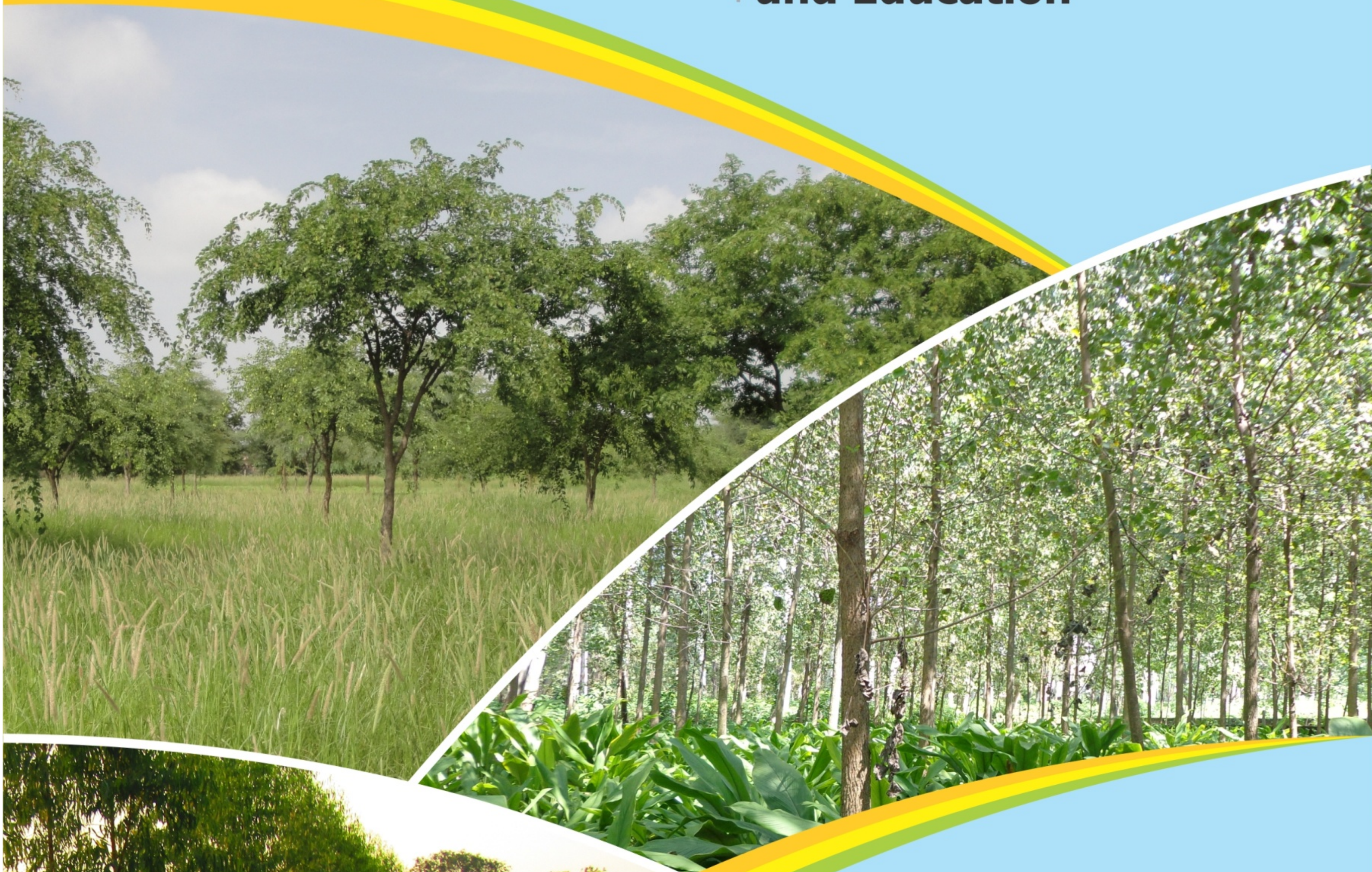
Agroforestry Models

Developed by Indian Council of Forestry Research and Education



Indian Council of Forestry Research and Education (ICFRE)
Dehradun, Uttarakhand

(An Autonomous body of Ministry of Environment, Forest and Climate Change, Government of India, New Delhi)

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Citation

ICFRE, 2020. Agroforestry Models Developed by Indian Council of Forestry Research and Education (A compilation)

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Published by
Indian Council of Forestry Research and Education,
P.O. New Forest, Dehradun- 248 006.

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Website: www.icfre.org

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Foreword

The practice of agroforestry is as simple as the term suggests. It is a system that combines agriculture and forestry in which trees or shrubs are grown around or among crops. Combining such agriculture and forestry technologies creates more bio-diverse, productive and sustainable land use system.

During the past three decades interest in agroforestry research, education, and training has increased substantially. Importance of agroforestry has been felt more during the last decade. In the scenario of climate change, perennial farming systems are considered more appropriate. Climate resilient and sustainable livelihood security has gained importance for poor, marginal and landless farmers in particular.

The benefits of agroforestry are already well known. Production of wood and other tree products for home and industrial consumption has increased. It contributes towards food security by restoring soil fertility, reduces deforestation and stabilizes the soil from erosion. Suitable combination of species enables agricultural land to withstand extreme events such as floods and droughts. It builds resilience of farmers and rural people against threats of climate change and natural calamities. For India, it is important for meeting the targets of increasing forest cover to 33 per cent as envisaged in the National Forest Policy, 1988 and reteriated subsequently in draft forest policy 2018.

India is the 1st country in the world which introduced a separate policy on agroforestry. The agroforestry policy aims at bringing coordination, convergence and synergy among various elements of agroforestry. It attempts improving the productivity; employment and livelihood opportunities to rural households, especially of the small land holder. The policy focuses on meeting the increasing demand of timber, food, fuel, fodder, fertilizer, fibre and other products.

Recent concerns such of ecosystem services, mitigating climate change, carbon sequestration, biodiversity conservation, value addition and role in health services through medicinal and aromatic plants are important contributions of agroforestry to the environment and livelihood.

Overall, agricultural ecosystem can further be improved through agroforestry to ensure environmental restoration, enhanced farm productivity, nutrient security and realization of ecological services for rural livelihoods.

This compilation gives details of the agroforestry models developed by ICFRE institutes in lucid manner. I appreciate the efforts made by the team for bringing out this publication.

Director General
ICFRE, Dehradun

Preface

The forest of India with a cover of about 23% of geographical area of the country is the most natural resource serving us economically, ecologically and socially. With changing era there has been a change in forest management approach. New draft Forest Policy 2018 aims to address the recent realities of climate change, human-animal conflict and declining green cover in addition to continuing focusing on the past efforts. It proposes public-private participation models for undertaking afforestation and reforestation activities in degraded forest areas, forest areas available with Forest Development Corporations and areas outside forests. Agroforestry still remains as essential tool for increasing the land cover of forest. Growth and innovation in agroforestry offers potential to improve farmland productivity, resilience and diversity, restoring soil health, creating wildlife habitats and sequestering carbon.

The Indian Council of Forestry Research and Education (ICFRE), Dehradun, is an apex body in National Forestry Research System to undertake need based futuristic forestry research to meet the emerging challenges in the field. The council has been undertaking research to resolve forestry research problems and extending the research outputs to various stakeholders like industry, State Forest Department and farmers etc. ICFRE released high yielding clones of *Eucalyptus camaldulensis*, *Eucalyptus teriticornis, Eucalyptus hybrid, Casuarina equisetifolia, Casuarina junghuhniana, Casuarina hybrid, Dalbergia sissoo, Melia dubia* and *Rauvolfia serpentina* and are in commercial production in the farmers' field now. Various institutes of ICFRE have developed best models, practices and benefits for agroforestry systems but the information is scattered and not easily available to those in need of it. The compilation "Agroforestry Models developed by Indian Council of Forestry Research and Education" gives details of the agroforestry models developed by ICFRE institutes. This compilation is an effort to fill the gap in accessing available knowledge. It brings together at one place the environment friendly agroforestry models that promise prosperity to the poor in different agro-ecological regions of India. This document will be of immense help to farmers, extension workers, researchers, teachers and students. It is also likely to bring more area under agroforestry for prosperity and climate regulations. At the end I acknowledge the efforts of Dr. Rajeshwar Rao, Director TFRI and his compilation team for bringing together the work on agroforestry models of all the ICFRE instituites in one draft. I also thank Dr. Vimal Kothiyal and his editorial team for reframing, editing and shaping this compilation.

Deputy Director General
(Research)
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Acknowledgement

While the potential of agroforestry in India is enormous, there are also challenges that must be met. Besides critical bottlenecks such as a shortage of quality planting material, unregulated nurseries, lack of credit and insurance for farmers, agroforestry lacked well documented examples of successful agroforestry systems that they could adopt or promote. Though research institutions have generated valuable data on best practices and benefits of several agroforestry systems, the desired information was not easily available to agroforestry practitioners and promoters. The editors of the new book set out to fill these gaps. The publication on "Agroforestry Models developed by ICFRE" will be useful not only for farmers but also for extensionists, researchers, research managers, teachers, students, agroforestry dependent industries and policy makers. The book showcases successful agroforestry models that promise prosperity to the poor in the various agro-ecological regions. The completion of this document could have not been possible without the participation and assistance of so many people whose names may not at all be enumerated. Their contributions are sincerely appreciated and gratefully acknowledged.

I am grateful to the Director General, Indian Council of Forestry Research and Education for his guidance, advice and encouragement in bringing out this compilation. I would like to express my sincere gratitude to the authors whose work has been quoted in the text of the book and in the reference section. I also thank DDG (Research), all Directors and respective scientist of ICFRE for their support in sharing the information on research work carried out on agroforestry models in their respective institutes. I also take this opportunity to thank all the team members, model developers and others who have contributed in compiling this book.

Assistant Director General
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Abbreviations

AFRI	Arid Forest Research Institute
AF	Agroforetsry
AFS	Agroforetsry System
AICRP-AF	All India Coordinated Research Project- Agroforetsry
B/C	Benefit/Cost
BAIF	Bharatiya Agro Industries Foundation
CAFRI	Central Agroforestry Research Insitute
DBH	Diameter at Breast Height
ETPs	Entire Transplants
FRI	Forest Research Institute
FRC-BR	Forest Research Centre for Bamboo & Rattan
FRC-CE	Forest Research Centre for Coastal Ecosystem
FRC-LE	Forest Research Centre for Livehood Extension
FRC-ER	Forest Research Centre for Eco-Rehabilitation
FRC-SD	Forest Research Centre for Skill Development
FSC	Forest Steward Council
FSI	Forest Survey of India
FYM	Farm Yard Manure
HFRI	Himalayan Forest Research Institute
ICAR	Indian Council for Agricultural Research
ICFRE	Indian Council of Forestry Research and Education
IFP	Institute of Forest Productivity
IFB	Institute of Forest Biodiversity
IFGTB	Instiute of Forest Genetics and Tree Breeding
IPCC	Intergovernmental Panel on Climate Change
IRR	Internal Rate of Return
IWST	Institute of Wood Science and Technology
MOP	Muriate of Potash
MPT	Multipurpose Tree
NABARD	National Bank for Agriculture and Rural Development
NAEB	National Afforestation and Eco-Development Board
NAP	National Agroforestry Policy
NDC	Nationally Determined Contribution
NFP	National Forest Policy
NGO	Non-Governmental Organization
NRCAF	National Research Centre for Agroforestry
RFRI	Rain Forest Research Institute
SDG	Sustainable Development Goal
SFDs	State Forest Departments
SSP	Single Superphosphate
TFRI	Tropical Forest Research Institute
TNAU	Tamil Nadu Agriculture University
UNFCCC	United Nations Framework Convention on Climate Change

Content

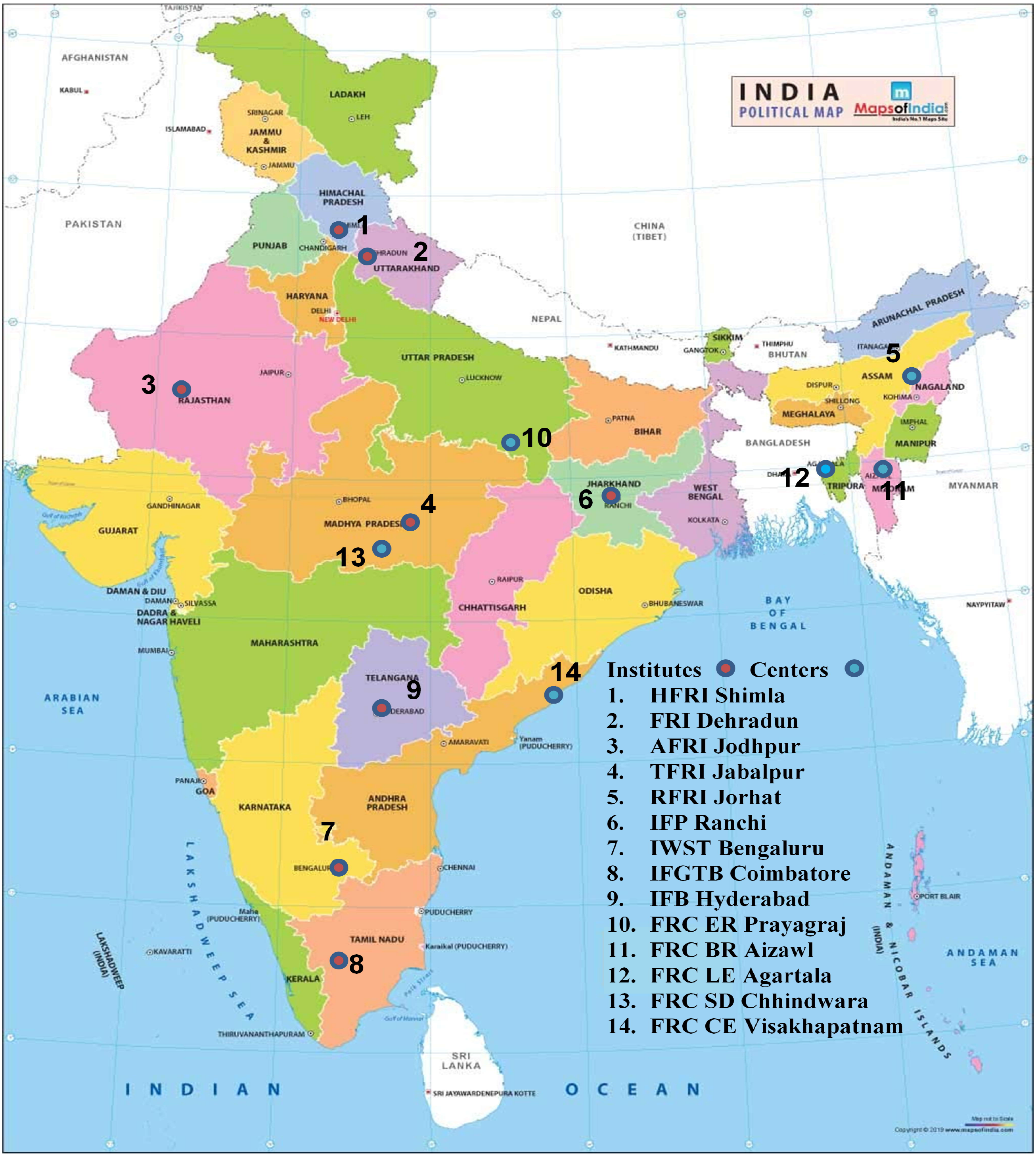
Summary

The agroforetsry system is being practiced by planting tree species with agricultural crop for enriching soil, enabling food security and maximizing economic return per unit area. Scientific interventions in agroforestry practices can enhance productivity and diversify the output. Since there is a limitation of plantation in natural forest, the targets of green cover can be achieved by encouraging plantation outside recorded forest areas particularly in agroforestry system. ICFRE with its nine research institutes and five advanced centers located all over the country is contributing towards long term sustainable development in the field of forestry research, education and extension covering all the aspects of forestry. It has made significant contribution to enhance the green cover of nation in forest landscapes as well as under agroforestry system in non-forest lands, increasing timber productivity through improved clonal plantation, enhancing conservation and sustainability of forest.

Research institutes of ICFRE does significant research in the field of agroforestry and the same has been demonstrated successfully in farmer's field for further expansion and adoption in a large scale. ICFRE institutes have developed improved germplasm of many forest tree species and has released 47 high performing and disease resistant clones and varieties of *Eucalyptus camaldulensis, Eucalyptus tereticornis*, *Eucalyptus hybrid, Casuarina equisetifolia, Casuarina junghuhniana*, *Casuarina hybrid, Dalbergia sissoo*, *Rauvolfia serpentina, Melia dubia*. These improved germplasm is being made available to the State Forest Departments and farmers for use in agroforestry plantations for increasing the productivity. ICFRE institutes have also developed package of practices of the above developed new clones/varieties in agroforestry model. These high yielding clones are not only productive but also have the potential to give additional income to farmers.

