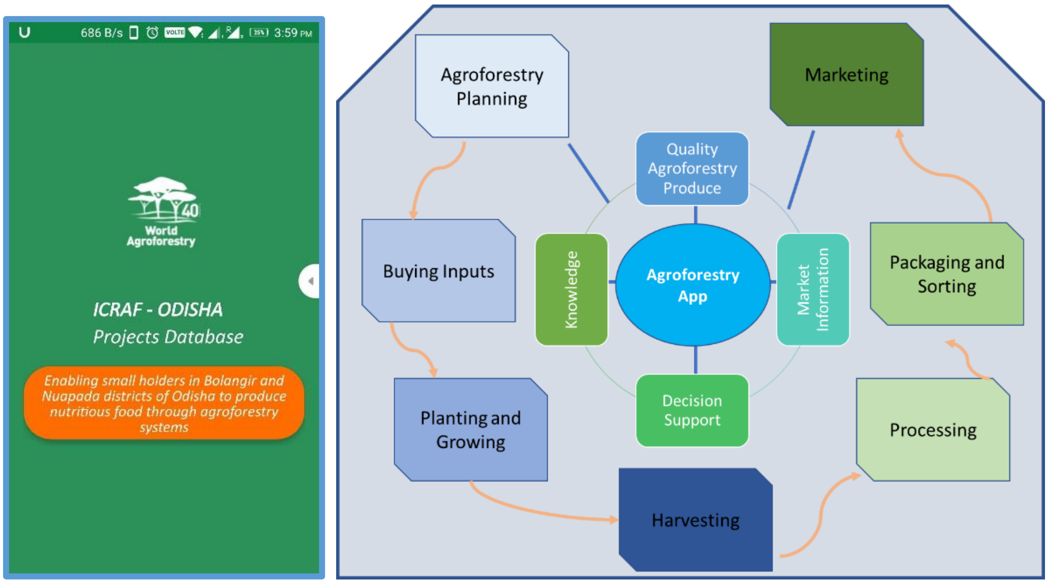

Figure 2. Overview of Agroforestry System App

The Agroforestry System app will be handy tool for the farmers and extension workers that will be used as Agroforestry Based Decision Support System (ABDSS) for the selection of appropriate tree species under agroforestry and suitable tree crop combination based on soil and climatic conditions.

Conclusions and Way Forward

In India, there are enormous opportunities for utilizing the smart phones. Using Information and Communication Technology (ICT) in practicing Agroforestry will help in improving productivity by timely and precise dissemination of appropriate information to agroforestry stakeholders. This may offer great easiness and wider access to the information for practicing profitable Agroforestry. With the use of such apps, farmers could save time and money since they don’t need to travel in order get information and documents by physical presence. On the other hand extension agencies and local government related to agriculture can lower their administrative burdens of dissemination of information.

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AF 4 -- Case Studies and Field Visits

Interactive Session on Reciprocal Learning and Knowledge Exchange

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Making agricultural fields the "right" place to grow trees requires an enabling environment of policies and availability of finance packages. Agroforestry is essentially doing away with the old paradigm that food will be grown on agricultural land and timber is produced on forest land. Up-scaling of effective agroforestry interventions require effective collaborations between and within governmental departments as well as policy framework that deregulate the private management and harvesting of trees as well directing financial support services to agroforestry farms. The purpose of this half day is to share experiences from the different countries on regulations, incentives and disincentives for private land owners to grow and harvest trees, as well as identifying possible opportunities to create an enabling environment for agroforestry.

The Session is organized by facilitated discussions. A panel, consisting of 5 participants will be providing a short introduction to the context, followed by facilitated discussions about country level experiences. The key topics that will be dealt with are the different institutional arrangements in each country with respect to the governance of agroforestry; incentives and obstacles for private land owners to plant and manage trees; existing mechanisms and instruments (such as certification, PES, funds, impact investment) and the role of public and private sector in supporting agroforestry practices.

Structure of the Interactive Session

1. Introduction by Anja/Javed (10 minutes)
2. Panel discussion, selecting 5 participants from different countries : setting the scene – why agroforestry needs new policies (30 minutes)
3. Short recapturing session key points from the discussion (10 minutes)
4. Plenary presentations on different agroforestry policies– India, Nepal
5. Facilitated group discussion – how does it work in other countries (institutional arrangements, incentives/obstacles, mechanisms and instruments, the role of public vs private sector (Anja to facilitate) (1 hour)
6. Group work – what are low hanging fruits to create an enabling agroforestry environment in your country (30 minutes)
7. Short recapturing of previous sessions

Enabling Small Holders to Produce Nutritious Food through Agroforestry in Odisha State- A Case Study

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Abstract
Natural calamities take toll on food grain production from year to year, especially in the eastern state of India, Odisha, which very often leads to food and nutritional insecurity, and irregular and unstable incomes of the communities. Farmers need to diversify agriculture production by growing climate resilient crop and tree species which provide a safety net against climatic uncertainty and provide additional and nutritive food. The project in Odisha uses the SMART protocol approach which advocates a gradual transition and transformation of "purely field crop agriculture" to "agroforestry-based livelihood systems" to improve availability of food, fresh fruits, fodder and vegetables. The project team introduced agroforestry systems to the rural farming communities in such a way that they increase production diverse and nutritive food round the year. It is also working with them to enhance their understanding about benefits of producing and consuming nutritious food. The paper presents a case study from the implementation of the large scale agroforestry project working with small holder farmers.

Keywords: SMART portfolio, agroforestry, nutrition, year round food, fruit trees

Introduction
Diversified food is highly potent and most important source for nutritive and balanced diet. According to Sarkar (2015), food and nutritional security is mainly based on four elements: Availability (production, storage and trade); access (income, prices, markets, public distribution and gender); utilization (food/nutrition knowledge, cultural tradition of food preparation and nutrition behaviour, health services, sanitation and hygiene); and environmental sustainability. The quantity of food consumed, and the quality of diets are affected by the knowledge, attitudes, practices and resources of the households (IFAD, 2015). Despite considerable progress in key health indicators, a report of Nutrition Baseline Survey, 2011 (http://www.nrhmorissa.gov.in) indicates about 40% children below the age of five suffer with the problem of underweight. To improve the nutritional status of communities in Odisha, it is imperative to introduce specific interventions around food addressing the underlying determinants of malnutrition.

SMART protocol advocates a gradual transition and transformation of "purely field crop agriculture" to "agroforestry-based livelihood systems" to improve availability of food, fresh fruits, fodder and vegetables. Natural calamities take toll on food grain production from year to year, which very often leads to food and nutritional insecurity, and irregular and unstable incomes of the communities. Therefore, farmers need to diversify agriculture production by growing climate resilient species (trees) which provide a safety net against climatic uncertainty and provide additional and nutritive food. Thus, the imperative is to introduce agroforestry-based interventions around food to increase the availability of nutritious food to rural communities.

The project in Odisha introduced agroforestry systems to increase the production of diverse and nutritive food round the year and is working with the communities to enhance their understanding about benefits of producing and consuming nutritious food.

Objectives

With overall objective to enable small holders to produce diverse and nutritious food, proposed project focuses on following specific objectives:

- Create awareness about benefits of consuming diversified nutritious farm produce, including, fruits, vegetables, and other tree- based produce, such as flowers, pods, leaves, etc.,
- Introduce and accelerate adoption of suitable agroforestry systems to enhance availability of nutritive food,
- Generate employment and income to support the efforts of Odisha Government to reduce in-country migration
- Assess the impact of introduced interventions on availability of nutritive food to support better decision making for scaling up and scaling out,
- Build capacity of all stakeholders and strengthen existing/ create structures to sustain the activities and impact of the project.

Besides offering most suitable agroforestry options to the participating communities, suitable nutrition related on-farm and household interventions, build skills and capacity of all stakeholders, and strengthening extension support through CBOs and local resources is another approach to achieve the goal.

Project Area and Implementation

The project is being implemented in Belpada and Nuapada block of Bolangir and Nuapada district of Odisha is about 5,008 ha area involving about 5000 Households comprising of a total of estimated 30000 men, women and children in total 149 villages from 30 village panchayats selected mainly on the basis of small and marginal farmers in country distress migration. Thus, benefitting a large population through direct and indirect knowledge enhancement (Table 1).

A basket of agroforestry interventions, best suited to nutritional and other needs of the communities is being introduced. These options include activities like: Bund plantation of trees, mixed-cropping of trees with annual crops; and establishment of nutri-gardens and nurseries. Nutri-gardens has been introduced supporting year-round availability of diversified, fresh and nutritious farm produce, including fruits, vegetables and eatable pods. Project will Development of mobile based E-tool (App) to support extension services in agroforestry is one of our major components of the project. The project is implemented from 1st April 2018 in close collaboration with Odisha University of Agriculture and Technology (OUAT); and with ICAR - Central Agroforestry Research Institute (CAFRI), and ICAR - National Rice Research Institute (NRRI).

As a confidence building measure, project started with some entry level activities like providing seeds of vegetables etc. and getting information about existing land use pattern (Table 2). A basket of agroforestry interventions with multiple choices was offered to communities to choose the best suited options for their nutritional and other needs depending on their resources. These options included activities like: Bund plantation of trees, mixed-cropping of trees with annual crops, establishment of nutri-gardens, and establishment of nurseries. Nutri-gardens in community land and Schools were introduced demonstrating year-round availability of diversified, fresh and nutritious farm produce, including fruits, vegetables, and eatable flowers and pods. In this process, Angan Wadi Centres (AWC), Primary Health Centers (PHC), and other stakeholders were consulted to understand the health profiles of the communities, especially children and pregnant women with a view to work with the communities to increase awareness about importance of consuming diverse nutritive food.

To understand the cropping pattern and systems of agroforestry plantations, project team interacted with the farmer. Discussions held around presently grown varieties of crops, yields, pest and diseases and available markets for agriculture produce. Farmer's in both the district expressed their concern about not being able to take the second crop during *rabi* season mainly due to low moisture in the field. Concern was also raised about the survival of the saplings in the field because of the stray cattle during fallow period.

While doing scientists-farmers interaction meetings for selection of beneficiaries, as our **Entry point interventions**, we provided vegetable seed packet, one each (one packet with 5 types of vegetable seeds: Brinjal, chilly, Okra, Onion, Cowpea) to total 7934 Households, 5294 Household (farmers) in Belpada and to 2640 Household in Nuapada, out of which, migratory farmers were 385 in Belpada and 134 in Nuapada.

Improved varieties of seasonal vegetables given to all farmers

Onion – AFDR;	Cowpea- Kashi Kanchan;
Okra - Arka Anamika;	Chilli- PSB;
Brinjal- PPL	

We selected 1763 farmer beneficiaries for crop demonstration with agroforestry interventions in Nuapada 10 Panchayats (1725-acre Paddy var. MTU 1010 & Var. Sahbhagi and 13-acre CR Dhan 310/311) while in Belpada 625 farmer beneficiaries (Paddy var. MTU 1010 in Belpada). We introduced Paddy var. CR Dhan 310/311 which is having Protein 10.3-11% besides zinc 40 ppm, thus helping in fighting mal nutrition (as rice is the staple food of area).