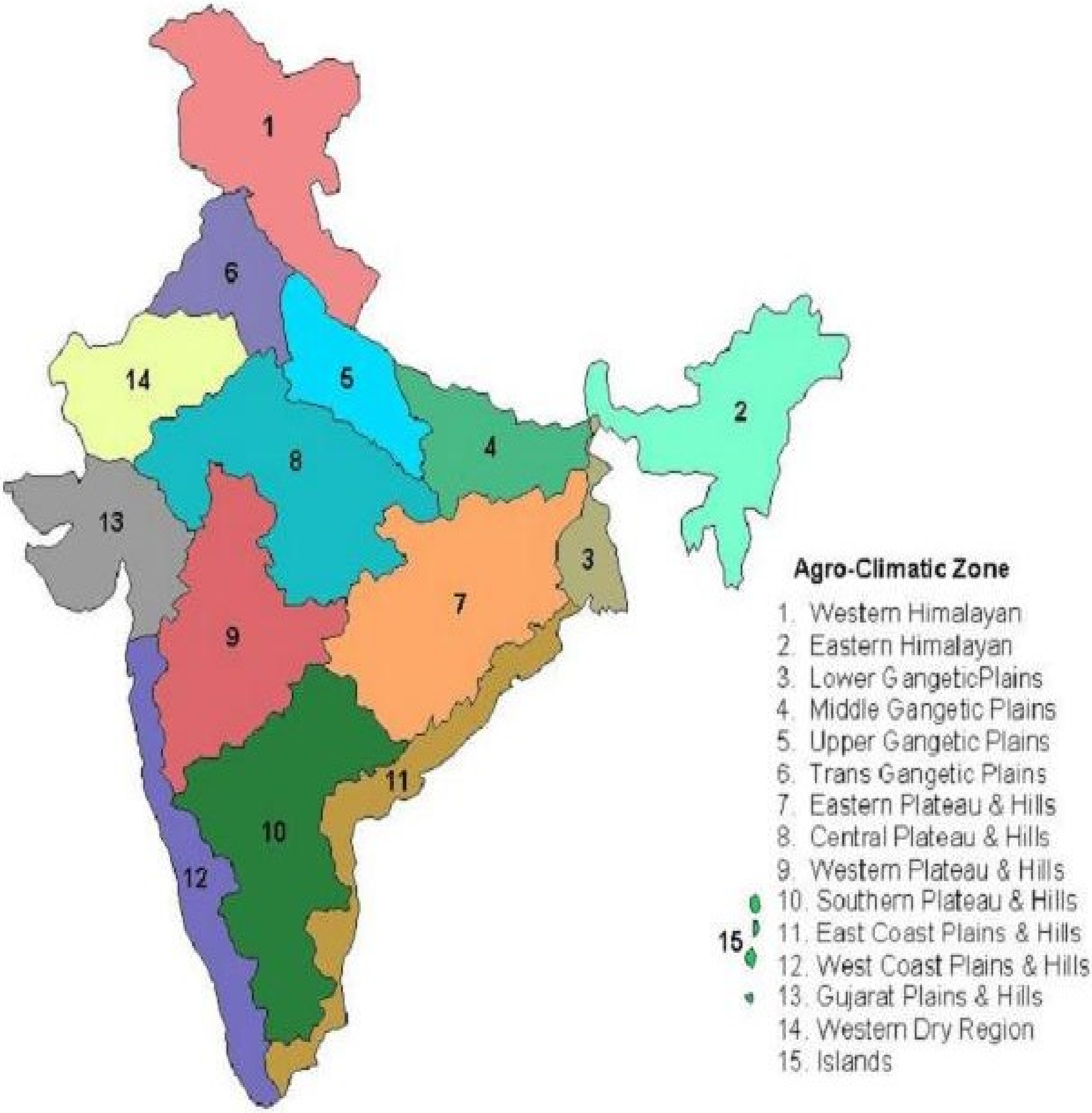
The agroforestry practices developed by ICFRE have been compiled and presented in form of a book "Agroforestry Models developed by Indian Council of Forestry Research and Education". This book especially talks about ICFRE intervention related with agroforestry models established with improved clones/varieties. It introduces the role of agroforestry in climate change mitigation, adaptation, sustainable development goals and its contribution in achieving SDGs. The book apprises ICAR contribution in developing agroforestry models and its profitability for farmers. Further the book provides comprehensive knowledge about the agroforestry models developed by ICFRE institutes in Trans Himalayan, Western Himalayan, Eastern Himalayan, Gangetic plains, Plateus, Western dry areas, Coastal plains and ghats. The way ahead reflects the focus of needed research in coming years in developing agroforestry system as a sustainable option for forest produce and addressing environmental concern. The government needs to build robust mechanism for ensuring that agroforestry is taken up by farmers and industries. The agroforestry entrepreneurial models are

evolved and price stabilization, economic incentives are maintained for benefit of farmers and other stakeholders. This document is an effort to impart synthesized information to the users such as to farmers, extension workers, researchers, teachers and students.



ICFRE Presence in the country

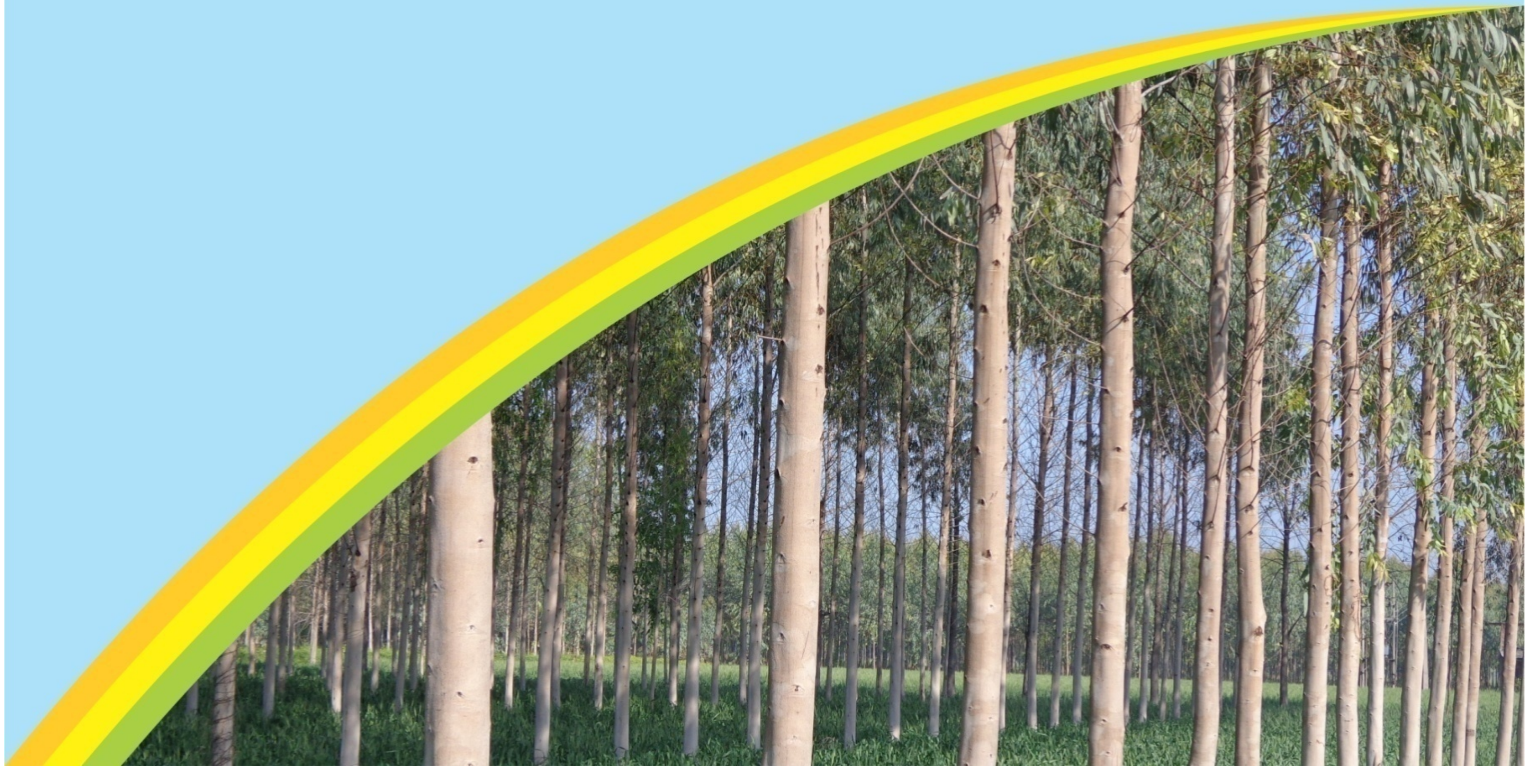
Agro-Climatic Zones of India



Source: https://vikaspedia.in/agriculture/crop-production/weather-information/agro-climatic-zones-in-india

Chapter 1

Introduction to Agroforestry



Introduction to Agroforestry

India's forest and tree cover is 8,07,267 square kilometers which is only 24.56 % of the India's geographical area (FSI Report 2019). The efforts are being made to achieve the national goal of 33% geographic area of the country under the forest and tree cover as enshrined in the National Forest Policy (NFP), 1988. The Ministry of Environment, Forest and Climate Change has framed a new draft of National Forest Policy in March, 2018. New draft Forest Policy 2018 aims to address the recent realities of climate change, human-animal conflict and declining green cover in addition to focusing on the past efforts. It aims to bring a minimum one-third of India's total geographical area under forest cover through scientific interventions and enforcing strict rules to protect the dense cover. It proposes public-private participation models for undertaking afforestation and reforestation activities in degraded forest areas, forest areas available with Forest Development Corporations and areas outside forests.

Our country has only 2.4% of the world's geographical area and 0.5% of the world's grazing area but supports over 16% of the world's human population and 18% of world's cattle population. This ever growing population puts massive demands and pressures on the land and forest resources. Agroforestry is the potential alternative choice for increasing the tree cover outside the notified forest areas to reduce the pressure on forest land. Moreover, agroforestry is the only viable option to achieve the 33% tree or green cover as mentioned in the NFP (1988).

Agroforestry has received much attention in India from researchers, policy makers and others for its perceived ability to contribute significantly to economic growth, poverty alleviation and environmental quality.Today agroforestry is an important part of the 'Evergreen Revolution' movement in the country. Over twenty five years of investments in research have clearly demonstrated the potential of agroforestry in many parts of the country and some practices have been widely adopted. But the vast potential remains largely under exploited and many technologies are yet to be widely adopted. Interplay of several complex factors, the understanding of the biophysical issues related to productivity, water-resource sharing, soil fertility, plant interactions in mixed communities is insufficient, mainly because of observational nature of research. Methods to value and assess the social, cultural, economic benefits (tangible and non tangible) of agroforestry are not available. The socio-economic processes involved in the success and failure of agroforestry have not been investigated properly. On the other hand, the success stories of wasteland reclamation by eucalyptus and poplar based agroforestry show that the technologies are widely adopted when their scientific principles are understood and socioeconomic benefits are convincing. It is crucial that progressive legal and institutional policies are created to eschew the historical dichotomy between agriculture and forestry and encourage integrated landuse systems.

1.1 Agroforestry

World Agroforestry Centre defines agroforestry as a collective landuse systems where woody perennials (trees, shrubs, palms, bamboos, etc.) are deliberately used on the same land management units as agricultural crops and/or animals in some form of spatial arrangement/temporal sequence (Nair *et al.,* 2008). In agroforestry systems there are both ecological and economical interactions between the different components. Traditionally people resorted to agroforestry practices for the interdependent benefits of the three components, *viz.* trees, crops and livestock in addition to food, fruit, fodder, fuel, fertilizer and fibre.

Agroforestry can also be defined as a dynamic and ecologically based natural resource management system that through the integration of trees on farms and in the agricultural landscape diversifies and sustains production for increased social, economic and environmental benefits for land users at all levels. In particular, agroforestry is crucial to small land holder farmers and other rural people as it can enhance their food supply, income and health. Agroforestry systems are multifunctional systems that provide a wide range of economic, socio-cultural and environmental benefits.

Agroforestry an age old practice is as an important form of subsistence farming. In the recent past it has been valued as a commercial and profitable landuse system across the world. Approximately, 1.2 billion people depend directly on agroforestry products and services in rural and urban areas of developing countries. These systems are superior to other land uses at the global, regional, watershed and farm scales as they optimize trade offs between increased food production, poverty alleviation and environmental conservation.

Agroforestry practices increase farm productivity, diversify income sources for farmers and offer unquantifiable environmental services. It improves soil, water, air quality and biodiversity while strengthening sustainable production of food, fibre and energy. IPCC's prediction of temperature increase between 1.1^{o} C to 6.2^{o} C by the end of the century due to excessive carbon dioxide emission will most likely create extreme changes in temperature and precipitation. Agroforestry gives an opportunity for sequestering more carbon per unit area and can be better address climate change mitigation than option provided ocean and other terrestrial ecosystems.

Agroforestry systems (AFS) are becoming more and more relevant due to their manifold roles. The initial emphasis of the research in AFS focused on AFS design, multipurpose tree species and their functions, products, and financial evaluations. Later, responding to increasing environmental and rural development issues worldwide, research focused to the challenges of alleviating poverty and improving food security. In the last decade emphasis has been on the role that AFS can play in adaptation to climate change and mitigation of greenhouse gas emissions through fixation of atmospheric carbon. Currently AFS are expected to achieve compromise among productive and environmental functions.

1.2 Agroforestry for climate change mitigation and adaptation

In India, average carbon sequestration potential in agroforestry has been estimated to be 25 t/ha over 96 million ha but it varied substantially by regions depending upon the production of biomass (Basu 2014). The role of trees outside forests in carbon balance has been considered only recently, reporting that trees outside forests in India store about 4 Mg C/ ha, in addition to the forests. The net annual carbon sequestration rates for fast growing short rotation agroforestry crops such as Poplar and Eucalyptus have been reported to be 8 Mg C/ha/yr and 6 Mg C ha/yr respectively.

The potential of agroforestry systems as carbon sink varies depending upon the type of species and its composition, age of trees, location, climatic and edaphic factors, and different management regimes. Agroforestry systems can sequester large amounts of above and below ground carbon compared to tree-less or pure agriculture farming systems (Handa *et al.,* 2015). As per FAO report on soil carbon sequestration, agroforestry for carbon sequestration is attractive due to following reasons (Lal 2011):

i. It sequesters carbon in vegetation and soil depending on the pre-conversion of soil.
ii. The more intensive use of the land for agricultural production reduces the need for slash and burn or shifting cultivation.
iii. The timber produced under agroforestry serve as substitute for timber/forest products unsustainably harvested from the natural forest.

1.3 Value chain in agroforestry

Agroforestry value chain involves activities such as harvesting, cleaning, transport, design, processing, production, transformation, packaging, marketing, distribution and support services. Such activities are important to add value to a product as it moves along the chain from the local to the global level (Haverhals *et al.,* 2014). Agroforestry provides ample opportunity for the bio-economy and for support of forest based industries, hence, play an important role in shifting India towards an innovative, resource efficient and bio-based economy.

In the agroforestry value chain, the roles and responsibilities of various institutions are dealt clearly to achieve the objectives. The main objective of the value chain in agroforestry is that research institutions will provide the quality planting materials with package of practices to the users especially to the farmers. The goal and objectives of the value chain in agroforestry are networking and establishing linkages with all stakeholders to augment the production to consumption system, promoting effective collaboration among public agencies, private industries and organizations engaged in industrial agroforestry. In addition to this other goals include developing suitable research and development (R&D) mechanism for industrial agroforestry and formulating policy guidelines for promotion of agroforestry among farmers.

1.4 Agroforestry System for Sustainable Development Goals (SDG)

NITI Aayog had constituted a task force on 3 January 2018 to develop a new business model to relieve farmers distress while implementing the pilot projects to demonstrate the doubling of farmers income. The key principle is to make the effort market driven, encourage the application of science and technology in agriculture production, minimize farmers' risks and be based on the use of modern business practices for value addition in agriculture sector.

The task force identified and studied existing successful business models in operation during the previous three to four years for upscaling based on four tiers for testing. Extensive consultations were held with the social entrepreneurs and other stakeholders from private sector for scaling up their successful models. The final draft has been submitted to the Chairman of the task force.

On September 25, 2015, a total of 17 Sustainable Development Goals (Anonymous 2015), also known as the Global Goals, were adopted as part of a new sustainable development agenda to be achieved over the next 15 years. The Sustainable Development Goals (SDGs) build on progress made toward the eight Millennium Development Goals from 1990 to 2015, and incorporate other emergent themes such as climate change, economic inequality, innovation, sustainable consumption, and peace/justice. The Sustainable Development Goals are unique because of the global nature of the goals. Because they are inclusive, their targets embrace ambitious objectives for nations often called "developed" in addition to "developing" countries, uniting countries in a global agenda.

The 17 Sustainable Development Goals are:

1. End poverty in all its forms everywhere,
2. End hunger, achieve food security and improved nutrition and promote sustainable agriculture,
3. Ensure healthy lives and promote well-being for all at all ages,
4. Ensure inclusive and quality education for all and promote lifelong learning,
5. Achieve gender equality and empower all women and girls,
6. Ensure access to water and sanitation for all,
7. Ensure access to affordable, reliable, sustainable, and modern energy for all,
8. Promote inclusive and sustainable economic growth, employment, and decent work for all,
9. Build resilient infrastructure, promote sustainable industrialization and foster innovation,
10. Reduce inequality within and among countries,
11. Make cities inclusive, safe, resilient, and sustainable,
12. Ensure sustainable consumption and production patterns,
13. Take urgent action to combat climate change and its impacts,
14. Conserve and sustainably use the oceans, seas, and marine resources,

15. Sustainably manage forests, combat desertification, halt and reverse land degradation, halt biodiversity loss,
16. Promote just, peaceful, and inclusive societies,
17. Revitalize the global partnership for sustainable development.

A glance at these goals can identify several SDGs where agroforestry can make a significant contribution like SDG 2 on hunger, SDG 5 on gender equality, SDG 6 on clean water, SDG 7 on affordable, clean energy, SDG 10 on reducing inequalities within and among countries, SDG 13 on climate action, and SDG 15 on sustainable forestry and restoration. However, because of the inter-connected nature of the SDGs, agroforestry systems make contributions to achieving an even wider range of goals than immediately apparent, including SDG 1 on poverty, and SDG 3 on good health and wellbeing.

1.5 Agroforestry systems contribution in achieving the SDG

With current growth of human population, land productivity in agriculture and forestry has to be increased. The sum of areas needed to achieve the SDGs at current production levels exceeds what is available on the globe, if calculations are based on monocultures (Van Noordwijk *et al.,* 2015). As a system that integrates land uses, agroforestry can offer a range of goods, benefits, and services along with providing nutritious food, renewable energy, and clean water, while conserving biodiversity. By allowing efficient, multifunctional land use (with a Land Equivalent Ratio > 1) agroforestry supports "sustainable intensification" (Roshetko *et al.,* 2008; Leakey *et al.,* 2012; Colfer *et al.,* 2015; Van Noordwijk *et al.,* 2015). In addition, the historical and current way of segregating forest land from agrarian communities leads to conflicts that reduce land productivity and increase inequity. Development challenges are in part the result of the sectoral (compartmentalized) approach that dominates government systems which tends to attribute the SDG to separate conventions and Ministries (Van Noordwijk *et al.,* 2015). Again, agroforestry can help as an institutional response to contested resource access, and can allow for gender and social equity enhancement as well as be a source of empowerment. Finally, agroforestry, as an integrative mindset and culture, can help create synergies between the SDG in multifunctional landscapes, developing innovative partnerships in pursuit of the goals as encouraged by SDG 17 (Roshetko *et al.,* 2008; Leakey *et al.,* 2012; Colfer *et al.,* 2015; Van Noordwijk *et al.,* 2015).

1.6 Nationally Determined Contributions (NDC) targets and Agroforestry

Since, the Paris Agreement of 2015, Nationally Determined Contributions (NDC) represent the main instrument for defining, communicating and potentially reporting contributions of countries to long-term climate goals of the UNFCCC. The NDC represent a process of prioritization in which countries consider options and possible scope for contributing to global climate mitigation objectives and increasingly, adaptation objectives beyond 2020. NDC cover most of the possible emission reduction pathways and sectors from energy, transport, industry, through land use and land use changes including agriculture and forestry among others. Depending on the circumstances, mainly the sources of emissions and opportunities for emission reduction and resources, countries choose and prioritize different sectors. Most parties to the UNFCCC have already submitted NDC.