Bund Plantation with Fruit and MPT: Agroforestry Interventions

For bund plantation of fruit trees, saplings and input were provided for 1484.4 ha.to total 3828 Household, 877 Household in Nuapada and 2951 Households in Belpada. We provided to the farmers following fruit plant and MPT sapling as per farmers' choice @ 8 plants per acre for bund planting (minimum 1 acre and maximum 5 acres):

1. Mango var. Amrapali	2. Guava Var. L49	3. Guava Var. VNR
4. Drumstick var. PKM-1	5. Apple Ber	6. Aonla var. NA-7
7. Custard Apple var. Balanagar	8. Aonla var. NA-7	9. Kagzi Lemon
10. Jack Fruit var.T. Baromese	11. Papaya var. Red Lady	12. Teak
13. Bamboo	14. Gambhar	

Backyard Plantation

The prevalent malnutrition in the Nuapada Block and Belpada block cannot be mitigated only solving the food security. Provision of fruits and vegetable is one the most important source to provide vitamins, minerals which may solve the malnutrition problem among rural mass which is only possible if small and marginal farmers have the fruits and vegetable in their backyard and not required to purchase from market. With this view, the small and marginal farmers in every villages were selected and were provided the fruit plant saplings and vegetable seed to grow in their backyard. Beneficiaries were convinced to consume these fruits and vegetables regularly in their diet. 902 Households in Nuapada and 1958 household in Belpada planted following fruits and vegetables in their backyard as per availably of space, provided to them under the project:

1. Mango var. Amrapali 2. Guava Var. L49 3. Papaya var. Red Lady
4. Drumstick var. PKM-1 5. Apple Ber 6. Custard Apple var. Balanagar
8. Aonla var. NA-7 8. Jack Fruit var.T. Baromese 9. Kagzi Lemon

Improved varieties of seasonal vegetables given to all farmers

1. Onion – AFDR 2. Cowpea- Kashi Kanchan 3. Okra - Arka Anamika
4. Chilli: PSB 5. Brinjal- PPL

During *Rabi* season also as per availability of soil moisture, toxin free seeds of lathyrus and Lentil (var. Pusa Vaibhav containing 102 ppm Iron) were provided to farmers. Total 613 farmers were provided Lathyrus var. Ratan and Prateek having 0.05 and 0.06 ppm ODAP for cultivation at Nuapada and Belpada wherever the residual moisture was available after paddy harvest. Thus, giving them 2^{nd} crop with availability of more protein and iron.

For development of livelihood, 12 SHG (10 IN Nuapada and 2 in Belpada) were encouraged to develop small nurseries where they were helped to grow Drumstick (PKM-1), Papaya (Red Lady) and some vegetable seedling, which were purchased initially to distribute among farmers to get their nursery popularized. This initiative provided livelihood to few SHG while farmers could get quality plant saplings and vegetable seedlings.

Ground truth data (Geotagging)

The ground truth data has been collected with geospatial location (Figure 1 and Figure 2). It can help people to find on satellite images and this information (Based on a location) combining with an application like Google Maps, Google Earth with geo-tagged photos.

Way forward

Agroforestry has a major role to play in addressing problems of food, nutrition, energy and environment. Agroforestry should integrate more fully into key areas for poverty alleviation- thus enhancing the nutritional security, rural livelihoods security, skill development, natural resources management, agricultural productivity enhancement, and restoration of degraded landscapes in order to be more effective. Providing the basket of options in agroforestry interventions to the farmers by integrating tree farming into conventional agriculture make them recognize that adoption of suitable agroforestry systems can enhance availability of nutritive food, generate employment and income to support their family, especially in climate distress situations. In this way Agroforestry interventions are helping to improve the livelihood, nutritional and environmental security to the poor farmers in rainfed area with the help proper policy implementation.

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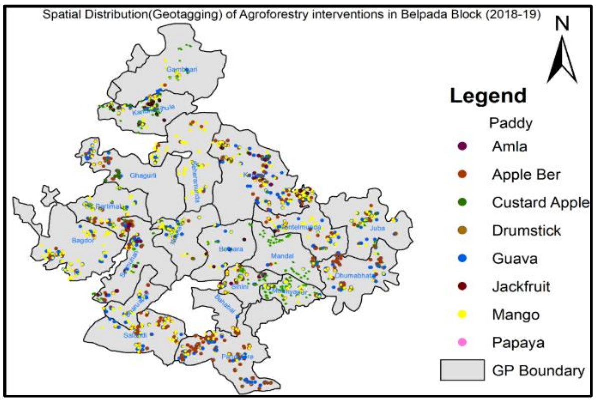

Figure 1: Spatial Distribution (Geotagging) of Agroforestry interventions in Belpada (2018-19)

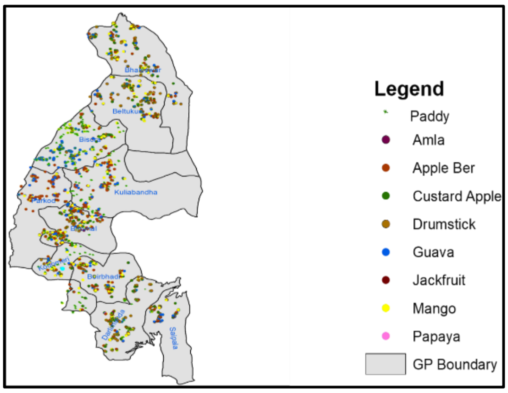

Figure 2: Spatial Distribution (Geotagging) of Agroforestry interventions in Nuapada (2018-19)

Table 1: Estimated direct and indirect beneficiaries

	Activities	Participating households	Estimated direct beneficiaries (individuals) *	Estimated indirect beneficiaries (individuals) #
1	Entry level activities	9,000	45,000	2,25,000
2	Mixed cropping agroforestry	1,794	8,970	44,850
3	Boundary planting	7,200	36,000	1,80,000
4	Backyard / Nutri-garden	5,400	27,000	1,35,000
5	Nursery establishment and running	76	380	1,900
6	Capacity development (formal training)	5,400	29,070	1,45,350
7	Capacity development (informal training)	9,000	90,000	4,50,000
8	Knowledge through field days	10,800	54,000	2,70,000
9	Knowledge through brochure/ cassettes	9,000	82,794	4,13,970
	Total		**3,73,214▲**	**18,66070▲**

**Assuming 5 Persons/ household*
 # One person acquiring knowledge/skills through project will transfer those to at least 5 persons
▲*Some of the community members will receive more than one of the above benefits. Thus, they are counted accordingly.*

Table 2: Existing farmers' practices in project area (pre-project land use)

Crops / Trees Planted	Varities used in Nuapada district	Varities used in Belpada district
Kharif season		
Paddy	MTU 1001, MTU 1010, MTU 7029, Pusa, Swarna, Sehbhagi, Kanda Giri, Jagannath	MTU 1001, MTU 1010, Swarna, Sehbhagi, Pooja, Silky, Parijaat rice
Black gram (Biri)	Local	Local
Green gram	Local	Local, IMP2-3

Pigeon pea	Local	Upas-120
Groundnut	Local & Kadri-6	Local & Kadri-6
Cotton	Very few	Tulsi & Parijaat
Rabi Season: completely fallow (only farmers with irrigation, takes paddy) :4-5 farmer per village		
Horticultural crops		
Mango	Amarpali, Dusheri	Amrapali, Dusheri
Papaya	Local	Local
Guava	Local	Local
Other		
Eucalyptus	Traditional and improved (new plants)	Traditional and improved (new plants)
Teak	Traditional and improved (new plants)	Traditional and improved (new plants)

Bamboo: A Potential Resource for Enhancing Rural Economy– A Case Study

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Importance of Bamboo

Bamboo is a valuable forest genetic resource which has been an integral component in agroforestry landscape over the greater part of India since ages. Bamboo, an easily grown, adaptable and fast-growing crop, is becoming popular as an eco-friendly substitute for timber. In view of its increasing commercial utility, it is more appropriate to refer bamboo as 'Green Gold' rather than 'Poor Man's Timber'. In the present scenario, bamboo plays a significant role in well-being of human society due to its immense contributions towards generation of livelihood for millions of people. This green resource is also being used as an industrial raw material for pulp and paper, construction and engineering materials, panel products, fabric, food, source of active minerals such as vitamins, amino acids, flavine, phenolic acid, polysaccharide, trace elements, etc. which qualifies it to be an asset that fulfils the basic needs of human survival, i.e., *roti, kapda aur makaan* (food, clothing and shelter). Many nutraceuticals can be extracted from bamboo culm, shoot and leaf. All these have anti-oxidation, antiaging, anti-bacterial and anti-viral functions. Bamboos have an about 1500 uses that includes food, construction, fuel, charcoal, medicinal products and the manufacture of paper, flooring, screens and clothing etc. Therefore, it plays a substantial role in the economy of India and provides livelihood support to millions of people. Only three countries, China, India and Myanmar have 80% of total bamboo area in the world. It is estimated that India is the second richest country in world with 13.96 million ha area under bamboo after the China. Out of total bamboo resources in the India, only 15.4% lie on private lands, hence 84.6 % bamboo resources are unavailable for the industrial process without excessive regulations by the forest departments (Dhyani *et al.*, 2016).

Research and development work done on bamboo under National Bamboo Mission by ICAR-CAFRI, Jhansi

A. Development of Bamboo based Agroforestry Systems for Six Agroclimatic Zones

The project envisaged to develop and standardize bamboo based agroforestry systems for six agroclimatic zones of the country. For this purpose six research centres of ICAR and State Agricultural Universities namely Jhansi (U.P.), Kahikuchi (Assam), Jhargram (West Bengal), Bhubneshwar (Orissa), Dharwad (Karnataka) and Dapoli (Maharashtra) situated in different agroclimatic zones of the country, were taken for the study. Bamboo based agri-silviculture systems evaluated at these centres revealed that growth of bamboo in terms of clump height, canopy and number of bamboo culms were higher under the agroforestry situation as compared to pure bamboo. Further, there was no much variation in the growth of bamboo and growth and yield of intercrops in 12 x 10 m and 10 x 10 m spacing, though, their performance was slightly better in closer spacing (10 x 10 m). The intercrops found suitable for bamboo based agroforestry are chickpea and sesame for Jhansi (U. P.); turmeric, pineapple and banana for Kahikuchi (Assam); paddy, groundnut, pigeon pea, turmeric, elephant foot yam and colocasia for Jhargram (W. Bengal); cotton for Dharwad (Karnataka); toria and sesame for Bhubaneswar

(Orissa) and Nagli (*Eleusine corasana*), sweet potato (*Ipomea batata*) and cowpea (*Vigna unguiculata*) for Dapoli (Maharashtra) region. The study also indicates that bamboo can tolerate diverse soil moisture regimes and with an extensive underground root-and-rhizome system it effectively binds the top soil, and help in soil conservation. The bamboo based agroforestry systems had positive effects on soil profile and surface soil properties as the organic carbon and organic matter content and available phosphorus increased. The exchangeable K, Ca and Mg decreased with increasing distance from the bamboo clumps. Soil pH and EC also improved under the system.

The experiments conducted at ICAR-CAFRI for Agroforestry, Jhansi and under the All India Coordinated Research Project (AICRP) on Agroforestry Centres in different agroclimatic regions reported better economic returns from bamboo based agroforestry systems in comparison of sole cropping. These studies revealed that the bamboo based systems yielded B: C ratio higher than one, indicating high profitability.

B. Bamboo (*Dendrocalamus strictus***) + sesame-chickpea based agroforestry system at ICAR-CAFRI, Jhansi**

This study was undertaken at the research farm of ICAR-Central Agroforestry Research Institute, Jhansi (Uttar Pradesh), India in the Bundelkhand region of central India to analyze the potential of bamboo based agroforestry system to sustain the livelihood of farmers. Some of the important results are given hereunder:

Culm yield

The maximum number of culms was found in 10m x 10m spacing as compared to 10m x 12m spacing in agroforestry system and sole bamboo spacing. The matured culms were harvested after 5^{th}, 6^{th} and 7^{th} years of plantation. The matured harvested culms were also recorded higher in the same treatments. The higher number of cumulative matured culms were harvested after seven year from the bamboo culms planted at 10m x 10m in agroforestry system (Fig 2). Averaged upon three years (5^{th}, 6^{th} and 7^{th} year), bamboo grown at a spacing of 10m x 10m (sole and with intercrop) recorded significantly ($P<0.05$) 20.60 % more harvested culms as compared to 12m x 10m (sole and with intercrops).