Agroforestry is one of the lands uses with most potential to fulfill commitments set out in NDC. Over 85% of the 22 NDC assessed, mentioned agroforestry as a strategy for achieving unconditional NDC commitments. The widespread use of agroforestry alongwith familiarity of smallholder farmers and local practitioners make it a potential low hanging fruit for achieving NDC commitments. Devising policy instruments that clarify tree tenure and carbon rights are fundamental to motivate local actors to implement agroforestry. Research should continue to provide technical and policy guidance on a number of issues needed for the advancement of agroforestry in NDC, including, among others, domestication of potential tree species, improved germplasm, potential impacts of climate change on the growing niches of tree species and more, capacity building and dynamic partnerships would be needed to overcome technological and investment challenges.

Emissions from agricultural lands have shown a rapid increse due to use of chemical fertilizers and unsustainable land use practices in developing countries. Therefore, developing countries NDC tend to prioritize agriculture and forestry or land use and land use change in general. Agroforestry has been identified as a key strategic dimension of many developing countries NDC, hence a potentially significant contributor to global climate change objectives. Agroforestry, defined as the integration of trees into farms and their management in agricultural landscapes, can help in emission reduction and carbon neutrality in agriculture in several ways. First, through carbon sequestration as trees grow; second, by substituting conventional fertilizer through nitrogen fixation and soil fertility enhancement. Indirectly, agroforestry could help reduce emissions from adjacent forests as sustainable intensification option and by providing on farm timber and tree products, avoided degradation (Minang *et al.,* 2014, Mbow *et al.,* 2014).

1.7 National Agroforestry Policy (NAP) 2014

The content of the National Agrofrestry Policy 2014 is reproduced below:
In absence of a dedicated and focused national policy and a suitable institutional mechanism major policy initiatives including the National Forest Policy 1988, National Agriculture Policy 2000, Planning Commission Task Force on Greening India 2001, National Bamboo Mission 2006, National Policy on Farmers 2007 and Green India Mission 2010 emphasize the role of agroforestry for efficient nutrient cycling, organic matter addition for sustainable agriculture and for improving vegetation cover. However, agroforestry has not gained the desired importance as a resource development tool due to various factors. Some of these factors include restrictive legal provisions for harvesting and transportation of

trees planted on farmlands, use of non-timber produce, non-existent extension mechanisms, lack of institutional support mechanisms, and lack of quality planting materials.Inadequate research on agroforestry models suitable across various ecological regions of the country, inadequate marketing infrastructure, inadequate price discovery mechanisms and lack of post- harvest processing technologies are also the reasons for stunted growth of agroforestry. This is also due to the fact that the mandate of agroforestry falls through the cracks in various ministries, departments, agencies, state governments. The value and position of agroforestry is ambiguous and undervalued, and despite of its numerous benefits. It is only sporadically mentioned at the national level because of the lack of appropriate public policy support. While there are many schemes dealing with tree planting / agroforestry, there is an absence of a dedicated and focused policy, and lack of an institutional mechanism for coordination and convergence among the schemes/ ministries to pursue agroforestry in a systematic manner.

The lack of policy initiatives and strict trade regulations restricted the growth of commercial agraoforerty. Agroforestry models developed in different parts of the country could not contribute significantly due to the absence of clear-cut mechanism from seed procurement to marketing of the products. In this context, the National Agroforestry Policy, 2014 came in limelight to address the issues of quality planting material, tree insurance, restrictions on transit, marketing of agroforestry produce, research and extension. Considering the importance of agroforestry in the ecology and economy of the country, National Forest Policy 2014 was drawn by Ministry of Agriculture, Govt. of India.

India is the 1st country in the world to introduce separate policy for 'Agroforestry'.The policy aims to bring coordination, convergence and synergy among various elements of agroforestry scattered in various existing missions, programme, and schemes. Thus improving the productivity; employment, income and livelihood opportunities of rural households, especially of the smallholder farmers along with meeting the ever increasing demand of timber, food, fuel, fodder, fertilizer, fibre, and other agroforestry products. Moreover, agroforestry is the only viable option to achieve the 33% of green cover as per the National Forest Policy (1988). In the present day context, considerable funding is required on agroforestry projects to enhance productivity and sustainability of smallholders' agroforestry.

The new policy talks of coordination, convergence and synergy between various elements of agroforestry, scattered across various existing missions, programme and schemes under different ministries; agriculture, rural development and environment. The policy also talks of amending unfavorable legislation and simplifying regulations relating to forestry and agriculture.

Agroforestry is receiving long overdue attention as an alternative land-use practice that is resource efficient and environmentally friendly. Multiple outputs and the flexibility of having several options for management make agroforestry an attractive alternative to conventional agriculture and forestry for landowners in many parts of both temperate and tropical regions of the world. Although design of these integrated tree–crop and/or tree-crop-livestock systems can be flexible in order to meet the different objectives or constraints of farmers or landowners, there are many obstacles, in both ecological and economic terms, to overcome to make them attractive to landowners.

The acceptability of agroforestry systems by landowners would be improved if interactions that exist between trees, crops, and/or livestock remain largely beneficial so that productivity per unit area of land is increased while reducing environmental risks associated with mono-cultural systems. However, this is not an easy task.

Chapter 2

ICAR Contribution in developing Agroforestry Models

ICAR Contribution in developing Agroforestry Models

The organized efforts by the Indian Council of Agricultural Research (ICAR) began in 1983 with the establishment of All India Coordinated Research Project on Agroforestry (AICRP-AF 1983) and later the establishment of the National Research Centre for Agroforestry (NRCAF, 1988), which has now been upgraded as the Central Agroforestry Research Institute (CAFRI, 2014) Jhansi. These efforts resulted in collection and evaluation of germplasm of multipurpose tree species and development of location specific agroforestry technology for different agro-climatic zones of the country such as *Grewia optiva* and *Morus alba* based system for the Himalayan zone; poplar-based system for the Indo-Gangetic plains; *Hardwickia binata* and *Ailanthus excels* based system for arid and semi-arid zones; *Acacia mangium* and *Gmelina arborea* based system for humid and sub-humid zones and *Tectona grandis* based system for tropical zone. There are number of studies from different parts of the country suggesting that agroforestry is more profitable to farmers than practicing pure agriculture or forestry. A comprehensive analysis indicated economic viability with internal rate of return (IRR) ranging from 25% to 68% and B (benefit)/C (cost) ratio of 1.01 to 4.17 for 24 agroforestry systems from different agroclimatic regions of the country.

Agroforestry models adopted by farmers in the upper Gangetic region especially in Haryana, Punjab and Western Uttar Pradesh are highly lucrative, thus attracting farmers in a big way. In these areas poplar planted on agricultural fields and field boundaries is harvested at 6 to 8 years rotation. The average economic return of poplar based agroforestry systems is higher than compared to that mono agriculture crop (Chavan *et al.,* 2015). Newaj and Rai (2005) analysed 13 years Aonla based agroforestry system in marginal lands under rainfed conditions and found a B/C ratio of 3.28, which indicated its profitability. Similarly, there are number of studies indicating profitability of the other agroforestry based systems. However, in most of the economic analysis of agroforestry systems, attempts have been made for accounting only the cost of inputs and outputs in material terms.

2.1 Wadi model

A livelihood programme named Wadi was initiated by Bharatiya Agro Industries Foundation (BAIF), a development research foundation in Gujarat. This was further expanded to different tribal regions of India. It is an agri-horti-silvi model spread over Maharashtra, Gujarat, Karnataka, Uttar Pradesh, Uttarakhand, Rajasthan, Madhya Pradesh, Chhattisgarh, Bihar, Andhra Pradesh and Jharkhand. So far, BAIF has assisted over 1.81 lakh families to establish 68,586 ha wadi. This concept is a comprehensive programme for natural resource management, adoption of sustainable farming practices to uplifts the rural communities and providing livelihood security (www.baifwadi.org).

2.2 Lok Vaniki in Madhya Pradesh- A scheme for management of private forest

This scheme was launched in 1999 for promotion of scientific management of degraded forest on private lands by farmers that will act as a vehicle for providing employment opportunities, ecological and economic development and poverty alleviation. Initially this scheme was implemented in four districts, and later extended to 10 districts, now it covers 45 districts of Madhya Pradesh. Under this scheme, foresters were engaged to prepare separate management plans. As of now 749 management plans have been prepared out of which 613 have been sanctioned by competent authorities. More than 23,707 farmers have been sensitized by conducting training, workshops, conferences and study tours. For example, in Hosangabad district, a farmer gets an annual income of Rs 97,705 in 3.05 ha area. In addition, quality planting material is being supplied. Lok Vaniki Kisan Sangh, a voluntary society of tree growers has attempted certification of timber produce by Forest Steward Council (FSC) (Chavan *et al.,* 2015, mpforest.org/lokvaniki.html).

2.3 Contract farming model in Tamil Nadu

Tamil Nadu Agricultural University (TNAU), Coimbatore has demonstrated contract farming based industrial agroforestry using tripartite and quadpartite model involving industries, farmers, researchers and financial institutions. Credit facilities are provided to the farmers at the rate of Rs 15,000 to 20,000 per acre. Industry supplies quality planting material at subsidized rate and assures prevailing market price. The farmer assures end product (timber) to contracting industry whereas research institutes advice on site-specific technology. TNAU has produced quality planting material and supplied to farmers at free of cost in five districts of Tamil Nadu using short rotation clones such as *Eucalyptus* (MTP 1), *Casuarina equisetifolia* (MTP 1 and 2), *Melia dubia* (MTP 1) and Subabul (*Leucaena leucocephala*) etc. (www.fcrinaip.org).

2.4 Agroforestry Models Developed by ICAR Institutes/Universities as per agroclimatic Zones: Some of the models developed by ICAR institutes are given as example below:

2.4.1 HIMALAYAN REGION

i. Vegetable based agri-silviculture system in sub temperate rainfed region of Himachal Pradesh
ii. Alley cropping system integrating Elm (*Ulmus wallichiana*) with kharif and rabi crops in Kashmir valley Apple (*Pyrus malus*) based horti-agri-pasture system under temperate conditions of Kashmir valley
iii. Jackfruit (*Artocarpus heterophyllus*) based agroforestry system
iv. Tree crops interaction studies in *Acacia mangium* based agri silvicultural system in Assam
v. Morus (*Morus alba*) based silvi-pastoral system in mid-hills of North Western Himalaya

2.4.2 INDO-GANGETIC REGION

i. Poplar (*Populus deltoides)* based agroforestry system (poplar + summer and winter intercrops)
ii. Bamboo based agri-silvicultural system for tarai and North-Western Himalaya region of Uttarakhand
iii. Poplar (*Populus deltoides)* based agrisilviculture system in Uttarakhand
iv. Eucalyptus (*Eucalyptus tereticornis)* based agrisilviculture system in Uttarakhand
v. Aonla (*Emblica officinalis*) based agri-horticultural system in North Western alluvial plain of Bihar
vi. Litchi (*Litchi chinensis*) based agri-horticultural system in North Western alluvial plain of Bihar
vii. *Casuarina equisetifolia-Dalbergia sissoo* based agri-silviculture system
viii. *Dalbergia sissoo* based silvi-pastoral system on sodic land

2.4.3 HUMID AND SUB-HUMID REGION

i. Mango (*Mangifera indica*)-Eucalyptus (*E. tereticornis*) based agri-horti-silvi system in Red and Lateritic Zone of West Bengal
ii. Mango (*Mangifera indica*)-Gamhar (*Gmelina arborea*) based agri-horti-silvi system in Red and Lateritic Zone of West Bengal
iii. Mango (*Mangifera indica*)-*Dysoxylum binectariferum* as boundary plantation based agri-hortisilvi system in new alluvial zone of West Bengal
iv. Guava *(Psidium guajava*) based agri-horti system in new alluvial zone of West Bengal
v. Ber (*Zizyphus mauritiana)* based agri-horti system in new alluvial zone of West Bengal
vi. Homestead Agroforestry in West Bengal
vii. *Acacia mangium* based agri-silvicultural system
viii. Gmelina (*Gmelina arborea)* based agroforestry system
ix. *Cassia siamia* based agri-silvicultural system
x. Subabool (*Leucaena leucocephala*) based agri-silvicultural system
xi. Bamboo based agroforestry system

2.4.4 ARID AND SEMI-ARID REGION

i. *Ailanthus excelsa* based agri-silviculture system under rainfed conditions of North Gujarat
ii. Aonla (*Emblica officinalis*) based agroforestry
iii. *Dichrostachys cinerea* (nutans) based silvipasture model for degraded wasteland or pasture land
iv. Aonla (*Emblica officinalis*) based agri-horti model
v. Poplar (*Populus deltoides)* based agroforestry system in Haryana
vi. Teak (*Tectona grandis*) based agroforestry systems
vii. Tamarind (*Tamarindus indica*) based agri-horticulture system
viii. Pongamia (*Pongamia pinnata*) based agri-silvi culture

ix. Pearl millet (*Pennisetum typhoides*)-Pongamia (*Pongamia pinnata*) based agri-silvi culture in marginal lands
x. Finger millet (*Eleusine coracana*)-*Melia azedarach* based agri- silvi system in marginal lands
xi. Eucalyptus (*Eucalyptus tereticornis*) based agri-silviculture system
xii. Guava *(Psidium guajava*) based agri-horticulture system in central India
xiii. Aonla (*Emblica officinalis*)-Bael (*Aegle marmelos*) based horti-medicinal system in central India
xiv. *Dalbergia sissoo*-Paddy (*Oryza sativa*)-Wheat (*Triticum aestivum*) based agri-silviculture System

2.4.5 TROPICAL REGION

i. Sapota (*Manilkara zapota*)-Teak (*Tectona grandis*) based agroforestry system for Karnataka
ii. Teak (*Tectona grandis*) based agroforestry system
iii. Melia (*Melia azedarach*) based agroforestry system
iv. Calliandra (*Calliandra haematocephala*) and mulberry based hedge row fodder production systems in coconut (*Cocos nucifera*) gardens of Kerala
v. Mango (*Mangifera indica*) based horti-agricultural system in Konkan region
vi. Cashew (*Anacardium occidentale*) based horti-agricultural system in Konkan region
vii. Coconut (*Cocus nucifera*)-Guava (*Psidium guajava*)-Mango (*Mangifera indica*) for North Eastern agro-climatic zone of Tamil Nadu
viii. Tree Borne Oil seeds (TBO's) based agroforestry system
ix. Dry land orchard fruit crop based agroforestry system
x. *Melia dubia* based agroforestry system

2.5 Factors hindering farmers to take up agroforestry

Based on several studies carried out on various aspects of agroforestry over the past three decades it has been concluded that a number of socio-economic factors like land holdings, land size, gender, marketing aspects, policy, rules and regulation regarding felling of trees and transportation, lack of availability of quality planting material, source of information, level of education, age of farmers have impact on agroforestry. For full adoption of all recommended agroforestry practices it is advised to intensify extension services and training programmes so that farmers could motivate themselves to adopt all the latest trends of agroforestry practices. It is important that proper market facility, complete freedom to farmers for harvesting and transporting their tree crop to the market are some of the majors to be taken up for promoting agroforestry.

Chapter 3

Role of ICFRE in promotion of Agroforestry

Role of ICFRE in promotion of Agroforestry

In 1986, the Indian Council of Forestry Research and Education (ICFRE) was formed as an umbrella organization for taking care of forestry research, education and extension needs of the country. The main objective of the council was to provide technical assistance to states, wood based industries, tree growers, farmers and others in forest protection, afforestation, agroforestry and allied activities. The institutes of ICFRE have done significant research in the field of agroforestry and the same has been demonstrated successfully in farmers field for further expansion and adoption in a large scale. The technical knowledge produced by ICFRE to utilize the Multi Purpose Trees in agroforestry systems has made it an attractive option for State Forest Departments, NGOs and farmers. The agroforetry models developed by institutes of ICFRE are listed as below.