It was observed that most of the growth parameters of bamboo viz. culm height, culm diameter, internodal length and leaf biomass were recorded significantly higher in bamboo grown in agroforestry system as compared to sole bamboo irrespective of spacing. This might be due to the benefits drawn by bamboo from various agricultural inputs, *viz.* tillage, irrigation, fertilizers etc. (Dev et al., 2016 and 2017).

Yields of intercrops

System productivity (Bamboo+Sesame-chickpea)

The system productivity expressed in terms of chickpea equivalent yield (Table 1) varied in the range of 836 to 1015 (Pure bamboo), 3088 to 3129 (Agroforestry system), 2405 kg/ha (Pure crops) during seventh years of study. However, during first five years, system productivity was observed relatively much higher in agroforestry systems (T1 and T2) and pure crop (T5) as compared to pure bamboo (T3 and T4). System productivity in agroforestry system and pure bamboo plantation increased when harvesting of bamboo culms were done in 6^{th} and 7^{th} year of study. Averaged upon seven years, T1, T2, T3, T4 and T5 recorded with 2584, 2636, 303, 252 and 2612 kg/ha chickpea equivalent yield, respectively.

Soil fertility

Irrespective of spacing, bamboo based agroforestry system had higher organic carbon (OC), available N and P in the soil surface (0-15 cm) in comparison to other land use after seven years of experimentation. After seven years of study, highest increase (60.2% OC, 27.7% available N, 12.7% available P and 5.9% available K) in soil nutrients were recorded in T1 (bamboo spaced at 10m x 10m in sesame-chickpea cropping system) followed by in T2 (58.7% OC, 24.4% available N, 9.8% available P and 5.4% available K). Bamboo leaf litter and fine root decomposition might have enhanced the soil organic matter and other nutrients (N, P and K) in bamboo based AFS as compared to sole crop.


Bambusa vulgaris


Dendrocalamus strictus

SUCCESS STORY

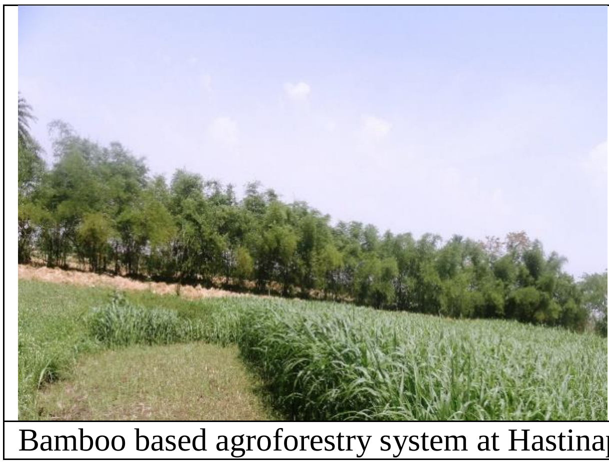
C. Bamboo the "Green gold" based agroforestry system has transformed the life of a farmer

Late Sh. Ram Singh s/o Shri Sarman village Hastinapur, Ambawai of Jhansi District (U.P.) was a humble farmer. He had 7.0 acres land and supported 10 members family. His holding on outskirts of village habitat was quite approachable for him. With a view of better care of his cropland, he had constructed one small animal shed near his holding and kept 5 buffaloes to support his economy. For irrigation to crop and drinking water for animals he had one bore well with 1.0 HP in one corner of his holding. Traditionally, he grew blackgram / groundnut in *kharif* and wheat, chickpea and in *rabi* season. For the past few years he had started growing vegetables particularly ladyfinger / chilly/ tomatoes etc. during summer for extra income in a part of his holdings. Fortunately his well supported 2 – 4 hours a day during summer. Along irrigation channel he retained ber plants for getting raw material for bush wood fencing, fuelwood and green leaf fodder. He also grew some papaya near well. The irrigation channel of the farmer goes around his holding to irrigate crops in rabi season. With the persuasion of the ICAR-CAFRI scientists, the farmer agreed to plant *B. vulgaris* on the bunds as a component of National Bamboo Mission Project in 2008. Considering farmers choice, 85 plants were planted on field boundary spaced 4.0 m apart. The farmer took keen interest in protecting and took due care of plants and established a land mark demonstration site for neighbour besides sustained additional earning defying ill effects of climate change. Several farmers approaching this institute to seek advice on agroforestry were facilitated visits to this site at Hastinapur.

ICAR-CAFRI took further initiatives to popularize *B. vulgaris* and distributed plantlets to the farmers in village Binwara, Dabar, Shyamshi, Kundar, Shivrampur, Rautianain Niwari tehsil of district Tikamgarh and Parasai, Chhatpur villages of Babina block in Jhansi (U.P).

Sudden demise of the farmer Sh. Ram Singh in 2011, led his son Sh. Harpal Singh to take over the family's livelihood options. He also continued to maintain the bamboo plantation. Besides routine cropping (sesame / blackgram / chickpea, wheat and lentil) he earned about ₹15,000.00 during 2012; ₹ 20,000.00 during 2013 and ₹ 35,000.00 during 2014 by selling the bamboo culms obtained through selective thinning. Forest Deptt., Datia (M.P.) showed keen interest in multiplication and large scale plantation of *B. vulgaris* in the district, as such the department purchased all available culms of *B. vulgaris* from Hastinapur for ₹ 1,15,000/- in March, 2015. The Department is planning to multiply them through culm cuttings. These bamboo culms had average height-12 m; average dbh- 4.1 cm ; average intermodal length-26 cm ; average number of inter nodes culm^{-1}- 20. Therefore over a period of seven years journey Sh. Harpal Singh earned about more than ₹ 26,000.00 per annum from bamboo as his net profit from bamboo. New culms arising from left over rhizomes will continue to produce new culms.

During this seven years journey there had been two years (2009 and 2014) of drought and extreme weather aberration incidents that affected crop production in this region. Year 2013 being of excessive rainfall year, also adversely affected *kharif* and *rabi* crops production in the region. Further rains during March 2015 spoiled the *rabi* crops (2014 – 2015) in the region. Economic losses due to crop failures as a result of bad weather were well compensated by the boundary bamboo plantation. Thus the green gold has transformed life of Late Sh. Ram Singh's family and likely to bring cheer to the farmers of the region. Bamboo is known to be the fastest growing plant and thus contribute to carbon sequestration, micro climate mediation and restoration of eco-balance in the era of changing climate.




Bamboo based agroforestry system at Hastinapur, Jhansi

Work done by ICAR-CAFRI on multiplication of Bamboo

Farmers' friendly technique for multiplication of bamboo (Bambusa vulgaris)

B*ambusa vulgaris* was multiplied by burying whole culm during 2014 and 2015 at Research Farm of ICAR-CAFRI, Jhansi. Two years old bamboo culm produced higher number (165) of shoots than one year (114) and three years old culm (57). The culm planting methods resulted in prolific rooting pattern during monsoon season and on an average 5.7 rooted plants were obtained from every alternate node. Rooted sprouts were separated from each productive node along with fibrous roots attached to it and were planted in polythene bag as new plantlet. This method of planting was found impressive for developing live bamboo fence and producing large number of plants from scarce planting material. This technique promises large number of planting material and readily acceptable technology to the farmers (Tewari et al., 2016).

	
Emerged shoots at 28 DAP from culm of *B. vulgaris*	Shoots and roots emergence at alternate node of culm
	
Rooting all around node without shoot emergence on first basal node of culm	Transplanted shoots of *B. vulgaris* in polythene bags

Policy initiatives taken by Government of India and state governments for development of Bamboo-based industries

The Government of India has taken several policy initiatives to overcome the challenges facing by various stakeholders of bamboo-based industry. Recently, on 5th January, 2018, the Government of India had passed the Indian Forest (Amendment Act, 2017) and omitted "Bamboos" from tree category. For holistic development and harness the potential of bamboo sector, Ministry of Agriculture & Farmers Welfare has been implemented "National Agroforestry & Bamboo Mission (NABM) formerly National Bamboo Mission" before a decade and significant achievement in terms of area expansion, skill development, quality planting materials and strengthening of marketing linkages is well documented. In addition to this the "National Mission on Bamboo Applications (NMBA)" had also been launched under Department of Science and Technology, Government of India to enhance technology development assistance (TDA) in the form of machinery/equipment for their new or existing ventures.

The Ministry of Micro, Small and Medium Enterprises (MoMSME), Government of India runs numerous schemes for skill development, financial assistance, technological assistance and quality up gradation of stakeholders especially for artisans of agro-based industries. The Scheme for Fund for Regeneration of Traditional Industries (SFURTI) is directly related to bamboo-based industries through application of cluster approach in a particular agro-climatic region.

National Bamboo Mission

Restructured National Bamboo Mission (approved by the Cabinet Committee on Economic Affairs (CCEA) on 25-04-2018) envisages promoting holistic growth of bamboo sector by adopting area-based, regionally differentiated strategy and to increase the area under bamboo cultivation and marketing. Under the Mission, steps have been taken to increase the availability of quality planting material by supporting the setting up of new nurseries and strengthening of existing ones. To address forward integration, the Mission is taking steps to strengthen marketing of bamboo products, especially those of handicraft items.

Objectives:

- To increase the area under bamboo plantation in non-forest Government and private lands to supplement farm income and contribute towards resilience to climate change as well as availability of quality raw material requirement of industries. The bamboo plantations will be promoted predominantly in farmers' fields, homesteads, community lands, arable wastelands, and along irrigation canals, water bodies etc.
- To improve post-harvest management through establishment of innovative primary processing units near the source of production, primary treatment and seasoning plants, preservation technologies and market infrastructure.
- To promote product development keeping in view market demand, by assisting R&D, entrepreneurship & business models at micro, small and medium levels and feed bigger industry.
- To rejuvenate the under developed bamboo industry in India.
- To promote skill development, capacity building, awareness generation for development of bamboo sector from production to market demand.
- To realign efforts so as to reduce dependency on import of bamboo and bamboo products by way of improved productivity and suitability of domestic raw material for industry, so as to enhance income of the primary producers.

Key outputs

NBM is a dedicated initiative focusing on comprehensive development of bamboo sector through cross sectoral and multi-disciplinary approach. Keeping in view Hon'ble Prime Minister's vision of doubling farmers' income and '*Har Medh Par Ped*', NBM will supplement income and livelihood sources, including risk management during crop damage caused by extreme events. Bamboo can grow on marginal land, not suitable for agriculture as agroforestry/farm forestry crop. Bamboo plantation will optimize the farm productivity and income thereby enhancing livelihood opportunities of small and marginal farmers including landless and the women. As such, given the factors like shrinking of land resources for cultivation and reduced farm income, the plantation interventions may become potential instrument to help achieve the desired sustainable growth in agriculture. Cooperatives farming or group farming models have proved to be of economic value in the context of fragmentation of holdings. Apart from the high above ground biomass production, bamboo also stores substantial carbon in below ground parts, i.e. rhizomes and roots and would contribute to enriching carbon pool at lower depths, even up to one metre and beyond. Hence scientific bamboo plantations would also be important for mitigating measures against climate change.

Modern technologies allow use of bamboo as a durable and high-quality wood substitute. Premium products such as bamboo flooring, laminated furniture, mat boards, strand lumber, etc. have huge international demand with big pro-poor financial impact and employment potential. Bamboo bridges and pre-fabricated houses have large potential in defence, disaster management and low-cost housing. Pack-flat and knockdown furniture are novel concepts. Hence there would be a focused approach towards blending traditional and innovations with infusion of technology to give value added products at par with global standards. North Eastern Council (NEC) has also identified bamboo cultivation as a major source of economic gains to the North Eastern Region having potential to provide additional source of income to the small and marginal farmers, which is the present priority of the Government. NCDC has re-oriented its strategy for bamboo sector development focused on cooperative societies at different levels, primary, District and State/Apex. With revitalizing of the bamboo industry, through various innovations and policy support, it would contribute by way of climate resilient structures and contribute to Make in India mantra also, giving stiff competition to other global players in the sector.

The key outputs envisaged are:

i) Coverage of 1,05,000 ha area under bamboo over a period of two years by ensuring adequate stocks of selected genetically superior quality planting material
ii) Promotion and diversification of bamboo products through establishment of micro, small, medium & large processing units and development of value chain in bamboo
iii) Setting up and strengthening of bamboo mandi/bazaars/rural haats, including promoting online trade.
iv) Enhanced cooperation within the country related to research, technology, product development, machinery, trade information and knowledge sharing platform particularly for NE States to give a boost to the low key bamboo based industry in the country (https://nbm.nic.in).

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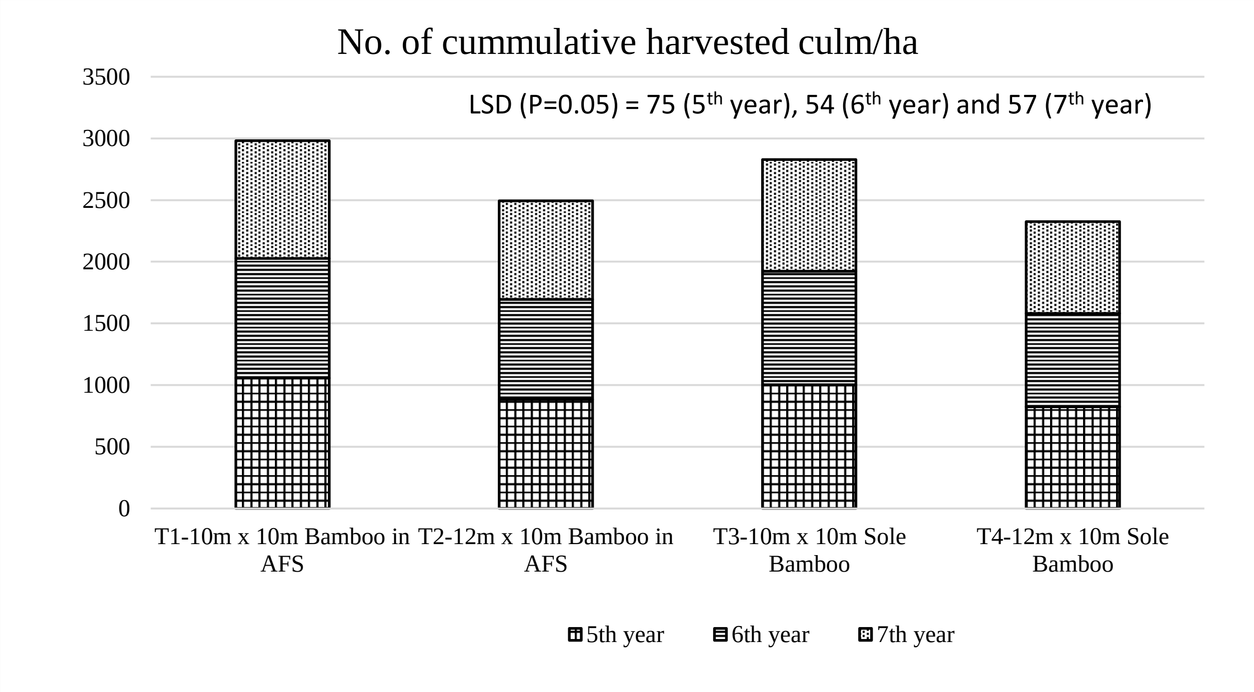

Figure 1. No. of harvested culm of D. strictus under bamboo+sesame-chickpea AFS

Table 1. System productivity (Bamboo+sesame-chickpea) of bamboo based agroforestry system

Treatments	System productivity (Chickpea equivalent yield, kg/ha)						
	2008-09	2009-10	2010-11	2011-12	2012-13	2013-14	2014-15
T1-10m x 10m Bamboo+chickpea	2767	2661	2238	2197	2053	3045	3129
T2-12m x 10m Bamboo+chickpea	2691	2692	2338	2366	2242	3038	3088
T3-10m x 10m Pure Bamboo	7	18	36	39	41	962	1015
T4-12m x 10m Pure Bamboo	6	18	35	38	40	791	836
T5-Pure crop (sesame-chickpea)	2757	2642	2790	2719	2593	2381	2405

Agroforestry for Drought Mitigation at Garh Kundar-Dabar Watershed in Semi-arid Climate - A Case Study

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Doughts and floods are major concern in present day scenario. The situation is worsened by worldwide deforestation and loss of permanent vegetal cover. The only option is to increase number of trees on the landscape. Forest area is shrinking day by day and tree density on decline due to over exploitation. Therefore, increasing trees on croplands seems vital alternative in light of facts:

1. Trees under private possession will be duly taken care of by owner (Farmer).
2. Consequent upon tree planting in croplands, Micro-climate of agricultural land will improve work efficiency of farmers.
3. Trees will harbor micro-organisms and birds which in turn will help crop production/protection.
4. Trees will yield direct revenue to the owner.

Emphasis on agroforestry in India is almost four decades old. All India Coordinated Research Projects were started way back in 1983. Central Agroforestry Research Institute (Erstwhile National Research Centre for Agroforestry) was established in 1988 to conduct basic and strategic research. A lot of information was generated on tree-crop combinations and their package of practices, skill adoption of agroforestry by farmers was moving at a slow pace probably by due to following reasons:

1. Long gestation period/harvest cycle.
2. Continuous protection to young plants particularly during young age of 3-4 years.
3. Availability of ready market.
4. Restrictions on harvesting and transport.
5. Food grain priority.
6. Mechanization and plastic culture.

With a view to gear up adoption of agroforestry, it was decided to conduct adoptive research work on farmers' field. After thorough discussion it was agreed to initiate work on watershed scale as watershed is a natural boundary and pivotal to manage water resource development. As such, GarhKundar-Dabar watershed was selected as pilot site on following merits:

- Independent hydrology of 850 ha area.
- Mixed population of caste-creed-religion.
- True representation of drought prone Bundelkhand region.
- Easily accessible throughout the year.
- Virgin area as per natural resource development concerned.

The area was extensively surveyed and traversed. Several rounds of discussions were held with dwellers. Socio-economic status, occupations, crops, cropping intensity, productivity, common package of practices, etc. followed by farmers was assessed. Data and cadastral map was collected from secondary sources. Following strategy was formed in due consultation with dwellers:

- Development of water resources.
- Introduction of trees on croplands.
- Improvement of trees on croplands.
- Enabling dwellers for new initiatives

Modus Operandi

Watershed dwellers were organized into watershed committee giving due representation to men and women across the sects. Team of Scientists discussed plan with them and requested them to identify sites for construction of water harvesting structures. Material required for construction was arranged locally involving watershed dwellers for transparency. Supervision of works was to be done collectively by team of Scientists and residents. Mason and labourers were engaged locally to facilitate employment. Farmers for tree plantation were identified by watershed committee. Only willing farmers were selected. They were motivated and exposed to existing agroforestry plantations elsewhere. Improved variety of plants was arranged by the institute. For crop improvement, selection of beneficiary was done by the committee. However, demonstration value of field and agroforestry adopting farmers were given priority. Soil test was carried out on grid basis. Depending upon soil test value, demonstrations on balanced fertilizer application and micro nutrients were also taken up in the watershed to improve overall productivity of the system. Considering fodder scenario of the watershed and estabilization requirement of earthen structures, fodder grasses were introduced. Further, capacity building of farmers was done to initiate group activities on alternate ventures aimed at increasing earnings of farmers.

Accomplishments

Water Resource

Developed water resources through construction of 8 check dams in treated area, 150 gabion structures of 3-5m^3 volume spread over landscape in first and 2nd order tributaries of main water course, 5 khadins (water spreaders) to check erosion and marginal and field bunding for 50 ha agricultural area. Thus, developed rain water harvesting capacity of 35000m$^{3.}$ As a result, all wells (shallow dug) showed 2-6 m increase in water column during post monsoon season. Harvested water increased cropping intensity and crop productivity. Succeeding normal rainfall, 35-40% drought was mitigated. After wet years (more than normal rainfall, year round surface water was available in water course to quench thrust to stray cattle and wild animals. From the study, was inferred that rain water harvesting increased base flow which regulated water flow in drain during past monsoon season and decreased surface runoff and soil loss.

Crop Productivity

Consequent upon water resource development introduction of improved crop varieties, balance use of fertilizer and capacity building of farmers cropping intensity in watershed area increased upto 207% from 69% prior to project works. Crop productivity across different crops increased by 20-60%. Large shift in agriculture was noticed in winter season as area under wheat crop increased. Cultivation of summer vegetables particularly chilli, brinjal, cucurbits, okra increased the farmers income and initiation. Increased moisture availability lead to increased production in the watershed. This lead to build up assets (brick houses, tractor, thresher and other machinery), improvement in economic status of farmers, drudgery reduction and agriculture employment. Distress migration of village folk reduced drastically.

Agroforestry Development:
Farmers were motivated to plant tree in croplands. Many farmers came forward to plant fruit trees particularly Guava, Citrus, Anola under agroforestry system and Teak, Kumat along field bunds. Bamboo (hollow bamboo) was promoted along water courses. Forage grasses were planted on loose soil for bund estabilization and fodder production. Live fencing was done by planting edible cactus, Kumat and Mehdi. For nutritional security, about 120 households were provided Pomegranate, Maringa, Citrus and Guava seedlings for planting in homestead where aftercare of plants is easy. This lead to increased biodiversity, quality and nutritious fruit production for home consumption. Poor fruit quality ber plants were top worked with improved variety. As top worked ber plants started yielding marketabel fruits from 2nd year onwards, it helped a lot in rapport building and convincing farmers to adopt planting of quality fruit plants for higher income in order to bear risk of crop failure on account of weather vagaries.

Alternative Livelihood:
Major occupation of watershed dwellers is farming. Agriculture labour and animal husbandry are other subsidiary occupations. Due to frequent droughts employment opportunities in village or neighboring area are limited. Therefore, large chunk of population migrated every year in search of job. Most of them were exploited by employers. Unemployment lead to crop-up many social, judicial and administrative issues. The situation warranted creation of more avenues for livelihood security. Therefore, gum and resin yielding trees were introduced in the watershed. Skill for top working of less productive ber, aonla, bael was imparted. Vegetable cultivation during summers was encouraged near water sources. Poultry and dairying was promoted for additional income. Farmers were organized into self-help groups and assisted to initiate joint ventures for extra income. Artisans were provided with small tools to carry out their activity in local market. All concerted efforts lead to development of entrepreneurship in villages. As such petty shops, means of local transport developed in the village itself. Development schemes of State Government were dovetailed to benefit farmers. These efforts brought sustainable development in the watershed.

Assets created in the watershed are serving people till date without any maintenance cost even after a decade. Drinking water supply in watershed village has been stopped from 2008 onwards. Mild droughts (30-35% deficit) do not bother agriculture production. Social harmony has been strengthened and court cases have reduced. Social and religious gatherings have becomes common. Presence of students in primary and middle school has improved. Transport vehicles are plying to the village from nearby town to collect school children. Few families have moved to District headquarter. Niwari (22 km away) to facilitate their children education.

The site has developed as model for drought prone Bundelkhand Region. The technology can go well in similar regions. Several agencies involved in development activities related to agriculture and environment visited the site. Farmers more than 5000 from different districts of Bundelkhand region have witnessed the site. Student across the country studied the site for their post graduate research work. The model is replicate and effective in increasing biodiversity, agroforestry adoption and bringing in overall development in drought prone regions.

Improved Rural Livelihood and Eco-System Services Through Agroforestry and Natural Resource Management Interventions in Drought Prone Bundelkhand Region of Central India

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Introduction

Integrated watershed development interventions strengthens rural livelihood through improved eco-system services in any region and particular in drought prone areas. Trees under traditional agroforestry system improve the ecosystem services as compared to sole agriculture in watershed. An ecosystem is generally accepted to be an interacting system of biota and its associated physical environment (NAS, 2004). They are complex however, making the translation from ecosystem structure and function to ecosystem goods and services (i.e., the ecological production function) is difficult. Ecological life-support systems are constantly depleted due to society's ever-mounting demand for natural capital (MA, 2005).