3.1 Agroforestry models developed by ICFRE for various agro-climatic zones of India

3.1.1 Trans Himalayan Region

The models for this region were developed by Himalayan Forest Research Institute (HFRI), Shimla. It covers the areas of Ladakh, Lahaul-Spiti and Kinnaur (Himachal Pradesh)

i. Salix (*Salix fragilis* and *S. alba*) and poplar (*P. euphratica, P. alba, P. nigra*) based agroforestry model
ii. Apple (*Pyrus malus*) based horti-medicinal model

3.1.2 Western Himalayan Region and Indo-gangetic Plains

The models for this region were developed by Forest Research Institute (FRI), Dehradun. It covers the areas of Jammu, Kashmir, Himachal Pradesh, Punjab, Haryana and the hilly region of Uttarakhand

i. Melia (*Melia composita)*-Aonla (*Emblica officinalis*) based agri-silvi-medicinal model
ii. Poplar (*Populus deltoides*) based agri-silviculture
iii. Poplar (*Populus deltoides)* based silviculture-medicinal models
iv. Melia (*Melia composita)* based agri-silviculture model
v. Eucalyptus (*Eucalyptus teriticornis*)-Wheat (*Triticum aestivum*)/Paddy (*Oryza sativa*) silvi-block model
vi. Poplar (*Populus deltoides*)-Wheat (*Triticum aestivum*) agroforestry model

3.1.3 Eastern Himalayan Region

The models for this region were developed by Rain Forest Research Institute (RFRI) Jorhat. The Eastern Himalayan region includes Arunachal Pradesh, hills of Assam, Sikkim, Meghalaya, Nagaland, Manipur, Mizoram, Tripura, and Darjeeling district of West Bengal.

i. King chilli (*Capsicum annuum*)-Arecanut (*Areca catechu*) based horti-spice model
ii. Gmelina (*Gmelina arborea*) based agri-silvi agroforestry model

3.1.4 Gangetic Plain Region

The models for this region were developed by Institute of Forest Productivity (IFP), Ranchi. It covers the areas of Uttar Pradesh, Bihar and West Bengal.

i. Poplar (*Populus deltoides*)-Wheat (*Triticum aestivum)* agri-silviculture model
ii. Poplar (*Populus deltoides)*-Maize (*Zea mays*) agri-silviculture model
iii. Poplar (*Populus deltoides*)-Banana (*Musa paradisiaca*) silvi-horticulture model
iv. Poplar (*Populus deltoides*)-Turmeric (*Curcuma domestica*) agri-silviculture model
v. Poplar (*Populus deltoides*)-Jimikand (*Pachyrhizus erosus*) silvi-horticulture model

3.1.5 Plateaus

The models for this region were developed by Tropical Forest Research Institute (TFRI) Jabalpur, Institute of Wood Science and Technology (IWST) Bengaluru and Institute of Forest Biodiversity (IFB), Hyderababd.

i. Teak (*Tectona grandis*)-Turmeric (*Curcuma domestica*) silvi-medicinal model
ii. Bamboo (*Dendrocalamus* species) based silvi-agri model
iii. Bach (*Acorus calamus*)-Paddy (*Oryza sativa*) agri-medicinal model
iv. Flemingia (*Flemingia macrophylla* and *F. semialata*) based silvi-agri-lac model
v. Agri-lac culture model
vi. Babul (*Acacia nilotica*)-Paddy (*Oryza sativa*) model
vii. Sandalwood-Teak-Eucalyptus-Redsanders based silvi-agri model
viii. Sandalwood (*Santalum album)* based agroforestry model

3.1.6 Western Dry Region

The models for this region were developed by Arid Forest Research Institute (AFRI) Jodhpur. The area covers Rajasthan, West of the Aravalli's, Gujarat and Dadar-Nagar Haveli.

i. *Hardwickia binata* based agroforestry model
ii. *Emblica officinalis* based agroforestry model
iii. *Colophospermum mopane* based agroforestry model
iv. *Prosopis cineraria-Zizyphus mauritiana* agroforestry model

3.1.7 Coastal Plains and Ghats

The models for this region were developed by Institute of Forest Genetics and Tree Breeding (IFGTB), Coimbatore. This covers the area of Coromandal and northern Circar coasts of Andhra Pradesh and Orissa, Malabar and Konkan coastal plains and the Sahyadris

i. Casuarina (*Casuarina equisetifolia*)-Maize (*Zea mays*) agri-silviculture model

ii. Casuarina (*Casuarina equisetifolia*)-Moringa (*Moringa oleifera*)-Maize (*Zea mays*) agri-silvi-horticulture model
iii. *Acacia auriculiformis*-Napier grass silvi-pasture model
iv. *Tectona grandis*-*Phaseolus mungo* agri-silviculture model
v. *Acacia mangium*-Beans (*Vigna* species) agri-silviculture model
vi. *Acacia mangium* -Pepper (*Piper nigrum*) silvi-horticulture model
vii. *Casuarina* spp. based windbreak agroforestry model

Chapter 4

Agroforestry in Trans Himalayan Region

Agroforesty in Trans Himalayan Region

Cold dry zone comprises of Ladakh, Lahaul-Spiti, Kinnaur and Pangi tehsil of Chamba district from Himanchal Pradesh. The temperatures remain well below sub-zero and the region is cut off from the rest of the country during long winter season. Only an extremely limited but important range of floral and faunal species are able to adapt to the frigid and arid climatic conditions. The major crops grown are Wheat (*Triticum aestivum)*, Barley (*Hordeum vulgare*), Pseudo-cereals like Buckwheat (*Fagopyrum esculentum*) and Amaranths (*Amaranthus cruentus*). It is ideally suited for the production of quality seed potato (*Solanum tuberosum*), temperate and European type of vegetables and their seeds, peas (*Pisum sativum*) as green and seed purposes. However, apples (*Pyrus malus*), almonds (*Prunus amygdalus*) and apricot (*Prunus armeniaca*) have become major cash crops of cold desert. It covers the areas of Ladakh, Lahaul-Spiti and Kinnaur (H.P). These regions have two main types of agro-forestry models develoed by HFRI, Shimla.

1. Salix (*Salix fragilis* and *S. alba*) and poplar (*P. euphratica, P. alba, P. nigra*) based agroforestry model
2. Apple (*Pyrus malus*) based horti-medicinal model

4.1 Salix and poplar based agroforestry model: The traditional willow and poplar (*Populus* spp.) based agroforestry systems contribute to the green cover in this cold desert landscape. Over a period cultivated poplars (*Populus balsamifera* and *P. nigra*) and willows (*Salix alba, S. fragilis, S. tetrasperma*) were introduced in cold desserts. Now people have developed rich silvicultural knowledge and practices that help to maintain these systems sustainably. The rich local vocabulary and a range of tools associated with the management right from identification of planting site, plantation, types of agroforestry systems to harvesting and multiple uses are the glaring testimonies for existing rich traditional knowledge.

Before the introduction of fast-growing willows and poplars in the traditional agroforestry of this region, people were dependent on Kashmir valley, Kullu and other lower altitude areas in Himachal Pradesh to meet their subsistence needs of timber and fuelwood. Presently the strengthened agroforestry systems help in meeting the subsistence through ecosystem goods/provisioning services along with supporting a range of ecosystem services. Many willow and poplar trees have been declared as sacred especially those grow near natural water bodies.

The people’s forestry is facilitating the strengthening of traditional dairy production in the region. Local people traditionally prepare a number of dairy products which are integral part of their culture. The economics of the model varies with the species planted, space given between plant to plant and other geographical location with is directly or indirectly responsible for plant growth, rotation and utilization.

Fig.1 Trans Himalayan Region

Fig. 2 Cold deserts landscape

4.2 Apple (*Pyrus malus*) based horti-medi model

4.2.1 Edaphic and environmental requirements of the model: This model performs better in well drained sandy loam soil condition with weekly irrigation during hot summer season along with weeding at 15 to 30 days interval during April to August for optimum growth and yield. It comes well in 1.4^{0}C to 27.6^{0}C with annual rainfall range of 164-231 mm and preferably at an altitude of 2000 m and above.

4.2.2 Significance of the model: This model is beneficial to the farmers who can plant high temperate medicinal plants with horticultural plantation. Himanchal Pradesh, Jammu, Kashmir and Uttarakhand are basically horticultural states. Accordingly, temperate fruit growing is the major activity in mid and higher Himalayas. At times failure of these fruit crops have forced the farmers and horticulturist to look for some other alternatives to supplement their income through diversification.The probable reasons for fruit crop failures were erratic rainfall accompanied with very less snow fall, increased incidence of various insect pest and diseases attacks, overall rising temperature and decreasing forest areas of the region, shortened chilling hours required by the apple trees during winter for optimum flowering and fruit setting thereby resulting in low yields and lower quality fruits.

Generally, farmers do not grow anything in the horticulture plantations after it has attained maturity thus interspaces can be utilized for enhancing income and productivity. As selected herbaceous medicinal plants are shade loving hence these can be grown in the interspaces. The choice of the species should be according to the altitudinal variation/nearer to natural habitat. Herbaceous medicinal plants have special significance for intercropping in fruit cultivation because of its high returns and less competition for nutrients with horticulture crops. It would provide early income to the farmers too.

4.2.3 Establishment and management of model: In the interspaces of apple orchard, field beds are prepared during the month of February-March. Paths are left between the beds for to and fro movement, thereby enabling to execute the other horticultural operations easily. A basal dose of FYM 20 t/h should be applied during the preparation of field beds. In the field beds medicinal plants viz. *Aconitum heterophyllum, Angelica glauca, Picrorhiza kurroa* and *Valeriana jatamansi* were planted in the spacing of 30x20 cm^2, 45x75 cm^{2,} 30x40 cm^2 and 30x40 cm^2 respectively. The apple trees were already planted by the farmers in the spacing of 5x5 m^2. Thus, in one hectare there was approximately 400 nos. of apple trees. Bio-pesticides should be used in case of insect pest attack on medicinal plants.

Fig. 3 Apple (*Pyrus malus*) based horti-medi model

4.2.4 Rotation and yield: Medicinal plant crops were harvested after 2¼ years and obtained yield was found 2.02 t/ha for *Aconitum heterophyllum*, 2.3 t/ha for *Angelica glauca*, 0.7 t/ha for *Picrorhiza kurroa* and 1.2 t/ha for *Valeriana jatamansi*.

4.2.5 Economics of the model: Total expenditure for whole model inclusive of all operations from sowing to harvest was Rs.1.10 lakhs**.** Income generated from *Aconitum hetrophyllum* was Rs. 2,62,600 for 2.02 t/ha at Rs 1300/kg. Income obtained from *Agnelica glauca* was Rs. 1,38,000 for 2.3 t/ha at Rs. 60/kg. In case of *Picrorhiza kurroa* income generated was Rs.1,40,000 for 0.7 t/ha at Rs. 200/kg whereas *Valeriana jatamansi* gave income of Rs. 1,44,000 for 1.2 t/ha at Rs.120/kg. The net income generated for *Aconitum hetrophyllum* was Rs. 1,52,000 lakhs and for *Agnelica glauca* was Rs.38,000 per hectare. In case of *Picrorhiza kurroa* and *Valeriana jatamansi* net income for both the crops was Rs. 40,000 per hectare.

4.2.6 Impact and upscaling: The technology is quite suitable in high temperate regions of north western Himalayas where horticultural crops viz. apple and cherry are being grown. There will always be the possibility for upscaling of technology as residual effect on medicinal plants could be studied as intercropping with horticultural crops.

Chapter 5

Agroforestry in Western Himalayan Region and Indo-Gangetic Plains

Agroforestry in Western Himalayan Region and Indo-gangetic Plains

Western Himalayan Region and Indo-gangetic Plains: Western Himalayan region covers Jammu, Kashmir, Himachal Pradesh, Uttarakhand, Uttar Pradesh, Haryana and Punjab. The models for this region developed by FRI, Dehradun are as below:

i. Melia (*Melia composita*)-Aonla (*Emblica officinalis*) based agri-silvi-medicinal model
ii. Poplar (*Populus deltoides*) based agri-silviculture model
iii. Poplar (*Populus deltoides*) based silviculture-medicinal model
iv. Melia (*Melia composita*) based agri-silviculture model
v. Eucalyptus (*Eucalyptus camaldulensis/ E. teriticornis)*-Wheat (*Triticum aestivum)*/paddy (*Oryza sativa*) silvi-block model
vi. Poplar (*Populus deltoides*)-Wheat (*Triticum aestivum)* agroforestry model

5.1 Melia (*Melia composita*)-Aonla (*Emblica officinalis*) based Agri-silvi-medicinal model

5.1.1 Edaphic and environmental requirements of model: The Melia-Aonla based agri-silvi-medicinal agroforestry system performed better on degraded lands in Uttarakhand and Punjab. The annual average rainfall during the study period was 1076 mm (Handesra) and 1182 mm (Naukragrant) and mean monthly temperature ranged from 7.7°C minimum in January to 41°C maximum in June. Most of the rainfall is received from July to September. The soil of both experimental sites was slightly alkaline and soil type of the both sites is sandy loam in texture.

5.1.2 Significance of the model: This model helped to evaluate productivity of some important medicinal plants under tree species in degraded land of Punjab and Uttarakhand. The study motivated the farmers/cultivators to adopt the technology and obtain maximum output per unit area of their valuable land and enhance the productivity of the land with improvement of soil quality. The farmers are not aware of quality planting materials and also for technical inputs on Melia-Aonla based agri-silvi-medicinal agroforestry. Most of the farmers are adopting these species on bunds and their farm lands in scatter form. For Aonla cultivation farmers are practicing old traditional varieties without using high yielding improved varieties.

The quality planting material of tree species of Melia (*Melia composita*), Aonla (*Emblica officinalis*), Sarpgandha (*Rauvolfia serpentina*), Ashwagandha (*Withania somnifera*) and improved seeds of agriculture crops like wheat (*Triticum aestivum)*, masoor (*Lens culinaris*) and groundnut (*Arachis hypogaea*) were taken. Six months aged seedlings of *Melia composita* and *Emblica officinalis* were planted at 6x4 m spacing and medicinal plants namely *Rauvolfia* *serpentina* and *Withania somnifera* at 60x60 cm spacing as an intercrop along with seasonal agriculture crops like wheat (*Triticum aestivum)*, masoor (*Lens culinaris*) and groundnut (*Arachis hypogaea*) were cultivated to increase nutrients and moist condition in soils which favors more yield. Canopy management was also done. This agroforestry model was designed for enhanced medicinal plant productivity as well as biomass production of woody trees for sustainable land use and to make the farmers economically viable.

5.1.3 Establishment and management of model: For establishment of experiment, two plots each of 1 acre in both sites were selected for block plantation of *M. composita* and *E. officinalis*. These fields were intercropped with seasonal agriculture crops along medicinal plants like Sarpgandha (*Rauvolfia serpentina*) and Ashwagandha (*Withania somnifera*). For nursery preparation, required seedling of *M. composita* were raised in the nursery and the variety NA-7 of Aonla (*Emblica officinalis)* plants were procured from the private nursery to plant at selected site in Punjab and Uttarakhand. Pit size of 45 cm^3 were kept for tree species with spacing of 4x6 m and medicinal plants *Rauvolfia serpentina* and *Withania somnifera* were cultivated at 60x60 cm as intercropped along with seasonal agriculture crops of wheat-masoor and groundnut. All silvicultural practices like weeding, pruning, soil working and some irrigation were required for first two years. Initially irrigation is needed to boost the early growth. One-year aged saplings of trees were preferred for best survival and easy establishment.

Fig. 4 Melia-Aonla based agri-silvi-medicinal model

5.1.4. Rotation period and yield: The Melia (*M. composita)* tree harvested in 8 years rotation gave timber yield of 1215 Q/ha. Yield of aonla (*Emblica officinalis)* fruit obtained was 20.57 Q/ha for 4th year, 40.39 Q/ha for 5th year, 100.98 Q/ha for 6th year, 160.82 Q/ha for 7th year and 183.26 Q/ha for 8th year. Total yield was 506.02 Q/ha. Similarly, the yield of agri crops masoor (*Lens culinaris*) was 7.90 Q/ha/yr. The yield of wheat (*Triticum aestivum)* was 15 Q/ha/yr and for groundnut (*Arachis hypogaea*) was 3.50 Q/ha/yr. Medicinal plants Sarpgandha (*Rauvolfia serpentina*) at 90% survival (root) yielded 14.15 Q/ha and Ashwagandha (*Withania somnifera)*) at 50% survival (root) yielded 5.53 Q/ha.

Fig. 5 Yield of Aonla in agroforestry model

5.1.5 Economics of the models (per hectare basis)

Model-1: The expenditure of Melia-Sarpgandha-Masoor block plantation was Rs.7,87,755. The income generated in eight-year rotation period for this model was Rs. 20,96,858 with net profit of Rs. 13,09,103 and B/C Ratio of 2.66.

Model-2: The expenditure of Aonla-Sarpgandha-Masoor block plantation was Rs.7,7,508. The income generated in eight years rotation period for this model was Rs. 21,65,39 with net profit of Rs 13, 77,885 and B: C Ratio of 2.7.

Model-3: The expenditure of Melia-Ashwagandha-Groundnut-Wheat block plantation was Rs.9,38,235. The income generated in eight years rotation period was of Rs. 22,15,63 with net profit of Rs 12,77,393 and B: C Ratio of 2.38.

Model-4: The expenditure of Aonla-Ashwagandha-Groundnut-Wheat block plantation was Rs.9,31,510. The income generated in eight years rotation period for this model was of Rs. 22,99,939 with net profit of Rs 13,68,430 and B/C Ratio of 2.47.

5.1.6 Impact and upscaling: *Melia composita* is a fast-growing species capable to fulfilling the timber and fuel wood demand of farmers in degraded lands of Uttarakhand and Punjab states without making adverse effect on under storey crops. Grafted Aonla (*Emblica officinalis*) is also short rotation cash crop suitable for degraded lands in Punjab and Uttarakhand. Likewise, medicinal plants like Ashwagandha (*Withania somnifera*) and Sarpgandha (*Rauvolfia serpentina*) are well suitable and synchronized with both *M. composita* and *E. officinalis* without releasing any negative effect on tree as well as agriculture crops.

Fig. 6 Groundnut collection under *M. composita*

Fig. 7 Groundnut collection under *E. officinalis*

5.2 Poplar (*Populus deltoides*) based agri-silviculture model

5.2.1 Edaphic and environmental requirements of model: The Poplar based agri-silviculture agroforestry system performed better and suitable for alluvial and sandy loam soils in Indo-gangetic alluvial plain of Uttar Pradesh, Uttarakhand, Haryana and Punjab.The annual average rainfall during the study period was 1400 to 1850 mm and mean monthly temperature ranged from 5^o C minimum in January to 38^o C maximum in June. Most of the rainfall is received from July to September.

5.2.2 Significance of the model: This contributed towards improving the local environment by increasing tree cover over a large area and reducing biotic pressure on the natural forests.This model will help to evaluate productivity of agricultural crops under tree species in alluvial soils of these states. The study on model will motivate the farmers/cultivators to adopt the technology and obtain maximum output per unit area of their valuable land and enhance the productivity of the land with improvement of soil quality. The farmers are not aware of quality planting materials and also for technical inputs on Poplar based agri-silviculture agroforestry. Most of the farmers are adopting this species on block and bunds in their farm lands.

Quality planting material of tree species Poplar, clone-G-48 and improved seeds of agriculture crops like Turmeric (*Curcuma domestica*), Sugarcane (*Saccharum officinarum*), Wheat (*Triticum aestivum)*, Paddy (*Oryza sativa*), Potato (*Solanum tuberosum*), Bajra/Millet (*Pennisetum typhoides*), Chari (*Sorghum bicolor*), Barseem (*Trifolium alexandrium*) were taken for this study. One year aged entire transplants (ETPs) of *P. deltoides* were planted at block plantation with 5x4 m and in boundary with 3 m spacing of trees and as an intercrop along with seasonal agriculture crops like Turmeric, Sugarcane, Wheat, Paddy, Potato, Bajra/Millet, Chari, Barseem were also cultivated to increase nutrients and moist condition in soils which favors more yield. This agroforestry designed for enhanced agriculture productivity as well as biomass production of woody trees and sustainable land use and shall make the farmers economically viable.

5.2.3 Establishment and management of model: For establishment of experimental plots each of 1 acre in five villages in Yamunanagar district viz. Urjani, Sherpur, Chuharpurkhurd, Nahar Taharpur, Balouli and five villages in Haridwar district viz. Ulheda, Sakoti, Kuahedi, Narson Kalan, Narson Khurd were selected for block plantation of *P. deltoides* and with intercrop of seasonal agriculture crops like Turmeric (*Curcuma domestica*), Sugarcane (*Saccharum officinarum*), Wheat (*Triticum aestivum)*, Paddy (*Oryza sativa*), Potato (*Solanum tuberosum*), Bajra/Millet (*Pennisetum typhoides*), Chari (*Sorghum bicolor*), Barseem (*Trifolium alexandrium*). For nursery preparation, different clones of *P. deltoides* were raised in the central nursery of FRI, Dehradun and the clone G-48 of Poplar plants were planted at selected sites. Pit size of 90 cm depth and diameter of 15 cm was dig by tractor mounted for tree species with spacing of 5x 4 m in block and 3 m on bunds. Seasonal agriculture crops were intercropped. All silvicultural practices like weeding, pruning, soil working and some irrigation were required for first three years in time to time. Irrigation has boosted the early growth. One year old entire transplant (ETP) of G-48 clone is preferred for best survival and easy establishment.