As per the Millennium Ecosystem Assessment report of World Resource Institute (MA, 2005), the ecosystem services derived from nature have been classified into the following categories:

- Provisioning services (food, fuel, fiber, fresh water, biochemicals, genetic resources)
- Supporting services (nutrient recycling, primary production and soil formation)
- Regulating services (climate, disease regulation, pollination, water regulation and purification)
- Cultural services (spiritual and religious, recreation and ecotourism, aesthetic, inspirational, educational and cultural heritage)

Present paper is based on the study conducted in Parasai-Sindh watershed, Jhansi, which is being developed in consortium of ICAR-Central Agroforestry Research Institute, Jhansi and ICRISAT, Hyderabad.

Experimental Site

The Parasai-Sindh watershed as part of Sindh river catchment is located at 25 º 23' 47.6" - 25 º 27' 05.1" N and 78º 20' 06.5" - 78º 22' 33.0" E, and about 270-315 m above mean sea level in Jhansi district of Uttar Pradesh (Fig. 1). The geographical area of watershed is 1246 ha, comprising three villages namely Parasai, Chhatpur and Bachhauni and has independent hydrology. The rainfall is highly erratic and uncertain. Long term weather data shows that the average rainfall in study region is 877 mm (standard deviation, $\sigma = 251$ mm), about 85% falling from June to September (Singh *et al*., 2014). The watershed experiences semi-arid sub-tropical climate and characterized by dry and hot summer, warm and moist rainy season and cool winter with occasional rain showers. Mean annual temperature ranges from 24 to 25 ^{0}C. The mean summer (April-May-June) temperature is 34 ^{0}C which may rise to a maximum of 46 to 49 ^{0}C during the month of May and June. The mean winter temperature (December-January-February) is 16 ^{0}C. Further, the diurnal variation in temperature is quite high.

Interventions in the watershed

To augment water availability and groundwater recharge, several *in-situ* and *ex-situ* interventions were taken up. Three *nallah* plugs (small checkdam), nine checkdams, one haveli (traditional rainwater harvesting structure), one community pond and one farm pond were constructed. To measure runoff and soil loss, twelve gauging stations were also constructed. In totality, about one lakh fifteen thousand cubic meter surface water storage has been created in the watershed. To improve *in-situ* moisture condition, field /contour bunding was done in 52 ha. Farmers were advised to cultivate across the slope. Besides, about 114 ha brought under various agroforestry interventions with majority under boundary plantation of teak. To improve the crop productivity, more than 265 participatory trials were conducted with good package of practices. About 1, 37,000 rooted slips of Napier bajra hybrid, guinea grass and TSH were transplanted on bunds, near checkdams and around ponds during 2013-14 & 2014-15. On an average biomass yield of 7.0 DMY t ha^{-1} could be obtained from the mixed pasture. Several exposure visits and trainings were also organized to improve the skill of farming community and landless.

Eco-System Services and Livelihoods

A. Impact of IWD interventions on Provisioning Services

Crop productivity

Productivity of different crop during both the season were improved in the range of 20 to 60 per cent. Farmers are switched over to recommended seed rate of wheat. Before interventions it was double the recommendation.

Water availability

Rainwater harvesting capacity of about 1, 15,000 cum. were created and it actually harvested 2 to 6 times of its created capacity depending on annual rainfall. This ensured water availability for irrigation and drinking even in case of 30% deficit rainfall.

Fruits

Trees are the major sources of different NTFPs (Non Timber Forest Products). The sustainable harvesting and management is the best way to achieve smoothen environmental and socio-economic benefits. Fruits and timber harvesting was compared and the result depicted that harvesting of both the products were proportionally increasing as per the size of the family (Fig. 2). The highest harvesting of fruits was carried out by the household having large family size. For the large family size (12 and more), fruits and timber harvesting was recorded to be approximately 1600 kg $yr.^{-1}$ and 190 kg $yr.^{-1}$ respectively. The least harvesting was depicted for the small family size (Less than 3).

Gum and Resins

Extraction of gums and resins was the least preference activity in that village. Generally, the landless people (so called tribals) collect and sell them in the market after their traditional process of the products. It was revealed from the survey that, very rare people do extract the gums and resins but also then for their housefull needs. Except the tribals, some people do extract gums and resins especially ‘Cutch and Katha’ from *Acacia catechu* (Khair) only for the household needs and extract about 2.5 kg $yr.^{-1}$. Among the total 100 households surveyed, only 7 % of the total were reported to be engaged in collection and extraction of gums and resins for their household needs and the remaining 93 %t of the household were not reported under this category (Fig. 3).

Fuelwood consumption

The responses received from different households during questionnaire survey for the fuelwood consumption and dry dung consumption in a year were very informative, conformed one with another, and was amplified by the spot checks made in 30 households. Similar procedure was followed in one of the objectives of fuelwood and fodder security in a traditional agroforestry system of arid western Rajasthan (Khan and Tewari, 2009). The result from the present study revealed that as the family size increases, the consumtion of fuelwood and dry dung in kg yr.$^{-1}$is also increases and vice versa. The R^2 values for both fuelwood (R^2= 0.952) and dry dung (R^2= 0.875) holds good and best for their yearly consumtions with respect to different households (Fig. 4).

The fuel preferences for cooking in the different households of the watershed were mainly of dry dung (57.8 %) followed by fuelwood (30.7 %) and others as 11.5 % of the total (including crop residues). There were hardly any gas or heater reported as fuel (Fig. 5).

Fodder from the trees is the important component for the livestock of dryer region where rainfall is scanty and hardly any fodder grasses are available during summer season. In such situation, agroforestry plays an important role for feeding the animals like cow, sheeps, goats, etc. Fodder collection from the trees of that watershe was found very systematic and were regulated to some extent based on other fodder availability. Based on the survey, it was revealed that there was a positive and strong regression coeficient (R^2= 0.880) fits for the consumption trend in respect of the different households in the watershed (Fig. 6). Maximum fodder collection and consumption (70 kg yr.$^{-1}$) to feed livestock was reported by family size of 9-12 and on the other hand fodder harvesting was reported (approximately 5 kg yr^{-1}) for the households of smaller family size (3 or less than 3). It was noticeably found that most of the households rear livestock mainly to get suppliment for the household needs rather selling it (Dhyani *et al*., 2007).

B. Impact of IWD interventions on Regulating Services

Groundwater recharge

With no interventions only 5 to 6% of annual rainfall was partitioned as ground water recharge. Now, it has been increased up to 11% of annual rainfall (Singh *et al*., 2014).

Base flow

With no interventions only 1 to 1.5% of annual rainfall was partitioned as base flow, which disappear by end of September. Now, it has increased up to 5 to 6% of annual rainfall and base flow was throughout the year in case of normal rainfall year.

Impact of trees on temperature and humidity

It was revealed from the study that, there was a significant difference in temperature and humidity from the outside extremes to the tree bases (Fig. 2). For that, three different tree species were chosen based on crown density. Tree like Babool (*Acacia nilotica*) as light crown density, Neem (*Azadirachta indica*) as moderate crown density and Mahua (*Madhuca integrifolia*) as dense crown density tree were selected. The temperature reduced maximum at the tree bases in all the selected trees. It was found that temperature got reduced to 37.6 °C (Fig. 7) under Neem tree base from outside extreme (39.5 °C) but humidity got increased from 21.4 % (outside) to 33.4 % (tree base), for Babool tree, temperature was recorded lower under tree as 38.8 °C and maximum was at outside extreme (40.2) but humidity was recorded higher at tree base (28 %) and lower at outside extreme (22 %) and for Mahua tree, temperature was recorded low as (38.1°C) as compared to outside extreme (40.4°C) and humidity was measured as high at tree base (35 %) as compared to outside extreme (22 %).

Impact of trees on working efficiency (%)

Based on the questionnaire survey, data was recorded and analyzed which revealed that there was a positive impact of trees of farmland on daily field work activities of different households. Comparatively working efficiency was found maximum in summer (increased by a maximum upto 33 %) and rainy (34 %), and the least was found 16 % during winter irrespective of family size. The working efficiency was increased about a range from 28-33 %in summer, 16-18 % in winter and 30-34 % in rainy. Valuation of season-wise increased working hour in economic and monitory terms was made after considering all the local parameters like Labour wages (Rs. Day^{-1}) and the approximate working hour from household survey. The result revealed that an amount of Rs. 94, 933 could be cut down from the extra expenditure incurred for labour.

C. Impact of IWD interventions on Supporting Services

Reduction in soil erosion

With integrated watershed interventions soil erosion could be reduced by 60 to 75% in red soil areas of Bundelkhand region.

Drudgery reduction and cost of cultivation

In irrigating wheat crops: Before interventions, open wells were hardly supported for 1-2 hrs during rabi season due to low water column. Again, the pumping was done next day after well got recharged. Therefore, farmers generally took 10 to 15 days to irrigate one ha. wheat crop. Mainly women were engaged in irrigation to field crops and generally they spent 40-50 hrs to complete irrigation in one ha. Now, majority of the wells are supporting round the clock and they can complete irrigation within a day (15-20 hrs). Now, the farmers, especially women have more time to care their children and other households' activities. **It also reduces cost of cultivation by Rs. 6000.00 to 8000.00 per ha.**

Drought Proofing of Semi-Arid Regions

It was observed that groundwater recharge in watershed reached 86 per cent capacity with 600 mm annual rainfall, however, this situation could be arrived at with 1100 mm annual rainfall in control watershed (watershed without any interventions). Probability analysis based on last 69 years annual rainfall suggests getting annual rainfall of 600 (32% less than the average annual rainfall) and 1100 mm (25% higher than avg.) is 86 and 20 per cent, respectively. Probability analysis shows that there are maximum chances to get 600 mm rainfall during the year. *Therefore, even with deficit rainfall by about 32 per cent, water crisis in drought prone Bundelkhand region can be averted by adopting agroforestry and watershed interventions as it will recharge the weathered zone by 86 per cent which will serve the purpose of drinking and irrigation*

Conclusion

The livelihood can be ensured in Bundelkhand region by improving different eco-system services through integrated watershed development interventions with major emphasis on woody perennials.