Fig. 8 Poplar-Turmeric silvi-medicinal system

5.2.4 Rotation period and yield: The Poplar trees harvested in 6 years rotation yielded 1992.60 Q/ha timber. The yield of additional crops with poplar was recoreded 2252 kg/ha (dry) for turmeric, 665 Q/ha for sugarcane, 30 Q/ha for wheat 35 Q/ha for paddy, 180 Q/ha for potato, 20 Q/ha for bajra, 250 Q/ha for chari and 760 Q/ha for barseem on annual basis.

5.2.5 Economics of the models

Model-1: The expenditure of Poplar-Sugarcane-Turmeric block plantation model was Rs.1,81,711 and income generated was Rs.5,55,807. Net Present value at 9% discount rate was Rs.3,74,096 and B/C ratio was 3.06 in six years rotation period.

Model-2: The expenditure of Poplar- Sugarcane- Wheat- Chari block plantation model was Rs.1,30,750 and income generated was Rs.4,53,150. Net Present Value at 9% discount rate was Rs.3,22,400 and B/C was 3.47 in six years rotation period.

Model-3: The expenditure of Poplar-Sugarcane-Wheat-Chari-Potato-maize-bajra block plantation model was Rs.2;18,083 and income generated was Rs.5,61,985. Net Present Value at 9% discount rate was Rs.3,43,902 and B/C was 2.58 in six years rotation period (Saresh *et al.,* 2018).

Model-4: The expenditure of Poplar-Sugarcane-Potato-Barseem-Chari block plantation model was Rs.1,71,067 and income generated was Rs.5,15,095. Net Present Value at 9% discount rate was Rs.3,44,028 and B/C was 3.01 in six years rotation period.

Model-5: The expenditure of Poplar-Paddy-Wheat boundary plantation model, was Rs.1,25,862 and income generated was Rs.3,04,291. Net Present Value at 9% discount rate was Rs.1,78,429 and B/C was 2.42 in six years rotation period.

Model-6: The expenditure of Poplar-Sugarcane-Wheat-Paddy boundary plantation model was Rs.1,20,862 and income generated was Rs.3,30,539. Net Present Value at 9% discount rate was Rs.2,09,677 and B/C was 2.73 in six years rotation period (Saresh *et al.,*2018).

5.2.6 Impact and Upscaling: *Populus deltoides* is a fast-growing species, which is capable to fulfill the timber and fuel wood demand of farmers in Uttar Pradesh, Uttarakhand, Haryana and Punjab states without damaging making under storey crops. Farmers have adopted agroforestry due to much higher economic returns from it, as compared to income from agriculture alone. Poplar based agroforestry has left a profound impact on the upliftment of the socio-economic status of the farmers in the region. The increased tree cover contributed towards improving the local environment and reducing biotic pressure on the natural forests. Poplar based agroforestry has benefitted farmers by increasing their income manifold, created wood-based industries, generated employment opportunities and developed ancillary units like transport, fertilizers, insecticides, pesticides, wood processing machineries etc. It has saved valuable foreign exchange by way of reduction in import of timber. This agroforestry system has brought the overall development in the region.

Fig. 9 Poplar with Chari

Fig. 10 Poplar with Wheat

5.3 Poplar (*Populus deltoides*) based silviculture-medicinal models

5.3.1 Edaphic and environmental requirements of model: The poplar based silviculture-medicinal agroforestry system performed better and suitable for alluvial and sandy loam soils in Indo-gangetic alluvial plain of Uttar Pradesh, Uttarakhand, Haryana and Punjab. The annual average rainfall during the study period was 1400 to 1850 mm and mean monthly temperature ranged from 5^{o} C minimum in January to 35^{o} C maximum in June. Most of the rainfall is received from July to September.

5.3.2 Significance of the model: This model will help to evaluate productivity of medicinal crops under tree species in alluvial soils of these states. The study will motivate the farmers/cultivators to adopt the technology and obtain maximum output per unit area of their valuable land and enhance the productivity of the land with improvement of soil quality. Studies conducted have made the farmers economically viable and sustainable. Farmers are not aware of quality planting materials and also for technical inputs on Poplar based Silviculture-medicinal agroforestry. Most of the farmers are adopting this species on block and bunds in their farm lands. Quality planting of tree species poplar (*Populus deltoides)* Clone G-48 and improved planting of medicinal crops Chitrak (*Plumbago zeylanica)* and Satavar (*Asparagus recemosus)* were done. One-year old entire transplants of *P. deltoides* were planted at block plantation with 5x4 m and boundary with 3 m spacing of trees and as an under storey crops with Chitrak (*Plumbago zeylanica)* and Satavar (*Asparagus recemosus)* were cultivated to increase moist condition in soils which favors more yield. This agroforestry designed for enhanced medicinal productivity as well as biomass production of woody trees and sustainable land use. Overall, this technique of growing poplar and medicinal plants was better than traditional one.

5.3.3 Establishment and management of model: For establishment of experiment, two plots each of 1 acre in both sites at village Kuahedi (Haridwar) and Doon valley (Premnagar, Dehradun) were selected for block plantation of *P. deltoides* and with under storey crops of Chitrak (*Plumbago zeylanica)* and Satavar (*Asparagus recemosus)* medicinal plants. For nursery preparation, required different clones of *P. deltoides,* were raised in the central nursery of FRI and the Clone G-48 of Poplar plants were planted at selected sites. Pit size of 90 cm depth were kept with specially designed Auger with a diameter of 15 cm which is essential for tree species with spacing of 5x4 m and medicinal plants Chitrak (*Plumbago zeylanica)* and Satavar (*Asparagus recemosus)* were planted at 60x60 cm as under storey crop. All silvicultural practices like weeding, pruning, soil working and irrigation were required regularly first two years. One year old ETPs of G-48 clone were preferred for best survival and easy establishment.

5.3.4 Rotation period and yield: The poplar tree harvested in 6 years rotation and the timber yield of poplar was 1992.60 Q/ha under irrigated condition. However, 972 Q/ha yield was obtained under rainfed condition.The yield of Satavar was 30 Q/ha (root-irrigation) and 20 Q/ha (root-rainfed). Chitrak yielded 7.50 Q/ha biomass and 10 Q/ha seeds for irrigated conditions and 5.0 Q/ha biomass and 6.0 Q/ha seed for rainfed condition.

5.3.5 Economics of the models

Model-1: The expenditute of Poplar-Satavar block plantation model was Rs. 3,24,716 and income generated was Rs.21,98,550. Net Profit in irrigated condition was Rs. 18,73,834 and in rainfed condition was Rs.11,75,450. In six years of rotation expenditure was Rs.3,04,516 with profit Rs. 8,70,934.

Model-2: In case of Poplar- Chitrak block plantation model expenditure was Rs. 2,55,274 and income generated was Rs.19,67,300. Net Profit in Irrigated condition was Rs. 17,12,026. In rainfed condition expenditure was Rs. 2,35,074 and income generated was Rs.7,05,376 in six years rotation of period.

Fig. 11 Poplar with Chitrak

Fig. 12 Poplar with Satavar

5.3.6 Impact and upscaling: Poplar (*Populus deltoides)* clone G-48 is a fast-growing species, which is capable to fulfill the timber and fuel wood demand of farmers in Uttar Pradesh, Uttarakhand, Haryana and Punjab without making adverse effect on under storey crops. The Satavar and Chitark having suitable combination with *P. deltoides* spacing 4x5 m and planted at 60x60 cm as under-storey crop (Kumar and Singh 2020). Through cost-benefit analysis it was found that Satavar (*Asparagus recemosus)* and Chitark (*Plumbago zeylanica)* are suitable medicinal crops with *P. deltoides*. A net gain of Rs. 17,12,026 per ha and Rs. 18,73,834 per ha is obtained from Poplar-Chitrak and Poplar-Satavar intercropping respectively, if two crops of each medicinal plant are grown as under storey crop of poplar. Hence, the model is helpful in socio-economic upliftment of farmer's associated directly and other stakeholders.

5.4 Melia (*Melia composita*) based agri-silviculture model

5.4.1 Edaphic and environmental requirements of model: The melia based agri-silviculture agroforestry system performed better and suitable for degraded lands in Punjab. The soil of both the experimental sites was neutral to slightly alkaline and sandy loam in texture. The annual average rainfall during the study period was 1076 mm to 1152 mm and mean monthly temperature ranged from 5.5^{o} C minimum in January to 40^{o} C maximum in June. Most of the rainfall is received from July to September.

5.4.2 Significance of the model: This study has helped to evaluate productivity of agriculture crops under tree species in degraded land of Punjab. The study has motivated the farmers/cultivators to adopt the technology and obtain maximum output per unit area of their valuable land and enhance the productivity of the land with improvement of soil quality. This model based study has made the farmers economically viable and sustainable.The farmers are not aware of quality planting materials and also for technical inputs on Melia based agri-silviculture agroforestry. Most of the farmers are adopting this species on bunds and their farm lands in scatter form.

The quality planting material of tree species of Melia (*Melia composita*) and improved seeds of agriculture crops Wheat (*Triticum aestivum*) and Maize (*Zea mays*) were taken for the study. Six months aged seedlings of *Melia composita* were planted at 4x5 m, 4x6 m and 5x5 m spacing and as an intercrop along with seasonal agriculture crops like wheat and maize were cultivated to increase nutrients and moist condition in soils which favors more yield. Canopy management was also done. This agroforestry model designed for enhanced agriculture productivity as well as biomass production of woody trees and sustainable land use make the farmers economically viable. Overall, the growing technique of Melia and agriculture crop combination was better than traditional one.

Fig. 13 *Melia*- Maize model

Fig. 14 *Melia*- Wheat model

5.4.3 Establishment and management of model: For establishment of experiment, two plots each of 1 acre in both sites were selected for block plantation of *M. composita* with intercrop of seasonal agriculture crops wheat (*Triticum aestivum*) and maize (*Zea mays*). For nursery preparation, required seedling of *M. composita* were raised in the central nursery of FRI Dehradun and planted at selected sites at Handesra and Hukuran in Punjab. Pit size of 45 cm^3 were dug for Melia planting with spacing of 4x5 m, 4x6 m and 5x5 m and wheat and maize crops were cultivated as an intercrop. All silvicultural practices like weeding, pruning, soil working and some irrigation were required to boost the early growth. One-year old saplings of trees may be preferred for best survival and easy establishment.

5.4.4 Rotation period and yield: The timber yield of Melia (*Melia composita)* tree harvested in 8 years rotation was 1360 Q/ha and 554.60 Q/ha fuel wood obtained from 400 trees. The yield of wheat was 371.31 Q/ha for grain and 482.70 Q/ha straw. The yield of maize was 327.29 Q/ha for grain and 818.22 Q/ha for straw yield in 8 years period.

5.4.5 Economics of the models: The total expenditure of Melia-wheat-maize block plantation was Rs.3,54,939 with total income of Rs. 27,97,111. For eight years rotation period net profit was of Rs. 24,37,172 with B/C Ratio of 6.86.

5.4.6 Impact and upscaling: Overall the study reveals that *Melia composita* is a suitable species under agroforestry system in Punjab and can attain height up to 14 m with an average girth of 65 cm in 4 years. The plants also produce a good quantity of fuel wood under a regular and proper canopy management. Under an agroforestry system the interaction of this species was found suitable with wheat and maize which are generally grown in Punjab (Kumar and Singh 2020). The combination with wheat and maize was best with spacing of the plantation at 4x6 m. The soil fertility also increases to some extent in *Melia composita* plantations. The study also reveals that a proper guidance to farmers to adopt agroforestry practices through different extension tools can also be helpful to raise the forestry specieseatures of fast growth like *Melia composita* on their farm land agroforestry without affecting under storey crops.

5.5 Eucalyptus (*Eucalyptus teriticornis*)-Wheat (*Triticum aestivum*)/Paddy (*Oryza sativa*) silvi-block model

5.5.1 Edaphic and environmental requirements of model: This model performs better in well drained clayey alluvial soil, red alluvial soil and sodic soil with optimum irrigation during first and second year. It is also suitable under water logged areas with mound plantation technology. Usually comes well in 12-45^{o} C temperature with annual rainfall range of 1000-1500 mm.

5.5.2 Significance of the model: This model is economically beneficial to the farmers, who can plant Eucalyptus trees on their farm fields on bunds or blocks along with other traditional agriculture crops for higher economic returns. Short rotation Eucalyptus trees are a viable alternative in producing high quality wood/plywood for industrial applications.The farmers are not much aware of quality planting materials (seeds, seedlings and clones), technical inputs of farming and trade of agroforestry produce. This species is most preferred one in the region of eastern UP on farm bunds in different agroforestry combinations. Research institutions and SFDs are developing quality planting materials. The improved and suitable clones of commercial agroforestry species for specific sites are now coming in practice.

5.5.3 Establishment and management of model: Land should be leveled and ploughed well; weeds/stones should be removed. Planting should be carried out in monsoon season for better survival and early establishment and good growth. Pit size of 45 cm^3 is essential for Eucalyptus with a spacing of 3x2 m. Irrigation is essential for first two years bi-weekly, especially during summer. The irrigation will improve the early growth. One year old seedling of site specific clone of Eucalyptus should be preferred for planting. Application of neem khali in pits protects plants against infestation while planting. The pruning (25% intensity) of undesired branches is required for straight growth of the tree. The weeding after monsoon in October is recommended for healthy growth.

Fig. 15 Eucalyptus-wheat bunds and block model

5.5.4 Rotation period and yield: The rotation of the tree crop is 5-6 years for clonal plants whereas for seed plants, it is 7-8 years. The Eucalyptus in silvi block (3x2 m) model may give 3500-4000 Q/ha. For Eucalyptus Wheat/paddy bund model, Eucalyptus may give 325 Q/ha, wheat 192 Q/ha and Paddy 210 Q/ha.

Fig. 16 Growth of Eucalyptus in agroforestry system

5.5.5 Economics of the model

Model 1: In Eucalyptus silvi block model with 3x2 m spacing the yield of Eucalyptus timber was 3523 Q/ha. The net profit at discounted rate of 12% was Rs.13.8 Lakh with B/C ratio of 2.25.

Model 2: In Eucalyptus-Wheat bund model with 3 m spacing the yield of Eucalyptus was 325 Q/ha and for wheat was 192 Q/ha. The net profit at discounted rate of 12% was Rs. 4.49 lakh with B/C ratio of 2.14.

Model 3: In Eucalyptus-Paddy bund model with spacing of 3 m the yield of Eucalyptus was 325 Q/ha and 210 Q/ha for Paddy. The net profit at discounted rate of 12% was Rs. 5.12 Lakh with B/C ratio of 2.38.

5.5.6 Impact and upscaling: Eucalyptus based agri-silvi block models with clonal planting material are a boon to farmers as these models are able to give good returns in 5-6 years of time span. Further, identification of suitable clones for specific sites will be helpful in increasing yield in wood production. Thus, adoption of these models in different crop combinations on block/bund may play a significant role in upscaling the economic status of rural masses.

5.6 Poplar (*Populus deltoides*) Wheat (*Triticum aestivum*) agroforestry model

5.6.1 Edaphic and environmental requirements of model: Model of poplar grows best on rich loamy soils. However, clay loam, sandy loam soils with well drainage system are best suitable for poplar tree farming. The soil pH of 6 to 8.5 is best for its optimum growth and quality. These models perform well in clayey alluvial soil and sandy loam soil with optimum irrigation during its growth period of 1 to 5 years. It is not suitable under clay, black cotton soil and water logged areas which affect its growth. Usually comes well in 12-45° C with annual rainfall range of 1000-1500 mm.

5.6.2 Significance of the model: Short rotation poplar forests are a viable alternative in producing high quality wood for industrial applications. This model has played important role in the socio-economic life of people. The features of fast growth (20-25 m^3/ha/yr), straight clean bole, deciduous nature, multiple uses, soil enriching property, compatibility with agricultural crops and high economic returns makes poplar useful for agroforestry. It is highly water use efficient perennial component having high CO_2 exchange rate (Saresh *et al.* 2018).

The poplar plantation status is very low in the eastern region of Uttar Pradesh in comparison to the Western part. On the basis of experiences of field visits in the districts of eastern region and literature review, the less adoption of Poplars by the farmers of Eastern Uttar Pradesh in agroforestry plantations was due to uncertainty about marketing/ sale of end produce, inadequate planting material, small landholding and limited technical knowledge regarding planting practices and suitable tree crop combinations. ICFRE has established some experiments of poplar in Sultanpur, Raibarelly, Pratapgarh and Vaishali district of Bihar. The performance and productivity was less as compared to plantation established in Western Himalaya. It indicates that *Populus deltoides* is latitude/longitude sensitive species and does not perform well beyond certain geographical limits.

The improved and suitable clones of commercial agroforestry species for specific sites are now coming in practice. FRI, Dehradun has more than 400 poplar clones. WIMCO released its six clones, viz., WSL22, WSLA/26, WSL27, WSL32, WSL 39 and WSLA/49 during the year 2000 for supply to the farmers. Choice of clones being grown is specifically driven by the demand from the growers. The fact that the WIMCO and farmers still grows a few thousand saplings of some introduced and those developed by other agencies, viz., L34, S7C15, S7C8, S7C4 etc. indicates that there is some demand of these clones from the growers and are produced to meet the requirement of growers.

5.6.3 Establishment and management of model: Cuttings are taken from stems of one year old poplar plants grown in the nursery. The cuttings from branches of trees are not taken into use for plantaion purpose. Cuttings size of 22 cm length and 1 to 3.5 cm diameter was immersed in clean water for 24 to 48 hours before planting. Pre-treatment with fungicide and insecticide was given after cleaning. A bed was ploughed to 25-30 cm depth, 5 m width and 12 m length with an irrigation channel must on one side of the bed. Best time of planting for production of entire transplants with pit size of 80 cm x 60 cm and for propagation purpose (i.e. production of cuttings for next year's propagation work) with pit size 60x60cm is February. Flood irrigation is essential and sprouts are cut within 10 days of planting. Poplar keeps producing branches in the nursery. For block plantation 5x4 m to 4x4 m spacing is required. For planting along boundary of field: 3 m pit size, 90 cm depth and 15 to 22 cm diameter is used. At time of planting 2 kg FYM, 50 g SSP, 25 g MOP and 15 g Phorate per plant is added in the soil. Urea should be applied at 100 g per plant (3 split doses). More abundant irrigation gives more rapid growth. Trees reach about 25-30 m height and 25-28 cm dbh in 6 years. Rotation age of 6 to 8 years in north India is optimum. Most of the agricultural crop, except paddy, can be grown with poplar. Net returns per unit area from poplar crop are much higher than returns from crop alone.

Fig. 17 Poplar plantation

5.6.4 Rotation period and yield: Poplar is harvested at six to eight years of rotation. Good growing plantations attains 5 m average height and 5 cm average diameter per annum with a ratio of around 100:1 for the first half of the rotation age of poplar growth. The Poplar-Wheat model in block (2.5x2.5m) may yield 3375 Q/ha.

5.6.5 Economics of the model

Model 1: Poplar-wheat in block (2.5x 2.5 m) model gives around 3375 Q/ha with net profit at discounted rate of 12 %. The net profit will be Rs.15.21 lakh with B/C ratio of 2.09 in six year rotation period.

Model 2: Poplar-wheat in block (2.5x2.5 m) model gave 3675 Q/ha at Gorakhpur with net profit at discounted rate of 12 %. The net profit will be Rs. 16.27 lakh with B/C ratio of 2.24 in six year rotation period.

5.6.6 Impact and upscaling: Poplar based agri-silvi/silvi block models with clonal planting material are a boon to farmers as these models are able to give good returns in 5-6 years of time span. Further, identification of suitable clones for specific sites will be helpful in increasing yield in wood production. Thus, adoption of these models in different crop combinations on block/bund may play a significant role in upscaling the economic status of rural masses.

Chapter 6

Agroforestry in Eastern Himalayan Region

Agroforestry in Eastern Himalayan Region

The Eastern Himalayan Region includes Arunachal Pradesh, the hills of Assam, Sikkim, Meghalaya, Nagaland, Manipur, Mizoram, Tripura and the Darjeeling district of West Bengal. The agrofroestry models developed by RFRI Joraht for these regions are:

i. King chilli-Arecanut agroforestry model (horti-spice model)
ii. Gamhar (*Gmelina arborea*) based agroforestry system

6.1 King Chilli (*Capsicum chinense*)-Arecanut (*Areca catechu*) model

6.1.1 Edaphic and environmental requirement of model: This model can successfully perform in Northeast region of India having unique ecological environment with hot and high-humid conditions. It can be established under diverse soil and climatic conditions. However for optimum growth, it requires well drained sandy loam, clay loam or laterite soils.

6.1.2 Significance of the model: Since, king chilli (*Capsicum chinense*) popularly known as *Bhoot jolokia* is most preferred species as an intercrop under areca nut trees for providing immediate economic returns. *Bhoot jolokia* is used as a food and a spice, as well as a remedy to summer heat. It is used in both fresh and dried forms, to not only “heat up” curries, pickles and chutneys, but also to impart two distinct flavors to them. The survival and growth of king chilii was better under areca nut trees in comparison to its monoculture. Areca nut is one of the important profitable crops and planted most of the household in North Eastern Region. Farmers getting a considerable extra income from the small block of areca nut plantation raised in their household. The arecanut trees are normally planted at a spacing of 4x4 to 7x7 m depending upon the availability of the land. Because of its thin canopy there is an advantage of raising intercrops beneath the tree.

6.1.3 Establishment and management of model: The area under Arecanut should be cleaned, ploughed and leveled. A small block is made up in between the rows of Arecanut. It should be well prepared to fine tilth and mixes with adequate quantity of compost/cow dung.

Fig.18 King Chilli-Arecanut model

6.1.4 Rotation period and Yield: Harvesting should be done when chillies are become 4-5 cm length and attractive red coloured and healthy. The crops which are planted in the month of November are ready to harvest from the month of April/May to July/August.

6.1.5 Economics of the model: Total expenditure of this model for one bigha (1333 sq meter) of land (in the existing area under Arecanut) was Rs. 25,000. Income from king chilly along with arecanut was Rs. 55,000 (200/kg) and Rs. 54,000 repectively.The net profit from this model was Rs. 84,000.

6.1.6 Impact and upscaling: The model is proved to be a successful for generating additional income to the farmers. It has become the most popular model as more than 60% farmers have areca nut plantation which is not utilized for any purpose. This model gives the best solution to utilize these areas by cultivating *Bhoot joloki.*

6.2 Gamhar *(Gmelina arborea)* based agroforestry system

Gamhar is an important fast-growing timber species commonly grown in all the Eastern states of India as monoculture plantation species and under agroforestry system. In one of the study conducted to determine biomass production, carbon sequestration and nitrogen allocation in *Gmelina arborea* planted agri silviculture system on abandoned agricultural land at 5 years total stand biomass was 14.1 Mg/ha. In agri-silviculture system crops recommended are soybean and cowpea in rainy season, wheat and mustard in winter season. After 5 years, soil organic carbon increased by 51.2 and 15.1% and Nitrogen by 38.4 and 9.3% in agri-silviculture system respectively. Total carbon storage in abandoned agricultural land before planting was 26.3 Mg/ha, which increased to 33.7 and 45.8 Mg/ha after 5 years.

Chapter 7

Agroforestry in Gangetic Plain Region

Agroforestry in Gangetic Plain Region

The Gangetic Plain Region covers Uttarakhand, Uttar Pradesh, Bihar, Jharkhand West Bengal, Punjab and Haryana. This region is dominated by cereals. Rice-wheat cropping system occupies more than 70% of the gross cropped area. Pulses occupy around 7% of the gross cropped area. The important cropping sequences of different zones are:

Zone-I	Rice *(Oryza sativa)*-Wheat (*Triticum aestivum*), Rice (*Oryza sativa*) - Rai (*Brassica nigra*), Rice *(Oryza sativa)*-Sweet Potato (*Ipomoea batatas*), Rice (*Oryza sativa*)-Maize (*Zea mays*)-Wheat (*Triticum aestivum*), Maize (*Zea mays*)-Sweet Potato (*Ipomoea batatas*), Maize (*Zea mays*)-Rai (*Brassica nigra*), Rice (*Oryza sativa*)-Lentil (*Lense ulinaris*), Rice(*Oryza sativa*)-linseed (*Linum usitatissimum*)
Zone-II	Jute (*Corcorus capsularis*)-Wheat (*Triticum aestivum*), Jute (*Corcorus capsularis*)-Potato (*Solanum tuberosum*), Jute (*Corcorus capsularis*) -Kalai (*Alphonsea arborea*), Jute (*Corcorus capsularis*)-Mustard (*Brassica compestris*), Rice *(Oryza sativa)*-Wheat (*Triticum aestivum*)-Moong (*Vinca radiate*), Rice *(Oryza sativa)*-Toria (*Brassica rapa*)
Zone-III	Rice *(Oryza sativa)*-Wheat (*Triticum aestivum*), Rice *(Oryza sativa)*-Gram (*Cicer arietinum*), Rice *(Oryza sativa)*-Lentil (*Lense ulinaris*), Rice *(Oryza sativa)*-Rai (*Brassica nigra*)

The agroforestry models for these regions have been developed by Institute of Forest Productivity (IFP), Ranchi. All these models are based on Poplar and annual crops like wheat, maize, banana and turmeric etc are grown in combination to tree. Therefore growing conditions and techniques are same for all the models motioned below:

- Poplar (*Populus deltoides*)-Wheat (*Triticum aestivum)* agri-silviculture model
- Poplar (*Populus deltoides*)-Maize (*Zea mays*) agri-silviculture model
- Poplar (*Populus deltoides*)-Banana (*Musa paradisica*) silvi-horticulture model
- Poplar (*Populus deltoides*)-Turmeric (*Curcuma domestica*) agri-silviculture model
- Poplar (*Populus deltoides*)- Jimikand (*Pachyrhizus erosus*) silvi-horticulture model

7.2.1 Edaphic and environmental requirements of model: These models will perform better in well drained loam soil or sandy-loam soil condition with optimum irrigation during its early period. The models are not suitable under clay soil, water logged areas and anaerobic conditions which affect poplar growth adversely. Usually poplar grows well in 15-40^{o} C with annual rainfall range of

800-2500 mm. In Bihar, poplar grows well at temperature of 6^0C to 16^0C in winter and up to 44^0 C in summer.

7.2.2 Significance of the model: These models are beneficial to the farmers, who can plant poplar trees in their farm fields along with other annual crops especially with wheat, maize, banana, turmeric and yam for higher economic returns. Cultivation of agriculture and horticulture crops was practiced by the farmers since long time using scientific techniques provided by the agriculture scientists. However, farmers were not aware of the scientific pattern of adopting agroforestry and planting trees along with their agricultural crops in a systematic manner.

Singh *et al.,* (1999, 2001a, b and c) strongly advocated the need for extending cultivation of *Populus deltoides* to lower latitudes. FRI, Dehradun, during 1999-2001 supplied germplasm of promising clones to researchers in areas both inside and outside the traditional planting zone covering Jammu and Kashmir, Himachal Pradesh, Punjab, Haryana, Uttar Pradesh, Bihar, West Bengal, Orissa, Chhattisgarh, Maharashtra, Gujarat and Assam. Among areas outside the traditional zone, performance of the clones in Bihar was encouraging and poplar cultivation was recommended in these sites. Encouraged by the initial performance of *P. deltoides* in Bihar, ICFRE introduced large scale cultivation of this species in northern Bihar. About 6.10 million plants of poplar have been multiplied and planted in district Vaishali, Bihar during the first phase of the project that started in 2005. Capacity building of farmers has also been done in large scale with trainings imparted to nearly 50,000 farmers about scientific methods and pattern of planting trees in the field. Since poplar is deciduous in nature it does not hamper the productivity of agriculture and horticultural crops. Introduction of poplar with agriculture crops is expected to generate additional income to farmers by using the natural resources in an optimum manner.

7.2.3 Establishment and management of model: Land should be leveled, ploughed well and weeds/stones should be removed. Planting should be carried out between late December to mid of February before sprouting of buds and emergence of new flush of leaves on ETPs. Pit size of 3 feet deep and 6-8 inches in diameter is essential for poplar with an escapement of 3x3 m in bund plantation, 6x3 m in row plantation and 5x4 m in block plantation. Irrigation is essential for first three years in an interval of 7-15 days, especially during summer. Irrigation will boost the early growth. One-year old ETPs of 10-15 feet in height are required for plantation and good establishment. Treatment of lower 1 m part of ETPs with Chloropyriphos 20 EC at 0.025 % and Emisan-6 at 0.15 % is required before planting to prevent termite and fungal attack. In the planting pits, 6-10 granules of Phorate is also required to be applied before planting to prevent insect attack on ETPs. Timely pruning (33% in 2-3 year of planting, 50% in 4-5 year of planting) of poplar branches is required to get straight stem. Weeding is necessary twice a year. Intercropping will be possible up to 6-8 years of harvesting of poplar.

Fig. 19 Poplar-Wheat agri-silviculture model

Fig. 20 Poplar-Maize agri-silviculture model

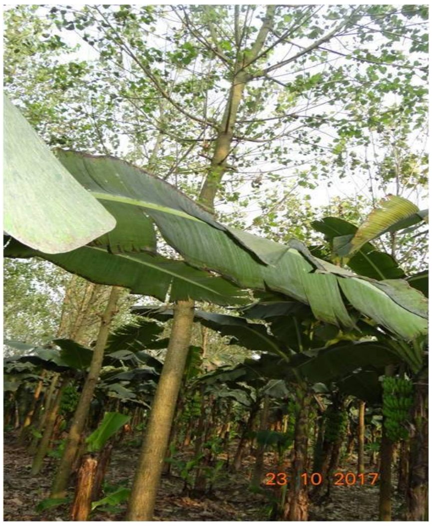


Fig. 21 Poplar-Banana silvi-horticulture model

7.3.4 Rotation period and yield: Poplar trees will be felled/ harvested at the age of 2-3 years for paper and pulp. Poplar will be harvested in 6-8 years for plywood purpose. Poplar trees in 6 to 8 years usually attain average height of 16 m and girth of 3-4 feet and yield timber at Rs. 5000/ton.

7.4.5 Impact and upscaling: Poplar based agri-silvi models besides having lower risks, sequesters more carbon and enhances overall productivity which ensures higher net farm income as per recent government targets. However, further up-scaling of the model is possible through training programmes, distribution of extension materials, farmer to farmer interaction and on farm field visits. In previous efforts, *P. deltoides* had been planted in Maharashtra where it showed good performance initially but died after 3-4 yrs (Ballal, 2001). Gera *et al.,* (1993) planted this species in sporadically irrigated site at Jabalpur in Madhya Pradesh and observed good early growth but the plants began to die back at 3 years of age. However, good growth of *P. deltoides* at six years of age was observed in farmers' field at Chhindwara in Madhya Pradesh, thereby, suggesting that inadequate irrigation during summer season and mono cropping of poplar might be the key factor behind failure of this species in introduction trials in some sites.

Fig. 22 Poplar -Turmeric agri-silviculture model

Fig. 23 Poplar-Amorphophallus silvi-horticulture model

Chapter 8

Agroforestry in Plateaus

Agroforestry in Plateaus

The agroforestry models for plateaus were developed by Tropical Forest Research Institute (TFRI), Jabalpur, Institute of Forest Biodiversity (IFB) Hyderabad and Institute of Wood Science and Techniology (IWST), Bengaluru. The plateaus are divided into four broad categories as below:

a) **Eastern Plateau** - Jharkhand, Orissa, Chhattisgarh and Dandakaranya
b) **Central Plateau**- Bundelkhand, Baghelkhand, Bhander Plateau, Malwa Plateau and Vindhyachal Hills.
c) **Western Plateau-**Southern part of Malwa plateau and Deccan plateau (Maharashtra)
d) **Southern Plateau** - Parts of southern Maharashtra, the greater parts of Karnataka, Andhra Pradesh and Tamil Nadu

The agroforestry models developed are as follows

i. Teak (*Tectona grandis*)-Turmeric (*Curcuma domestica*) silvi-medicinal model
ii. Bamboo *(Dendrocalamus* species) based silvi-agri model
iii. Bach *(Acorus calamus*)-Paddy *(Oryza sativa*) agri-medicinal model
iv. Flemingia (*Flemingia macrophylla* and *F.semialata*) based silvi-agri-lac model
v. Agri-lac culture model
vi. Babul (*Acacia nilotica*)-Paddy (*Oryza sativa*) model
vii. Sandalwood (*Santalum album*)-Teak (*Tectona grandis*)- Eucalyptus (*Eucalyptis camaldulensis*/ *E. teriticornis*)-Red sanders (*Dalbergia latifolia*) based silvi-agri models
viii. Sandalwood *(Santalum album*) based agroforestry system

8.1 Teak (*Tectona grandis*)-Turmeric (*Curcuma domestica*) silvi-medicinal model

8.1.1 Edaphic and environmental requirements of model: This model will perform better in well drained sandy soil condition with optimum irrigation during its early period (first 1-2 years). It is not suitable under clay, black cotton soil and water logged areas which affect teak growth. Usually grows well in 15-40^{o}C with annual rainfall range of 800-2500 mm and prefers sea level to an altitude of 1200 m.

8.1.2 Significance of the model: This model is beneficial to the farmers, who can plant teak trees in their farm fields along with other annual crops especially with turmeric for higher economic returns. Farmers are not aware of quality planting materials (seedlings and clones) and lack technical know how on teak farming. Farmers are practicing old systematic turmeric cultivation techniques without using high yielding improved varieties.Introduction of teak with turmeric will give additional income to farmers by using the natural recourses in an optimum way.

8.1.3 Establishment and management of model: Land should be leveled, ploughed well and weeds/stones should be removed. Planting should be carried out at onset of monsoon for better survival and early establishment and good growth. Pit size of 45 cm^3 is essential for teak with an espacement of 4x4 m. Irrigation is essential for first three year in a interval of 3-4 days, especially during summer. Irrigation will boost the early growth. One year old root shoot (stump) of teak should be preferred for best survival and easy establishment along with Suroma variety of Turmeri. Application of chloropyriphos 20 EC at 2 ml/liter soon after first monsoon showers kills the adults of termites and white grub and reduces the infestation level. Timely pruning (25% intensity) of teak branches is required to get straight stem. Two times weeding is necessary in a year. Intercropping will be possible for 8-10 years.

Fig. 24 Teak-Turmeric silvi medicinal model

8.1.4 Rotation period and Yield: Teak trees will be felled/harvested in the age of 10-12 years for pole purpose (average height 11m and girth 55-60 cm) and in 20 years for timber purpose (average height 16 m and girth 80 cm). The yield of turmeric was 3.5 t/ha/year.

8.1.5 Economics of the model: Total expenditure for whole model inclusive of all operation from sowing to harvest was Rs.1.50 lakhs. Total production of turmeric was found 3 t/ha for one year. Income from turmeric was Rs.1.80 lakhs at Rs 60/kg. Income from teak poles Rs. 6.50 lakhs at Rs.1250 per pole for 200 pole and Rs 2000 per pole for 200 poles. Net Income was Rs 6.80 lakhs.

8.1.6 Impact and Upscaling: Teak-turmeric based agri-silvi model gives risk free farming to farmers, sequesters more carbon and enhances overall productivity which ensures higher net farm income to fulfill the Govt. of India slogan of "Doubling the farm income". This model can be upscaled through training programmes to farmers, extension materials, farmer to farmer interaction and on-farm field visits.

8.2 Bamboo (*Dendrocalamus* species) based silvi-agri model

8.2.1 Edaphic and environmental requirements of model: This model will perform better in well drained sandy loam soil condition with optimum irrigation during its early period (first 1 -2 years). Bamboo can grow in river and gullies to control the soil erosion and conserve moisture. The system is not suitable under clay, black cotton soil and water logged areas which affect teak growth. Usually grows well in 15-40^{o} C with annual rainfall range of 800-2500 mm and prefers sea level to an altitude of 1200 m.

8.2.2 Significance of the model: This model is beneficial to the farmers, who are interested to improve degraded lands by adopting Bamboo along with suitable annual crops especially with *Vigna mungo* and *Triticum aestivum* in a crop rotation to improve the soil fertility and water conservation purpose and simultaneously for additional income from Bamboo. Generally farmers are not aware about the high yielding and thorn less bamboo species, as well as quality planting materials (seedlings and clones). The other limitation is lack of technical knowlwdge on bamboo farming especially in sustainable harvesting methods. They are adopting desi lathi bamboo (*Dendrocalamus strictus*) in field bunds. Framers are not aware about different bamboo species suitability in different soil conditions along with crop combinations.