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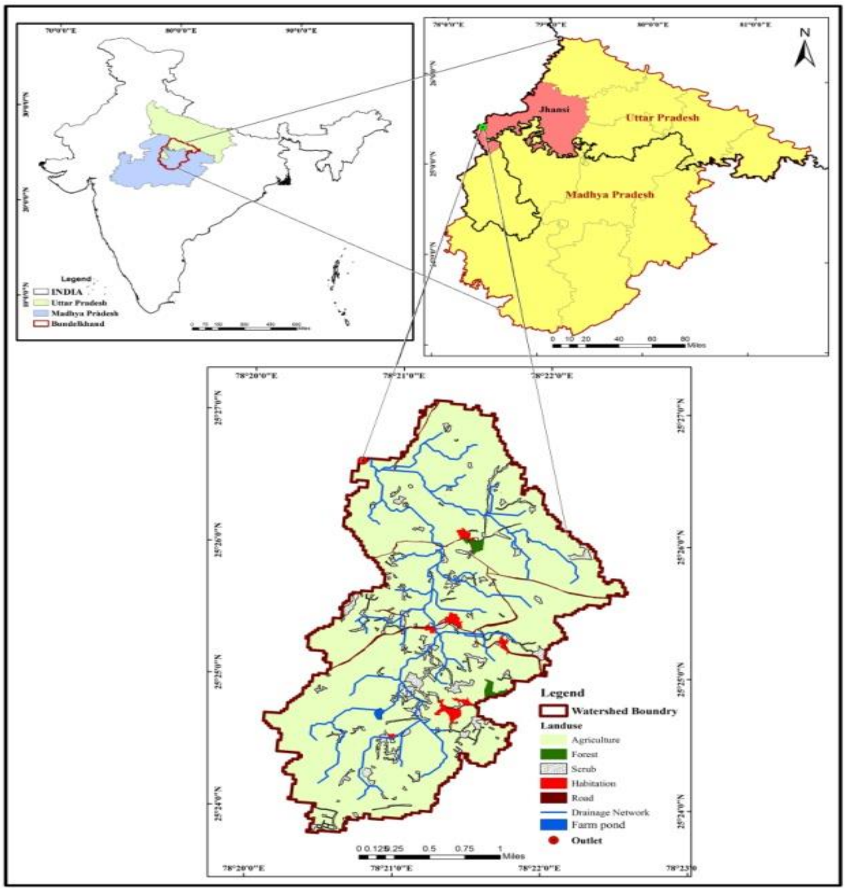


Figure 1: Location map of study Parasai – Sindh watershed

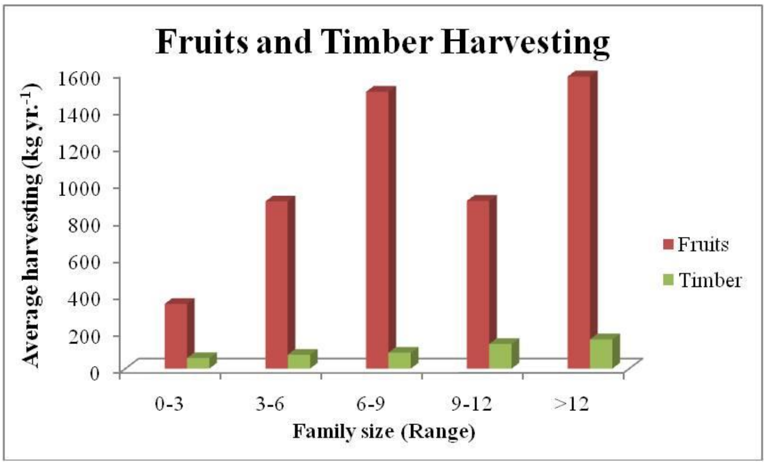


Figure 2: Harvesting of fruits and timber for households need

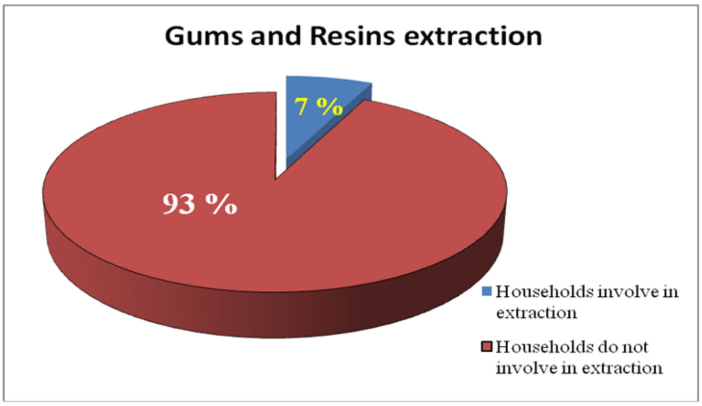


Figure 3: Percentage of total households of the Parasai- Sindh Watershed involve in Gums and Resins extraction from Acacia catechu

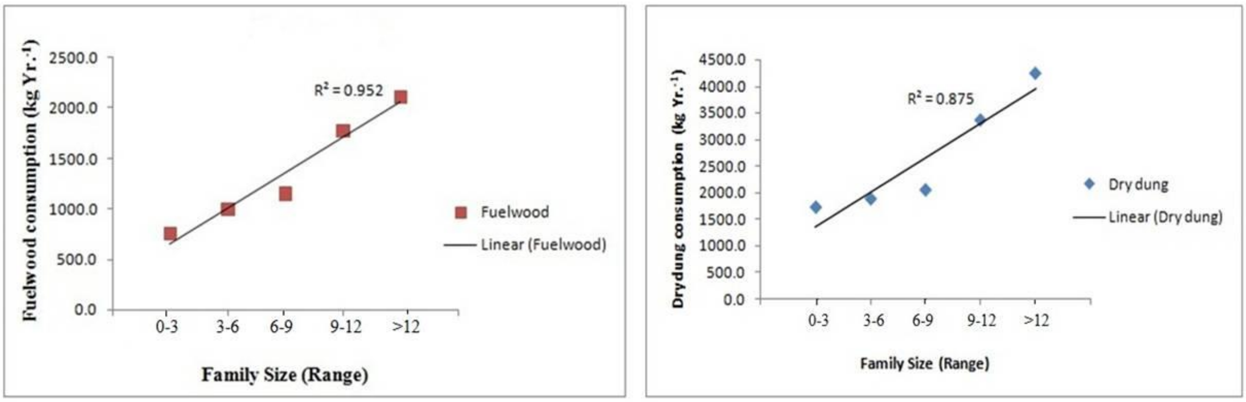


Figure 4: Consumption trends of fuelwood and dry dung in the different households of the village of Parasai-Sindh watershed

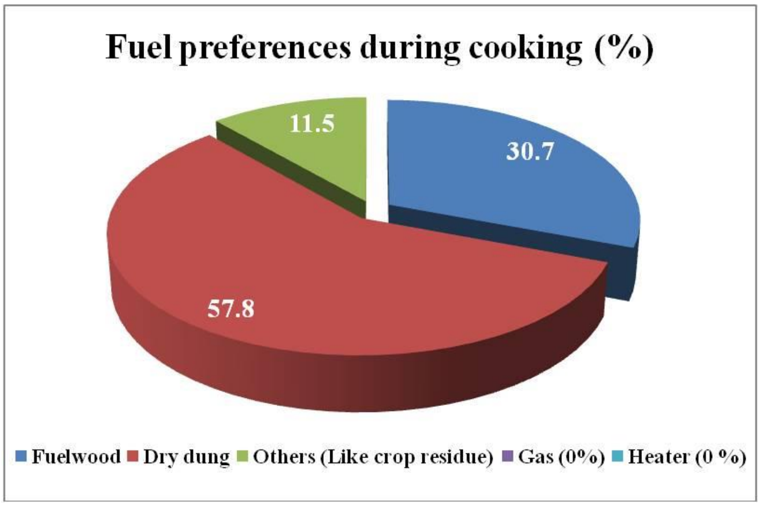


Figure 5: Fuel preferences scenerio for cooking in the different households of watershed
Fodder from trees

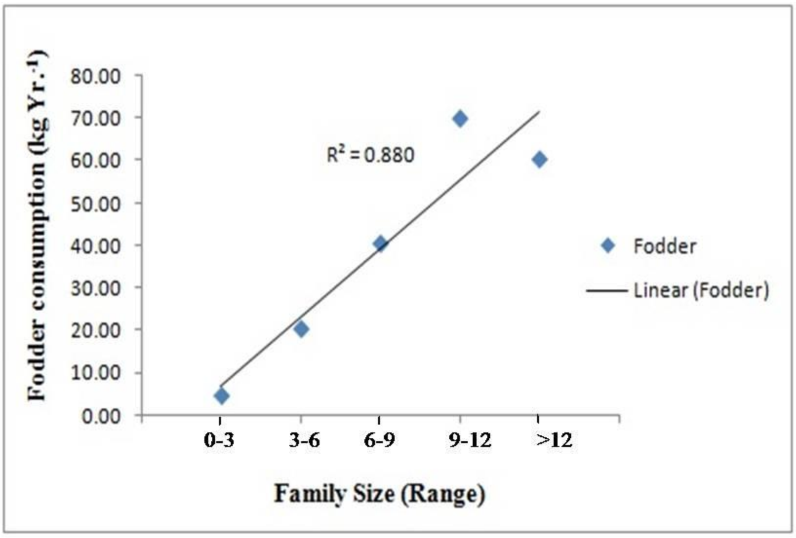


Figure 6: Consumption trend of fodder in different households of the village of Parasai- Sindh watershed

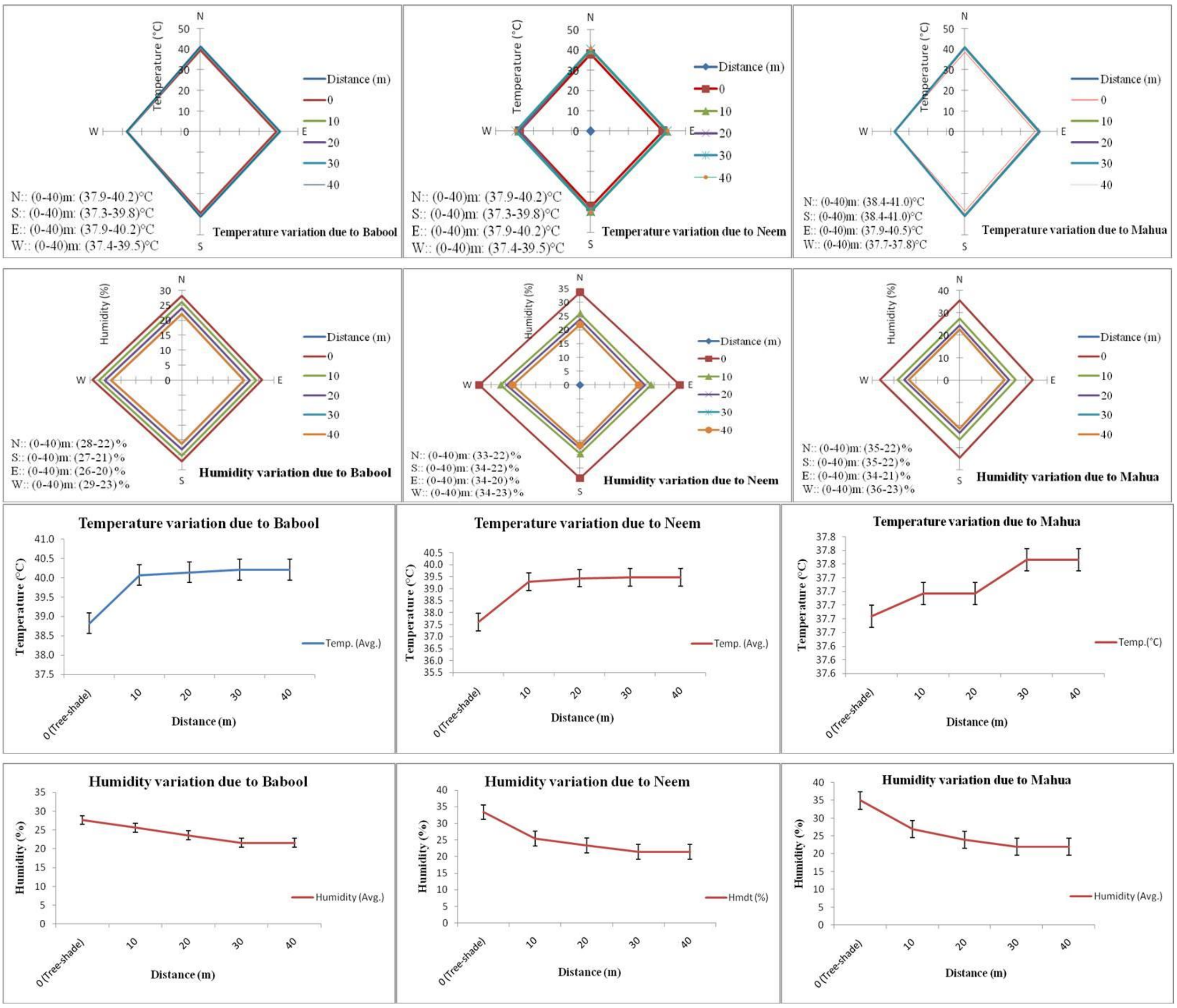


Figure 7: Effect of trees on temperature and along and across the distances from tree base

Visit to IGFRI and CAFRI Farm: Technology Development

CAFRI Team
CAFRI, Jhansi, India

ICAR-CAFRI Research Farm

Central Agroforestry Research Institute (CAFRI), erstwhile National Research Centre for Agroforestry (NRCAF) was established at Jhansi on 8th May, 1988 under the aegis of Indian Council of Agricultural Research (ICAR), New Delhi to cater to basic, strategic and applied research needs in the field of Agroforestry.

The Institute is having a total Research Farm area of 74 ha (67 ha- arable & 7 ha-rocky); Research farm possess seven shallow dug wells (3-5 m below ground). Cultivation is totally dependent on rainfall and operation of canal.

Field sites for visits:

- Development of Quality Planting Material for Agroforestry
- Hi-Tech Nursery for the Production of Quality Planting Material
- Development of Nursery of TBOs for Quality Planting Material Production
- Agroforestry based Integrated Farming System for small and marginal farmers in semi-arid region
- Relevance of soil and water conservation measures in enhancing productivity and sustainability of silvipastoral system in semi-arid conditions
- TBOs based Agroforestry models
- Agroforestry based conservation agriculture for sustainable landuse and improved productivity
- Structural and Functional Analysis of Short Rotation Tree Based Agroforestry System
- Evaluation and characterization of different leucaena germplasm at CAFRI, Jhansi
- Nutrient management in ber based agri-horti system
- Germplasm collection and evaluation of bamboo
- Aonla based Agroforestry system
- Neem (*Azadirachta indica* A. Juss), germplasm collection and evaluation
- Shisham (Dalbergia sissoo Roxb.) based Agroforestry system
- Harvest and post-harvest processing and value addition of natural resins, gums and gum resins
- Functional genomics for early drought tolerance in *Pongamia pinnata* genotypes

Differernt Agroforestry systems at ICAR-CAFRI Research Farm

ICAR-IGFRI Research Farm

ICAR-IGFRI, a national Institute is mandated to conduct basic, strategic, applied and adaptive research; development and training in forage production and it's utilization. IGFRI today stands as the premier R&D institution in South Asia for sustainable agriculture through quality forage production for improved animal productivity. The Indian Grassland and Fodder Research Institute, established in 1962, has been instrumental in fostering research, training and extension programmes on all aspects of forage production and utilization through inter-disciplinary approach. IGFRI has about 800 acres of research farm having various fodder crops and animal species.

Field sites for visits:

Technology Demonstration block

- Technology Demonstration block demonstrates all the technologies as live demonstrations unit at one place.

Plant genetic resources and genetic improvement of forage crops

- Enrichment, evaluation, conservation and documentation of genetic resources of fodder crops

Biotic and Abiotic stress management and climate resilient fodder production

- Flagship programme on "Livestock based Integrated Farming Systems for Sustainable Productivity and Income of Farmers in Semi-Arid region of Central India''
- ICAR-ICARDA collaborative project: Promoting cactus (*Opuntiaficus-indica*) as drought resilient feed resource under different agro-ecological production systems across India

Diversification and sustainable intensification of fodder production in different land use system including grasslands

- Silvipasture system for round the year top feed and fodder availability
- Evaluation of shrubs in *Hardwickia binata* based three tier silvopasture systems under semiarid rainfed situation
- Hortipastoral system for fruit and forage security in semi-arid condition
    - Aonla based hortipasture system
    - Guava based hortipasture system

Enhancing seed production, development of seed standards and study on seed biology

- Identification of physiological and harvesting maturity stage in dinanath and berseem crop

Nutritional evaluation of forage resources & improving crop - livestock production systems

- Long term effect of different grazing intensities on soil health and pasture-animal productivity
- Development of nutritionally balanced and economic feeding system for livestock through cereal-legume intercropping.

Mechanization & maximizing utilization, conservation and fortification of feed and fodder resources

- Design and development of tractor operated grass seed harvester
- Operational Research Project on feed and fodder products for commercialization and entrepreneurship development"

Social, economic, policy and translational research

- Livelihood improvement of farmers through quality seed production of fodder crops.

Agroforestry for Doubling Farmer's Income (DFI): a new initiative (visit to Lalitpur Watershed)

Inder Dev
CAFRI, Jhansi, India

Background

Bundelkhand region spread over 7.16 million ha in Central India between seven districts of U.P. (Jhansi, Jalaun, Lalitpur, Hamirpur, Mahoba, Banda and Chitrakoot) and six districts of M.P. (Sagar, Tikamgarh, Chhatarpur, Panna, Damoh and Datia) is resting on vast granite massif. The Bundelkhand region is prone to drought and is the hotspot of water scarcity, land degradation, poor productivity, poor permanent vegetal cover and miserable socio-economic status. The region has experienced severe drought during 2004 to 2007 and 2014 to 2017. More than 80% open wells dried up soon after monsoon season due to deficit rainfall and poor ground water recharge.

Keeping in view this background a project entitled, "Transforming rural livelihood through agroforestry based natural resource management in drought prone Bundelkhand region, UP" has been initiated in seven Bundelkhand region of U.P.

Pilot site

Need based interventions are being undertaken in identified villages of Lalitpur under Doubling Farmers' Income (DFI) project. The interventions are being executed by consortia of ICAR-CAFRI, Jhansi and ICRISAT, Hyderabad.

Activities being undertaken in the pilot site

a) Agroforestry

Undertaking tree plantation at farmers' fields/bunds under agroforestry for enhancing land and water use efficiency. (Note: Agroforestry interventions are being implemented at @ 100-150 ha per year in identified DFI villages).

The tree plantation under agroforestry at Lalitpur has been undertaken as following

i. Bund plantation: Teak (3 m spacing)
ii. Agri-horti system: Guava based AFS (8m x 6 m) ; Lemon based AFS (8m x 6 m)
iii. High density plantation: Guava based (3 m x 3m)
iv. Agroforestry for Nutritional security: Guava, Moringa, Lime, mango, Pomegranate
v. Live fencing: Live fencing of *Acacia senegal*

Table 1. Details of the tree plantation under Agroforestry at Lalitpur

Sr. No.	Fruit /Timber trees	Lalitpur (UP)
1.	Guava lalit	350
2.	Moringa	220
3.	Custard Apple	220

4.	Lime	500
5.	Mango	150
6.	Pomegranate	150
7.	*Acacia Senegal*	3314
8.	Teak	9000
	Total	**13904**

b) Water conservation and monitoring

- Field bunding and field channels for soil and water conservation
- Identifying potential locations for construction of rainwater harvesting structures
- Designing location specific RWHS based on hydrological assessment
- Construction of RWHS and establishing monitoring system

Note: Approximately 8-10 RWHS will be constructed in identified villages

Table 2: Water harvesting works completed at Lalitpur

District	**Village**	**Structures**
Lalitpur	Pura-birdha	2 *Haveli* tanks, 1 Large pond, 3 Field channels (450 m x 3 m x 1.2 m), 4 Farm pond (10 m x 10 m x 2.5 m)

Other interventions:

Soil health card distribution; crop demonstrations; laser levelling; Ber budding, Forage resource enhancement and livestock productivity improvement are some of the other interventions besides agroforestry and water harvesting work being undertaken in Lalitpur.

Agroforestry and water harvesting activities at village Birdha in Lalitpur district

Visit to Experimental Plots, Farmers' Fields at FCRI

FC & RI, Mettupalayam

International participants will be visiting the following experimental fields to learn to state of the art recent developments in the field of forestry and agroforestry. The participants of international training will be exposed to various experimental plots which include tree breeding and improvement trials, multifunctional agroforestry, precision silviculture and NTFP species evaluation trial.

Experimental Plots

i. Tree Breeding Experiments

The tree breeding experiments like seed sources evaluation programme, progeny and clonal tests of various industrial wood species like Casuarina, Malabar neem, Kadam, Silver oak, Acacia hybrid, Sterculia, Albizia, Red sanders, Shisham and Biofuel crop will be exposed during the visit. The process of selection and deployment in the varietal development will be shared.

ii. Multifunctional Agroforestry

The participants of the program will be exposed to the multifunctional agroforestry research experiments which includes industrial agroforestry, silviagriculture, silvihorticulture, climate resilient, alley cropping, silvipasture, protein bank, windbreaks and small farmer multifunctional agroforestry model. Various aspects of tree crop interactions and ecosystem services rendered by multifunctional agroforestry model will be briefed to the participants.

iii. Precision silviculture

The growing interests on plantation forestry have attracted precision silviculture towards increasing the productivity and profitability with judicial management of soil, water and genetic resources. Precision packages followed for most commercial industrial agroforestry tree species will be shown to the international participants to learn the approaches and methods.

iv. NTFP germplasm collection

The genetic resource of Non-Timber Forest Products will also be visited by the international participants to learn the production potential of non-timber forest product through plantation and agroforestry systems.

Hi-tech Nursery, Plywood, Other Wood-based Industries

FC & RI, Mettupalayam

Farmers Fields

The participants of international training will be taken to farmers fields which incorporate industrial agroforestry, silviagriculture and agroforestry based integrated farming system in order to witness the success of agroforestry in Tamil Nadu.

Hi-tech Nursery

The growing importance of mini clonal technology and the associated process of mass multiplication of superior clones will be given hands on training to the participants. The mother garden establishment, green house management, cutting preparation, hardening chamber management etc., will be highlighted during the training period. The consortium nursery who adopted the technology will be visited during this program.

Wood based industry

The success of agroforestry in India in general and in the state of Tamil Nadu in particular depends primarily on participation of wood based industries who extend price support system, ensure market mechanism and facilitates felling and transportation of farm grown trees. In this regard, the following consortium industries *viz.*, plywood industry, timber, match splints, packaging case, and value addition industries will be visited to learn the process of supply and value chain.

In a holistic perspective, the training period at Mettupalayam will be approached through experimental field visit, hands on training, industrial exposure coupled with experiences with members of the CIAF towards the successful implementation of agroforestry in Tamil Nadu in association with all levels of stakeholders.

AF 5 -- A Glimpse of Cultural History of India and Its Agriculture

Dilli Darshan - Cultural & Historical Heritage

Atul Dogra, Santosh Yadav, S K Dhyani
World Agroforestry (ICRAF), New Delhi

1 **Rashtrapati Bhawan**: The president's official residence built on Raisina Hill is strictly private. It is spread in 330 acres of land and has 340 rooms. There is a magnificent Durbar Hall, with its massive 8m dome and marble walls are used for formal ceremonies

2 **Baba Kharak Singh Marg**: This Street is renowned for handicrafts as it is the hub of handicraft emporiums. People from all parts of India and abroad come here to hunt for handicrafts at these emporiums. Prior to freedom, this road was known as Irwin Road, after Lord Irwin, the Viceroy of India.

3 **Gurudwara Bangla Sahib**: It is the most prominent Sikh gurdwara, known for its association with the eighth Sikh Guru, Guru Har Krishan. Gurdwara Bangla Sahib was originally a bungalow belonging to Raja Jai Singh, an Indian ruler in the seventeenth century, and was known as Jaisinghpura Palace. The eighth Sikh Guru, Guru Har Krishan resided here during his stay in Delhi in 1664. During that time, there was a smallpox and cholera epidemic, and Guru Har Krishan helped the suffering by giving aid and fresh water from the well at this house. Soon he too contracted the illness and eventually died on March 30, 1664. A small tank was later constructed by Raja Jai Singh over the well, its water is now revered as having healing properties and is taken by Sikhs throughout the world back to their homes.

4 **Red Fort**: Also known as 'Lal Quila' made of red sandstones, one of the most magnificent monuments in Delhi, built by Emperor Shah Jahan in 1639. The National Flag on Independence Day (August 15) is unfurled by the Prime Minister here.

5 **Rajghat:** A place where Mahatma Gandhi was cremated in the year 1948. The sprawling site on the banks of river Yamuna is marked by a brick platform flanked by an eternal flame, surrounded by lush green lawns and imposing boundary walls.