Farmers can grow various intercrops *viz.*urad, wheat, etc. up to 5 years, till the bamboo canopy closes. Bamboo farming will provide income till 40 years of its age at one planting. Weeding should be done three times during each cropping period to get maximum production from annual crops. Further, turmeric is partial shade loving crop and require moist condition which favours more yield. Introduction of teak with turmeric will give additional income to farmers by using the natural recourses in an optimum way.

8.2.3 Establishment and management of model: Land should be leveled, deep ploughed well and weeds / stones / agricultural residues etc should be removed. Planting should be carried out onset of monsoon for better survival and early establishment and good growth of bamboo and crops. Pit size of 45 cm^3 is essential for bamboo with aespacement of 5x5 m. Irrigation is essential for first two year in an interval of 3-4 days, especially during summer. Irrigation will boost the early growth. Healthy seedlings of bamboo developed through cuttings should be preferred for best survival and easy establishment. The high yielding thorn less bamboo species *viz. Bambusa nutans, B. balcooa, B. tulda, B. vulgaris,* etc. are highly suitable for this model. Vegetative propagated plants of bamboos should be preferred for best survival and easy establishment in the main field. Bamboo seedlings (400 seedlings per ha) should be planted at spacing of 5x5 m after making pits size of 45 cm^3 during the onset of monsoon. Bamboos are managed by timely pruning of the culms from second year onwards to avoid the congestion within the culm/clump and to maintain a healthy growth to fetch better growth and returns. Lateral roots of bamboo should be pruned at 2.5 m away from the periphery of the clump to reduce root competition within associate intercrops.

Variety 306 of wheat (average yield 0.16 t/ha), jawahar and urad (average yield 0.10 t/ha) is preferred. Further, farmers can grow various intercrops *viz.*urad, wheat, etc. up to 5 years till the canopy closes. Weeding should be done three times during each cropping period to get maximum production from annual crops. Application of chloropyriphos 20 EC at 2 ml/liter soon after first monsoon showers kills the adults of termites and white grub and reduces the infestation level. Timely pruning of lateral branches of bamboo is required to get straight culm (stem) and to avoid conjunction within the clump.

8.2.4 Rotation period and yield: Bamboo culms can be harvest from 4th year onwards. Generally bamboo is ready to harvest from 5th year onwards under monoculture but in agroforestry, it is ready to harvest after 4th year due to its fast growth and benefited from the various inputs given to annual crops. During the month of March-April 6 to 7 culms of bamboo per clump may be harvested subject to growth and maintenance of the system. The average height of bamboo is 11m and 15cm diameter when harvested. In this model average yield of wheat and urad was obtained 0.16 t/ha and 0.10 t/ha respevtively

8.2.5 Economics of the model: Total expenditure for this model was Rs. 96,000 per ha (inclusive of field operations). Income genetated from urad and wheat was Rs. 40,000 per ha and Rs. 70,000 per ha respectively. Income from bamboo poles was Rs. 2 lakhs per ha at rate of Rs. 100 per culm for 2000 culm (first harvesting after 4 years). Net income of Rs 2.17 lakhs is obtained.

8.2.6 Impact and upscaling: Bamboo-Urad/Wheat agroforestry model has potential to provide additional income in a sustainable manner and this model will fulfill the government goal of 'Doubling the farm income' from its intercrops within short rotation period of 5 years. Further the model generates rural and women employment opportunities throughout the year. In addition, this model improves soil fertility and increase the overall productivity.

8.3 Bach (*Acorus calamus*)-paddy (*Oryza sativa*) agri-medicinal model

8.3.1 Edaphic and environmental requirements of model: The system is suitable under clay, black cotton soil and water logged areas for its best growth. *Acorus calamus* (Bach) can grow in waterlogged area hence it is suitable to intercrop with paddy. Usually it grows well in hot humid condition under 15-40^{o} C with annual rainfall range of 800-2500 mm and prefers sea level to an altitude of 1200 m.

8.3.2 Significance of the model: This model is beneficial for the paddy growers who can utilize their waterlogged land by intercropping of commercially valuable medicinal crops viz. *Acorus calamus* (Bach). *A. calamus* (Bach) is a perennial herb, commonly known as sweet flag in India. It is upto 6 feet tall, aromatic and small yellow/green flowers with indefinitely branched rhizomes. It has several medicinal uses to cure cough and cold, improve nervous system and also the respiratory disorders like bronchitis. Generally farmers are not aware about the high yielding bach planting material.

Fig. 25 Bach (*Acorus calamus*) paddy (*Oryza sativa*)

8.3.3 Establishment and management of model: Land has to be leveled, deep ploughed and weeds/stones/agricultural residues should be removed. Planting should be carried out onset of monsoon for better survival and early establishment and good growth of bach and crops.

8.3.3.1 Nursery technique of Bach

Rhizomes of bach plants are cut into the small pieces of 4-5 cm in length. Each small piece having two internodes is suitable as planting material for better regeneration, growth and yield. These cuttings should be sown in the soil upto 4-5 cm depth during the month of May. New sprouts may come out after 15 to 20 days. This sprouted material is ready for transplanting in the rice field during second week of July to August at the spacement of 30x30 cm. FYM of 15 t/ha is necessary for the bach-paddy system It should be applied 1/4th of quantity (3.5) as basal dressing, half of the quantity (7) after two months of planting and remaining 1/4th quantity (3.5) after 6th month of crop. Further farmers can grow bach along with paddy up to 5 years till its lateral roots will spread. Weeding should be done three times during each cropping period to get maximum production from annual crops. Bach is highly sensitive to salinity. The crop is free from grazing. The crop is resistant to insect, pests and fungal attacks. The first year crop provides planting material for next season at least for one hectare area besides marketable produce.

8.3.4 Rotation period and yield: Bach plants was harvested after 10 months, which yielded 3.5 t/ha of dried rhizomes and 1.00 lakh propagules of fresh rhizomes for 1 ha.

8.3.5 Economics of the model: Total expenditure was Rs.1,20,000 inclusive of field operations cost of planting material, preparation of field, FYM and wages. The income genreted from paddy was Rs. 50,000/ha/year and for Bach plants was Rs. 2 lakhs (market rate). So the net income obtained in this model was Rs 1,30,000 lakhs/ha/year.

8.3.6 Impact and upscaling: Bach-paddy agroforestry model having the potential to provide additional net farm income to farmers and will one of the best model for doubling the farm income in short rotation period of years. In addition, this model can utilize the waterlogged area efficiently and effectively and convert into increase in overall productivity and additional income to farmers.This model can be up scaled through training programmes to farmers, extension materials, farmer to farmer interaction and on-farm field visits.

8.4 Flemingia (*Flemingia macrophylla*) based silvi-agri-lac model

Flemingia macrophylla and *F. semialata* is a source of fuel wood, fodder, tannin, dyestuff and medicines. *Flemingia* spp. are very promising species for lac cultivation in India. The study conducted by Kumar *et al.,* (2017) suggested that *F. semialata* and *F. macrophylla* are the best host species for lac cultivation in India.

8.4.1 Edaphic and environmental requirements of model: This model will perform better under well drained sandy loam soil condition. *Flemingia* plants are fast growing in nature and having narrow crown hence farmers can utilize its interspaces by growing traditional agriculture crop like *Cajanus cajan* for their regular income. *Flemingia* usually grows well in 15-40^{o}C with annual rainfall range of 800-2500 mm and prefers sea level to an altitude of 1200 m.

8.4.2 Significance of the model: This model is beneficial for the lac growers especially farmers who are not having traditional lac host trees like (*Butea monosperma*) or Kusum (*Schleichera oleosa*) in their field bunds. *Flemingia semialata* is a bushy leguminous plant and proved as a good host to Kusumi strain of lac. This *F.semialata* plants are ready to inoculate brood lac within a year after its planting and farmers can maintain this model and get lac up to 8 years. Lac growing farmers are not aware of quality planting materials (seedlings and brood lac) and also scarcity of technical knowhows about the species on lac farming on *Flemingia*. Farmers are practicing lac farming on old traditional host plants existing on their field bunds in unscientific manner without using high yielding improved varieties. Introduction of lac cultivation of *Flemingia* under agroforestry system will provide additional income to farmers by using the natural recourses in an optimum way.

8.4.3 Establishment and management of model: Seeds of *F.semialata* should be sown during April in the polybags with 1:1:1 ratio of soil, sand and FYM mixture. The seedlings will be ready for the transplantation during rainy season. Healthy seedlings should be preferred for best survival and easy establishment. Land should be ploughed and FYM may be applied (10 t/ha) as basal dressing in the month of May. *Flemingia* seedlings (625 plants per ha) should be planted with spacing of 4x4 m after making pits size of 45 cm^3 during the onset of monsoon. Soil surface along the pit should be treated with chloropyriphos (2 g/litre) to control termite attack before rainy season. After one year of planting, plants are ready to raise good quality of brood lac. Rabi season is the best time for its cultivation.

***Cajanus cajan* cultivation** -To manage the field activity Asha variety of *C.cajana* having average yield of 0.10 t/ha is planted in July with 75x75cm spacing after transplanting of *Flemingia* plants. Weeding should be done three times to get maximum production.

Fig. 26 *Cajanus cajan* collection

Lac farming- Good quality brood lac should be selected by the farmer to get maximum yield. Farmers can select healthy, soft, disease free shoots for the infestation of brood lac at 40 g per plant. *F. semialata* plants should be pruned from its tip to maintain certain height (upto 1.5 m) for easy cultural operations like weeding, ploughing, etc. and to protect it against heavy wind during summer season, otherwise plants will be damaged. This system performs better in well drained soil condition with optimum irrigation during first 2 years.

Fig. 27 Lac farming and collection

8.4.4 Rotation period and yield: *Flemingia semialata* seedling is ready for lac cultivation after one year of its planting. The plant is a shrub and needs to maintain certain height (2.5m) and more branches for management of lac crop. The lac crop will be ready to harvest within a year.

8.4.5 Economics of the model: Total expenditure of this model was Rs.75,000 per ha (inclusive of field operations). Total income generated from lac and *C.cajan* was Rs.2.00 lakh /ha/year with Rs.1.00 lakh per ha for each crop. *F.semialata* based silvi-agri-lac model has potential to generate Rs.1.25 lakhs year/ha than monoculture of conventional crops like Lac or *C.cajan*

8.4.6 Impact and upscaling: Tropical Forest Research Institute, Jabalpur has introduced this lac host species in tropical region of Madhya Pradesh for the first time to explore the possibilities of Lac culture on *Fleminga* under agroforestry model with *Cajanus cajan* and become popular among the lac growers due to its short period of maturity. This model is able to generate income as well as employment throughout the year as compared to traditional farming. This model alos improves soil fertility and provide additional income.

Training and demonstrations are most important component to popularize this model among the farmers especially for rural women with one time investment. This model can be upscaled through various training programmes including demonstrations, farmer mela, farmer to farmer interaction, farm field visits and distributing extension materials.

8.5 Agri-Lac culture model

8.5.1 Edaphic and environmental requirements of model: Babul trees have high calorific value therefore farmers retain these trees in their paddy field bunds to meet daily needs of fuelwood. This model will perform better under sufficient water condition. Usually grows well in 15-40^{o}C with annual rainfall range of 800-1400 mm and prefers sea level to an altitude of 1200 m.

8.5.2 Significance of the model: This model is beneficial for the farmers who can utilize their farmland by intercropping of suitable agriculture crops *viz.Cajanus cajan* (Arhar) with Lac. Generally lac is cultivated on the host plants of *Butea monosperma* and *Ziziphus mauritiana* which are existing in the farmers field bunds and require inputs to maintain the crop. Integration of lac with agriculture crops not only helps the farmer*s* to get additional income but also security against crop failure due to climate vagaries and insect/pest attacks. Adoption of such high income practice will increase the net farm income as a whole and also increase the productivity and generation of rural employment opportunities with fewer inputs. Farmers can practice this model in their courtyard also. They can grow the lac on perennial variety of *C. cajan* for the period of two years. This model in farm field required timely weeding which favours *C. cajan* growth. Partial irrigation further boost the growth of *C. cajan* in agri-lac culture model and increases the production of lac. Improved variety of *Cajanus cajan* require less time for its maturity and maintain moisture for grain production.

Fig. 28 *Cajanus cajan*

8.5.3 Establishment and management of model: Cultivation of Asha variety of *C. cajan (*average yield 1t/ha) should be sown at 1.5x1.5 m spacing during kharif season or onset of monsoon. Seeds of *C. cajan* should be sown in line with proper spacing for obtaining maximum growth, yield and more branches which will help in production of lac. Weeding should be done three times to get maximum production. Healthy seedlings should be preferred for best survival and easy establishment. Land should be ploughed and FYM may be applied (10 t/ha) as basal dressing in the month of May. Soil surface along the pit should be treated with chloropyriphos (2 g/liter) to control termite attack before rainy season. After one year of planting, plants are ready to raise good quality of brood lac. Rabi season is the best time for its cultivation. *C.cajan* plants should be pruned from its tip to maintain certain height (upto 1.5 meter) for easy cultural operations like weeding, ploughing, etc. and to protect it against heavy wind during summer season, otherwise plants will be damaged. This system performs better in well drained soil condition with optimum irrigation during first 2 years.

Lac Farming: Lac (*Laccifera lacca*) is the resinous substance used for manufacturing several items like bangles, articles, toys, paint varnish, CD cover etc. Brood lac (seed lac) will be inoculated on the soft shoots of *C.cajan* during rabi season. Good quality brood lac should be selected by the farmer to get maximum yield. Farmers can select healthy and soft disease free shoots for the infestation of brood lac at 40 gm per plant.

8.5.4 Rotation period and yield: Farmers can grow the lac on perennial variety of *C. cajan* for the period of two years. This model in farm field required timely weeding which favours *C. cajan* growth. Partial irrigation boosts the growth of *C. cajan* and increases the production of lac.

8.5.5 Economics of the model: Cost of cultivation for this model was Rs.80,000 per ha. Total income generated from *C. cajan* was Rs. 1.00 lakh per ha for Rs.100 per kg. Income from lac crop for 12 t/ha at Rs.200 per kg was Rs. 2.40 lakh. Net income generated from this model was Rs 2.60 lakh per ha.

8.5.6 Impact and up-scaling: Agri-lac culture model having the potential to provide additional income to farmers and can be the best model for "Doubling the farm income" from lac within short rotation period of 2 years and also generate the employment. Further the introduction of legume in farm fields will enhance the soil fertility through fixation of atmospheric nitrogen which will help in productivity of crops and reduce the input costs. This model can be further up-scaled through training programmes to farmers, farmer to farmer interactions, farm field visits and providing extension materials in local languages.

8.6 Babul-paddy silvi-agri model

8.6.1 Edaphic and environmental requirements of model: The system prefers sodic and alkali soils with pH of 7-8. Though babul is leguminous tree but it can adapt well to all range of pH where paddy is grown. Usually grows well at an altitude of 1200 m (sea level) with temperature range of 15-40^{o}C and annual rainfall range of 800-1400 mm.

8.6.2 Significance of the model: The model consists of agriculture crop paddy (*Oryza sativa) variety* JR75 (78 days crop) intercropped with tree babul (*Acacia nilotica* wild ex. Del.). Babul seedling raised in the nursery should be transplanted in field during rainy season before paddy transplantation. This model is beneficial for the paddy farmers who are not aware of management of huge canopy cover of babul tree as well as paddy crop. Scientific management of babul trees along with short rotation variety with high yielding paddy crop provide double grain production and efficiently utilized leaf litter as green manure. This model does not require inputs like insect-pest management to maintain the trees and crop.Farmers who resorted root and canopy pruning measure of babul tree could obtain higher crop yield. From third year onwards farmers will get interim annual income from pruned biomass of 1.60 kg per tree for *Acacia nilotica var.indica* (telia). The trees are pruned initially to promote the formation of a clean straight bole that can fetch premium price in the market with 10 year rotation period for babul.

8.6.3 Establishment and management of model

Cultivation techniques: This model prefers sodic and alkaline soil with pH 8 and higher organic matter. Though it is leguminous tree but it can adapt well to all range of pH where paddy is grown.

Nursery techniques of Babul: Seeds of babul can be raised in polythene bags with 1:1:2 ratio of Sand: Soil: FYM**.** Seed is treated with sulphuric acid or soaked in water for 12 hours. Best season for sowing babul is first week of March to mid April. Plants of nursery raised babul seeds should be transplanted after ploughing of the field just before paddy transplanting or seed broadcasting of paddy. The spacing of 5x5 m is kept for intial five years raising with 400 plants/ha. From sixth year onwards 200 plants per ha are managed with spacing of 6x6 m. From eigth year 100 plants per ha are retained and managed. Timely canopy pruning is done to reduce the shade effect and to improve the production of fire wood and fodder. Lateral root pruning can also be done to enhance the crop yield.

8.6.4 Rotation period and Yield: The Babul-paddy model has a benefit cost (B/C) ratio of 1.47 during ten year period of the system. Over ten year rotation the trees provide variety of products such as fodder, fuel wood (30 kg per tree), brushwood for fencing (4 kg per tree), small timber for farm implements/furniture (0.2 m^3) and non timber forest products such as gum. The yield of paddy obtained from farmers field for this model is 2.5 t/ha against 1.5 t/ha from traditional varieties.

Fig. 29 Babul-paddy silvi-agri model

8.6.5 Economics of the model: Total expenditure of this model was Rs. 70,000 per ha inclusive of field operations with net income of Rs 3 lakhs per ha.

8.6.6 Impact and up-scaling: By adopting/practicing the babul-paddy agro-forestry system farmers can get higher cash returns upto Rs.3.00 lakh within 10 years of harvest cycle of trees. The babul-paddy model is a good insurance against failure of monsoon or climate vagaries. Farmers who adopted scientific management of babul trees like pruning of root and canopy of the tree could get higher crop yield. Training and demonstrations are most important component to popularize this model among the farmers especially for rural women with one time investment. This model can be upscaled through various training programmes including demonstrations, farmer mela and distributing extension materials.

8.7 Sandalwood-Teak-Eucalyptus- Red sanders based silvi-agri models

8.7.1 Edaphic and environmental requirements of model: This model was found suitable for well red loamy soil condition with optimum irrigation during its first 2 years. The total rainfall in arid and semi-arid climate on an average ranges from 0 to 400 and 400-800 mm respectively. This model performs well in 90 to 650 mm average rainfall and temperature ranges between 13 to 43 ^{o}C.