6 **National Gallery of Modern Art**: The former presidential palace of Maharaja of Jaipur was later transformed into National Gallery of Modern Art. It is situated at the eastern end of Rajpath near India Gate and is administered by the Government of India. Former Vice President of India, Dr. S. Radhakrishnan inaugurated the gallery in presence of Jawaharlal Nehru on March 29, 1954. The gallery has a wonderful collection of around 15,000 paintings, sculptures and works of arts by Indian as well as international artists. The National Gallery of Modern Art bears witness of the transition taken place in the field of art in last century. The gallery obtains, preserves and displays works of modern art from mid-19th century till date. Explore the history of Indian contemporary art through ages under one roof. It is a tribute to art in the nation.

7 **India Gate**: It is known as the war memorial arch 42 metre in height, built in honour of 90,000 Indian Soldiers who died in World War | with their names inscribed all over it. Beneath it burns an etrnal flame, the Amar Jyoti, as a tribute to these soldiers.

8 **Purana Qila**: This destination will transport you to 5000 years back in history of great Mughals and Afghans. In the city of Dinpanah, Refuge of the Faithful, Purana Qila stood with its royal might. It was started by Humayun in 1533 AD and was completed by the Afghan ruler Sher Shah in five years time. This monument is a perfect blend of Hindu elements with Muslim style of arches and domes. Simply said, the style of architecture of the Purana Qila can be considered as a secular architectural style.

9 **Humayun Tomb**: Like a true example of Mughal imperial architecture, your next destination has a royal aura about it. Humayun's Tomb was built by his widow Hamida Banu Begam, also known as Haji Begam in 1569 after his death in 1556. Mirak Mirza Ghiyath, a Persian, was the architect employed by Haji Begam for this tomb. It is considered as the first distinct example of proper Mughal style inspired by Persian architecture. The influence is evident as it was the first garden tomb built in the Indian Subcontinent. Humayun's Tomb was declared a UNESCO World Heritage Site in 1993.

10 **Lotus Temple**: It is situated on top of the Kalkaji hill in distinctive Baha'i House of Worship is shaped to form a Lotus of 45 petals in white marble and surrounded by a landscaped garden. People of all faiths are free to visit and pray in the temple.

11 **Embassy Lane (Drive Pass)**: An Embassy is the diplomatic representation of a country's government in another country. It transmits messages of its home government to the government of the host country and vice versa. It informs its home government about important political, social, economic, military and other events happening in the host country.

12 **Dilli Haat**: It's a treat for those who swear by traditional artisans and food. This place is bubbling with sheer energy of the visitors enjoying various craft products at 62+ stall and 25 + food stalls located within the complex. Craftsmen from different corners of India come over to showcase their products which are reasonably priced. Delhi Haat presents two passions in a platter- food joints and crafts market – both inspired from the village style.

13 **National Rail Museum**: The National Rail Museum is a museum which focuses on the rail heritage of India it opened on the 1 February 1977. It is located in over 10 acres of land with both indoor and outdoor exhibits. The most amazing feature of the rail museum that attracts the children as well as train buffs is the toy train that provides a joyful ride. The National Rail Museum is a highly informative place in Delhi that educates us of the history of railways in India.

14 **Nehru Museum**: Walk through the life our first Prime Minister Jawaharlal Nehru with the help of many precious moments captured on camera and original manuscripts. The Nehru Memorial Museum established in the memory of Jawaharlal Nehru (1889 – 1964) is located in the majestic Teen Murti House. It has four major constituents namely, a Memorial Museum, a Library on modern India, a Centre for Contemporary Studies and a Planetarium. Nehru's bedroom, the drawing-room and study have been preserved the

way they were in used. The Nehru Planetarium gives an overview of the Indian Space Program through interesting shows.

15 **Jantar Mantar**: Jantar Mantar will introduce you to ancient science in India. It is a remarkable structure built by Maharajah Jai Singh II of Jaipur between 1727 and 1734. The 5 astronomical observatories, each with a specialized function for astronomical measurement, have captivated the attention of architects, artists, and art historian's worldwide. It consists of fourteen geometric devices used for measuring time, forecasting weather changes, predicting behaviour of planets and finding extra-terrestrial altitude. Jantar Mantar is very popular among tourists and the people of Delhi. This structure shows the scientific acumen of ancient India.

16 **Qutub Minar**: This minaret stands at 278 ft. And has 5 distinct stories. Started by Qutub-ud- din-Aibak and completed by Firoz Shah Tughlaq in 1368, the minaret contains many ornamental inscriptions. One of the most popular items here is the fourth century Iron Pillar. This 7m high iron pillar was erected to commemorate Chandragupta Vikramaditya.

17 **Sarojini Nagar Market**: Its get fashionable clothes at affordable prices. Export-surplus garments as well as rejected export clothing come to this market at throwaway prices. That is why product of even reputed brands available here at cheap prices. But don't expect trial or changing rooms at street-side shops. Besides, use your art of haggling. The market remains closed on Mondays. There are different areas within the market. Babu Market houses several sweet shops. The many shoe shops in the vicinity of the market also catch the eye. Subzi Mundi offers the freshest and choicest fruits and fresh vegetables.

18 **National Museum**: The National Rail Museum is a museum which focuses on the rail heritage of India it opened on the 1 February 1977. It is located in over 10 acres of land with both indoor and outdoor exhibits. The most amazing feature of the rail museum that attracts the children as well as train buffs is the toy train that provides a joyful ride. The National Rail Museum is a highly informative place in Delhi that educates us of the history of railways in India.

Reference:

Delhi Tourism's Hop-On-Hop-Off (HOHO) Sightseeing Tours; http://hohodelhi.com/

Visit to NASC Museum: History of Agriculture

Raj Kumar
World Agroforestry (ICRAF), New Delhi
Email: r.kumar@cgair.org

National Agricultural Science (NASC) Museum

National Agricultural Science (NASC) Museum, situated in the National Agricultural Science Centre campus of ICAR in New Delhi, is the first of its kind in the country. Spread over a two story specially designed building of floor area of 23,000 sq ft, the museum portrays the development of agriculture in India since prehistoric time and the present state-of-the-art technology in agriculture in our country, with a futuristic projection.

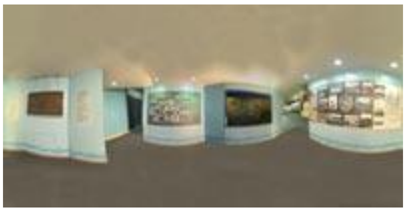
Agriculture and animal husbandry have been the backbone of Indian economy since prehistoric time. Even today, about 65% of the Indian population directly or indirectly lives on Agriculture. Agriculture has also shaped the literature, creed and culture of the Indian Society. The rich agricultural wealth of the country attracted hordes of migrants to arrive and settle in India.

Ancient literature and archaeological excavations have provided us with innumerable evidences of agricultural practices in ancient and medieval India. After Independence, utmost emphasis was laid on agriculture in the consecutive five-year plans. As a result, India achieved green revolution and self-sufficiency in food production. Today, we can not only feed a billion people, but also have enough potential to cope up with the future challenges. Thus, the story of agriculture is the story of Indian society. This story has been documented in a popular form at the National Agricultural Science Museum. The museum has 150 exhibits which are displayed in 10 major sections viz. Six Pillars of Agriculture, Agriculture in Prehistoric Era, Indus Valley Civilization, Vedic & Post Vedic Era, Sultnat & Mughal Era, Advent of British, Advancement of agricultural sciences in Independent India, Global Issues related to Agriculture, Towards a Food-Secure Future, and Children's Section.

General Information about the Museum

Address	:	**National Agricultural Science Museum** NASC Complex, Dev Prakash Shastri Marg Opp. Dasghara, Pusa Campus, New Delhi 110012
Timing	:	**10.30 A.M. to 04.30 P.M.**
Environment	:	Pollution free, spacious and full of greenery
Entry Fee	:	**Rs. 10 Per Individual**.
		Free entry for School, College students and Groups of farmers
Holiday	:	Mondays and National Holidays
Parking	:	Ample & Free
Telefax No.	:	**+91 11 25846375**

Pictures of different sections of Museum:

	
Introduction to National Agricultural Science Museum	Six Pillars of Agriculture
	
Prehistoric Man-hunter gatherer	The Trail of Human Development
	
Advent of Aryans	Agriculture during Vedic and Mogul Period
	
Agriculture during the British Period	About Indian Council of Agricultural Research
	
Domestication of Animals	Farm Mechanization
	
Information about Fisheries	Protected Cultivation

	
Green Revolution	Global Issues and Natural Disasters
	**Address** National Agricultural Science Museum NASC Complex, Dev Prakash Shastri Marg Opp. Dasghara, Pusa Campus, New Delhi 110012.
Children Section	

Visit to Jhansi Museum and Jhansi Fort- Cultural and Historical Glimpses

R P Dwivedi
CAFRI, Jhansi, India
Email: raghudwivedi66@gmail.com

JHANSI

Jhansi is the gateway to Bundelkhand a region rich in culture and heritage. Located centrally between the central, western and southern India the place used to be a stronghold of the Chandela kings. After losing its significance in the 12th century the kingdom in Jhansi rose again to prominence in the 17th century. However, its greatest claim to fame was under the rule of the legendary queen Rani Lakshmi Bai. Rani Lakshmi Bai along with Ghulam Gaus Khan, Jhalkari Bai and others led forces against the British rule during the revolt of 1857. She bravely died at the age of 22 years while fighting for India's freedom. Later, Chandra Shekhar Azad, Pandit Parmanand, Bhagwandas Mahaur and others lead the freedom movement from here.

Great writers like Acharya Mahavir Prasad Dwivedi, Maithilisharan Gupta, Vrindavan Lal Verma, Siyaramsharan Gupt and hockey wizard Dhyan Chand have added glory to the city.

GOVERNMENT MUSEUM, JHANSI

Weapons, statues, dresses and photographs that represent the Chandela dynasty and a picture gallery of the Gupta period are the highlights of the museum. An exclusive gallery on Rani Lakshmi Bai is a unique attraction.

The State Museum has a fine collection of terracotta, bronzes, Weapons, Sculptures, Manuscripts, Painting and Coins of Gold, Silver and Copper.

Timing: - 10:00 AM to 5:00 PM
Closed on Mondays and second Saturday of every month.

JHANSI FORT

In 17th century, this fort was built by King Bir Singh Judeo of Orchha on top of a hill as an army stronghold. The fort has been a witness to the fiery battle led by Rani Lakshmi Bai. There are temples of Lord Shiva and Lord Ganesha within the fort.
The fort has ten gates (Darwaza). Some of these are Khandero Gate, Datia Darwaza, Unnao gate, Jharna Gate, Lakshmi Gate, Sagar Gate, Orchha Gate, Sainyar Gate, Chand Gate.

Among places of interest within the main fort area are the Karak Bijli Toup (Tank or cannon), Rani Jhansi Garden, Lord Shiva and Lord Ganesh temples and a "Mazar" of Ghulam Gaus Khan, Moti Bai and Khuda Baksh.

The Jhansi fort, a living testimony of ancient glamour and valour, also has a fine collection of sculptures which provide an excellent inside into the eventful history of Bundelkhand.

Sound and Light Show at Jhansi Fort:

The sound and light show is organized in Jhansi Fort and is based on the life of Rani Lakshmi Bai and the First War of Independence in 1857.

Venue - Jhansi Fort
Fees - Rs. 50/- (Indian), Rs. 300/- (Foreigner)
Timings - 7.45 PM **Hindi** (April to October)
Timings - 8.45 PM **English** (April to October)

PALACE OF RANI LAKSHMI BAI
Rani Mahal, Palace of Rani Lakshmi Bai embellished with multi colored art and painting on its walls and ceilings. Presently this palace is converted into a museum. It has a massive collection of Sculptures of the period between the 9th and 12th Centuries AD, housed here by the Archaeological Survey of India

Visiting Hours: - Sunrise to Sunset

(Source: Department of Tourism, Government of Uttar Pradesh, INDIA)

Contact Details

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