8.7.2 Significance of the model: This model is beneficial for those farmers who can plant *Santalum album*, *Pterocarpus santalinus*, *Eucalyptus* species and *Tectona grandis* tress in their farm fields along with other short term agriculture crops such as *Cajanus cajan, Phaseolus aureus* and *Sorghum vulgare.* Agroforestry systems based on Red sanders-Sandal, Teak-Sandal and Eucalyptus-Sandal were evaluated across different agricultural crops viz., green gram (*Vigna* *radiata*), jowar (*Sorghum bicolor*), red gram (*Cajanus cajan*) and castor (*Ricinus communis*). It was found that Red sanders-Sandal was very suitable for the cultivation of green gram, jowar and red gram. In contrast no tree combination was helpful for castor cultivation as weeds suppressed the crop and castor was unable to grow with vigour. Therefore based on this study for semi-arid tropics of Andra Pradesh, Red sanders -Sandal with green gram, jowar and red gram can be recommended on farmlands without irrigation.

8.7.3 Establishment and management of model: Land should be leveled, ploughed well and weeds, stones bushes/shrubs should be removed. Sowing or planting is done during rainy season for better survival, timely germination and good growth. The trees are placed at a closer spacing within the row at 4 m and in between Sandal are planted. An effective distance of upto 5 m between the rows is maintained for cultivation and mechanization. The planting is done in a factorial randomized block design with tree sole crops and agricultural sole crops and their intercrops as per the treatments. One block of all trees except Sandal at 4x4 m as control is also established in the experimental trials. Spacing of two trees or more were maintained depending on land availability. The spacing of 2 m within the row and 5 m between the rows were employed in four replications.

8.7.4 Rotation period and yield: Tree crop combinations like Red sanders-Sandal, Teak-Sandal and Eucalyptus-Sandal were raised. Agricultural crops like green gram, pigeon pea and jowar were raised till third year. In fourth and fifth years castor was raised between the tree rows. It was observed that under Red sanders-Sandal system in the first three years for per unit cropped area green gram, pigeon pea and jowar have performed equally well when compared with control lands. However the yield was found to be reduced in Teak-Sandal system and was lowest in Eucalyptus-Sandal system.

8.7.5 Economics of the model: Net income generated from green gram was Rs. 60,000 per ha, pigeon pea was Rs. 1.00 lakh per ha and jowar was Rs. 50,000 per ha. Castor as intercrop did not perform well when compared to its income as sole crop.

Table 1: Yield (Q/ha) per year for Green Gram, Pigeon pea, Jowar and Castor

S. No	Treatments	Green Gram	Pigeon pea	Jowar	Castor
1	Red sanders + Sandal	10.0	23.8	19.5	6.5
2	Teak + Sandal	9.5	20.0	17.0	5.3
3	Eucalyptus + Sandal	7.5	17.5	15.3	3.8
4	Red sanders sole crop	11.3	-	-	-
5	Teak sole crop	10.0	-	-	-
6	Eucalyptus sole crop	8.5	-	-	-
7	Agri-crop (sole)	11.0	24.3	19.5	20.0

8.7.6 Impact and upscaling: Sandal-Redsanders agri-crops based agri-silvi model gives risk free farming to farmers. The end users are farmers from sem-arid tropics covering nine districts of Telangana and Rayalaseema region of Andhra Pradesh. The farmers with small or large land holdings of Nalgonda, Mahabubnagar, Ranga Reddy district, Kurnool, Cuddappah and Vishakhapatnam have shown keen interests in this system. Farmers need planting materials and the extension support for adopting these systems. Even the Van Sanrakshan Samiti of Andhra Pradesh, State Forest Department has shown interest in these systems who may need extension support of these systems especially from Adilabad and Khammam districts.Van Sanrakshan Samiti of Cuddappah and Chittor districts of Rayalaseema region have also shown keen interest in the system and wanted its retention in their fields.

8.8 Sandalwood based agroforestry systems

8.8.1 Edaphic and environmental requirements of model: This model performs fine in well drained red ferruginous loam soils. It requires optimal aeration during early stages of plantation establishment (1-3 years). Soil should be moderately deep with good drainage, good physical properties and moderately acidic to neutral with pH 6.5 to 8.5. It flourishes well in moderate rainfall of 600 mm in cool climate with a long period of dry weather but adapts well to different climatic conditions except for water logged and very cold places. It grows well in the early stages under partial shade but at the middle and in later stages it shows intolerance to heavy overhead shade.

8.8.2 Significance of the model: This model is of significant use to the farmers who can plant sandalwood in their farm field along with crops like horse gram, aonla and block plantation with Casuarina. Farmers are not aware of quality planting materials like seedlings and also on technical input on sandalwood farming. Horse gram cultivation is done based on the traditional system without using high yield improved varieties. Research institutions are identifying better genotypes for developing quality planting materials in sandalwood. Further, the Aonla (*Phyllanthus emblica*) and Horse gram (*Macrotyloma uniflorum*) are cultivated as an intercrop for getting additional income and optimal usage of natural resources.

8.8.3 Establishment and management of model: Site preparation involves leveling, marking of pits with recommended spacing, fencing and digging of pits. Digging of pits enable develop deep tap root, improve aeration, water permeability, removal of weeds, exposing insects pests and spores for sunlight. Usually site preparation activity will be done three to four months before planting. In Indian condition planting will be done in June-July, hence site preparation may be planned well in advance by March/April. Seedlings for planting should be of height greater than 1.0 foot, collar diameter more than 3 mm and 1/3rd seedling stem should be brown in colour. The seedlings should be devoid of forked branches and must be healthy and straight with a leading shoot. Pits of size 45×45×45 cm should be left for weathering for minimum of one month. Insecticide/fungicide may be applied during planting in pit to kill the harmful organisms. At the time of planting 2 kg of farm yard manure may be applied in the pit to increase water holding capacity. Planning configuration in this model is 6x3 m and usually planting is done after the onset of monsoon. Irrigation is essential for first three year in an interval of 3-5 days, especially during summer. Application of suitable fungicide and insecticide in pit before planting will reduce the infestation level. Intercropping is possible for 5-6 years in this model.

8.8.4 Rotation period and yield: Sandalwood trees will be felled / harvested at the age of 15 years for heartwood purpose with a yield of 15 kg of heartwood. The average height of the tress will be 8-10 m and 40-50 cm girth and fetched Rs. 6000 per kg heartwood. The yield obtained from Horse gram was 500 kg/year/ha and for aonla was 4 ton/ha from 5th year onwards. Casuarina in block plantation yielded 500 poles in ten year.

8.8.5 Economics of the model: Total expenditure for whole model (inclusive of all operation from sowing to harvest) was Rs. 1.5 crores. Income from aonla was Rs.1.2 lakhs for 4 t/ha/year at Rs. 30/kg. Income generated from sandalwood at 15 years age was Rs. 3.6 crores for 6000 kg of heartwood/ha at 15 Kg/tree at Rs. 6000/kg. Income from horse gram was Rs. 20,000 for 0.5 t/ha/year at Rs 40/kg. Income from Casuarina was Rs. 50,000 for 500 poles at Rs. 100/pole. Net income generated from this model was Rs 2.00 crores.

8.8.6 Impact and upscaling: Sandalwood based agroforestry system having aonla and horse gram as intercrops will help farmer to gain initial income from horse gram and intermediate income from aonla. It also helps to sequester more carbon and enhances overall productivity which ensures higher net farm income by optimal usage of natural resources. This model can be upscaled through training programme to farmers, extension materials, farmer to farmer interaction and farm field visits.

Fig. 30 Sandalwood based agroforestry Systems

Chapter 9

Agroforestry in Western Dry Region

Agroforestry in Western Dry Region

Western dry region covers hot dessert, arid and semi-arid areas extending over Rajasthan, west of the Aravallis, Gujrat and Dadar-Nagar Haveli. Following models have been developed by Arid Forest Research Intstitute (AFRI), Jodhpur for western dry regions:

i. *Hardwickia binata* based agroforestry model
ii. *Emblica officinalis* based agroforestry model
iii. *Colophospermum mopane* based agroforestry model
iv. *Prosopis cineraria -Zizyphus mauritiana* agroforestry model

9.1 *Hardwickia binata* based agroforestry model

9.1.1 Edaphic and environmental requirement of model: This model is performing well in arid and semi-arid region of Rajasthan. *Hardwickia binata* is a tree of the dry deciduous forests. In India, it is found in the western Himalayas up to an elevation of 1500 m and dry open forests of Central and South India. The tree grows best in sandy loam or reddish gravelly sand but tolerates light acidic to moderate saline soils. Overlying soil does not have to be deep since the taproot has a capacity for growing through fissures in solid rock. It can be grown well in the soils with low in organic matter, nitrogen and phosphorus.

9.1.2 Significance of model: *Hardwickia binnata* (Anjan) is the most important agroforestry tree in dry areas of India. The tree is utililized optimally in terms of food, fodder and fuel wood. In experiments fixed and rotational crop sequence were used i.e. *Cyamopsis tetragonoloba* (cluster bean or Guar), *Sesamum indicum*, *Pennisetum glaucum* and *Vigna radiata*. Tree heights are comparatively more under rotational crop than in fixed crop plots of *Vigna radiata*. Crop yield reduction is about 24% with pearl millet in crop rotation and 77% with *V. radiata* in tree canopy zone area with limited water availability. Since 2012 onwards in this model along with intercrop *Cyamopsis tetragonoloba* different silvicultural treatments like intact tree, tree branch removal up to 70% tree height, root barrier treatment and combination of both tree branched removal-root barrier treatment was practiced.

H. binata based agroforestry model is common in central India particularly as boundary plantation. This species was introduced in western dry region to enhance fodder production to feed the domestic animals on which the economy of the local people depends to larger extend. Block plantation with suitable crops combination provides higher land productivity and improves soil fertility. Its easy management in block plantation with intercrops should encourage farmers for the plantation on their land. Likewise, lopping and putting root barriers minimizes the competitive effects of trees on the companion intercrops.

9.1.3 Establishment and management of model: Four month old seedling of *Hardwickia binata* was planted to maximize fodder and fuel wood with different crop sequences. Spacing of the plantation was 5x5 m. Pit size is 45x45x45 cm^3.

Basal doges of 10 kg FYM and 20 g forate (anti-termite insecticide) per seedling were applied at the time of plantation. Life saving irrigation was provided at time of plantation and after rainy season 25 liter water was provided to each plant at one month interval. Plantation was maintained through different silvicultural activities viz. irrigation, soil working, weeding, protection, anti-termite treatment, pruning etc.

In subsequent experiment, different silvicultural treatments like intact tree, tree branch removal up to 70% tree height, root barrier treatment and both tree branched removal-root barrier treatment were practised. These treatments showed varying effects on tree growth and productivity of the companion crops. Tree pruning along with root barrier observed detrimental for the growth of *H. binata* but it was beneficial in enhancing productivity of intercrops. *H. binata* was found competitive with *Cyamopsis tetragonoloba* crop. Growth and grain yield of *C. tetragonoloba* crop was found highest in lopped tree with root barrier and lowest yield under unlopped trees condition. Competition was minimized through pruning and trenching around tree. *H. binata* is also favourable in enhancing nutrient availability and carbon sequestration.

Fig. 31 *Hardwickia binata* based agroforestry model

9.1.4 Fuel wood and fodder yield from *H. binata*: Pruned biomass (fodder) of *H. binata* was 3.99 kg in rotation crop and 3.33 kg in fixed crop per plant at 8 years age· Average total dry biomass of *H.binata* trees ranged between 4.49 to 135.85 kg per tree at 17 years age. Biomass accumulation in stem was 45.7% of total biomass. Foliage contribution of the total biomass was 23.5%. *C. tetragonoloba* crop production was highest in pure crop plot followed by lopped and then in root barrier treatment.

9.1.5 Impact and upscaling: The study demonstrates the usefulness of tree in increasing total productivity of land. The resource competition was minimized through silvicultural practices which improved crop production. The model also helped in carbon sequestration and thus indirectly mitigating climate change and environmental effects.

9.2 *Emblica officinalis* (Aonla) based agroforestry model

9.2.1 Edaphic and environmental requirement of model: This model performed well in dry region of Rajasthan and Gujarat where soil is loamy sand to loamy silt. The mean annual rainfall zone is from 400-900 mm. It is not suitable for arid zone facing drought in rainfed condition.

9.2.2 Significance of model: *Emblica officinalis* (Aonla) model is suitable for maximising food and fruit yields under crop sequences of *Cyamopsis tetragonoloba*, *Sesamum indicum*, *Pennisetum glaucum* and *Vigna radiata*. Tree height is favourable under rotational cropping system than fixing a single crop continuously. Although crop yield reduction has been observed up to 32% for pearl millet and 5% for *V. radiata,* but the yield of fruits from *E. officinalis* are better compensations for adopting this model, particularly in irrigated condition.

E. officinalis based agroforestry model is not much practiced in the region rather The tree is cultivated occasionally to obtain Vitamin C enriched fruits of this species for preparation of different dishes like Murabba, Achar, jelly etc. *E. officinalis* was introduced to enhance total yield per unit area along with fruit production and to enhance income of farmer. The fruits obtained from *E. officinalis* can compensates with reduced crop yield in the system.

9.2.3 Establishment and management of model: *E. officinalis* was planted to maximize food and fruit yields under different crop sequences. The spacing of the plants was 5x5 m and the container grown seedlings were planted in pit size of 45x45x45cm. Each sub plot had 12 trees. Basal doges of 4 kg FYM and 20 g forate (termiticide) were applied at the time of plantation. Life saving irrigation was provided at time of plantation and after rainy season i.e. 30 liter water per plant at one month interval. Plantation was maintained through different silvicultural activities viz. irrigation, soil working, crop sowing and related cultural operations.

The treatments plots were (i) *E. officinalis* intercropped with *Vigna radiata* throughout the study (FC) and (ii) *E. officinalis* intercropped with *Vigna radiata*, *Pennisetum glaucum*, *Cyamopsis tetragonoloba* and *Sesamum indicum* in rotation (RC). The RC plots had *Penisetum glaucum*, *Vigna radiata*, *Sesamum indicum*, *Cyamopsis tetragonoloba*, *S. indicum* and *P. glaucum* as the agricultural crops grown in 1996, 1997, 1998, 1999, 2000 and 2001 respectively. Crops were sown and harvested in the rainy season (July to October) under rainfed conditions.

9.2.4 Impact and upscaling: Because of relatively more water requirement of *E. officinalis,* this model can be more suited to semi-arid areas with supplemental irrigation. Integrating *E. officinalis* improves soil conditions like soil organic carbon and soil fertility, decrease soil pH and increase overall system productivity.

9.3 *Colophospermum mopane* based Agroforestry model

9.3.1 Edaphic and environmental requirement of model: The model performs well in dry region of Rajasthan as well as in similar climatic conditions. *C. mopane* often grow on loamy sand and clay loam soils with low organic matter, available nitrogen and phosphorus and tolerates saline and poorly drained soils better than other species. It is a dominant species of dry deciduous forest. It grows between 300-1000 m altitudes, -3 to 50 °C temperature and 200-800 mm mean annual rainfall zone.

9.3.2 Significance of model: *Colophospermum mopane* (Mopane) is introduced for maximising food, fodder and fruit yield with fixed and rotation crop sequences. The tree height is comparatively more under rotation cropping system than in fixed cropping system. It is highly competitive with intercrops because of competitive use of soil resources as soil water content reduces by 12.6% - 15.4% in the canopy zone of *C. mopane* than in the soils of control plots. *C. mopane* tree is not commonly planted on farmers land in the region due to its exotic nature. However it has been introduced to enhance fodder production, sand dune stabilization and rehabilitation of wastelands. Row plantation or boundary plantation with suitable crops combination works as safeguard to enhance total land productivity and improved soil fertility. Because of strong competitive nature for available natural resources *C. mopane* is not a suitable integration in farmlands. It is most suitable to rehabilitated degraded sites. *C. mopane* have greater adaptability for survival in the degrade sites due to well developed root system with high root/ shoot ratio.

9.3.3 Establishment and management of model: *C. mopane* was planted in July 1994 in pit size is 45x45x45 cm to maximize fodder and fuelwood production with different crop sequences. Spacing of the plantation was 5x5 m. Basal doges of 10 kg FYM and 20 g forate were applied at the time of plantation. Life saving irrigation was provided at time of plantation and after rainy season. About 30 liter water was provided to each plant at one month interval. Plantation was maintained through different silvicultural activities viz. irrigation, soil working, weeding, protection, anti-termite treatment, pruning etc. Different intercrops were sown in different years starting from 1996.

Silvi-pasture was adopted by dibbing the seeds of *Cenchrus ciliaris* grass manually in the furrows and reducing both above and below ground competition in 2012. Four treatments practiced were intact tree, tree branch removal up to 70% tree height, root barrier treatment and both tree branched removal-root barrier treatment. The treatment maintained through lopping in each year.

In another experiment seeds of *C. mopane* were broadcasted after deep ploughing, mixing and covering of the seeds with soil. It provided 98% germination and 92%

survival at one year of age and has developed into dense vegetation cover at 16 years of age.

Fig. 32 *Colophospermum mopane* based agroforestry model

9.3.4 Fuel wood and fodder yield from *C. mopane:* Seventh year onwards *C. mopane* produces 3 to 4 kg dry fodder/fuel wood per tree per year. Fruit production was 0.5 kg per tree at 5 years age and 1.25 kg per tree at 9 year age. Fruit production was less when pearl millet (*Pennisetum typhoides*) and guar (*Cyamopsis tetragonoloba*) were intercrop. Average total dry biomass ranges between 5.91 to 130.41 kg per tree at 17 years of age. Biomass accumulation in stem was 28.6%. The contribution of foliage was 40.2% in *C. mopane* trees.

C. ciliaris grass production was highest in sole grass plot (20.61 t/ha) followed by lopped and root barrier treatment (16.72 t/ha). The grass production was lowest (13.61 t/ha) in intact trees plot.

9.3.5 Impact and upscaling: Lopping of *C. mopane* along with root barrier was found beneficial in enhancing productivity of silvipastoral system in dry areas. Thus this species is most suitable for silvipastoral system in dry land for fodder production rather than its integration in farmers land. It can be utilized for rehabilitation of degraded wastelands under site preparation and direct seeding. Resources competition between trees and grass can be minimized through silvicultural practices for benefits of enhancing total productivity and improve people livelihood. It facilitates in carbon sequestration and thus helping indirectly in mitigating climate change and environmental effects.

9.4 *Prosopis cineraria-Zizyphus mauritiana* (grafted Ber) agroforestry model

9.4.1 Edaphic and environmental requirement of model: The model will perform well in dry region of Rajasthan where soil is well drained having irrigation facility. Life saving irrigation is required upto 3 years after plantation. Generally these species are grown in temperature range of 4°C to 45°C with annual rainfall of about 400 mm.

9.4.2 Significance of model: This model provides economic benefit and income to the farmers along with cultivated arable crop like wheat. Integration of grafted ber (*Z. mauritiana*) and khejri (*P. cineraria*) with wheat crop was best agroforestry model where reduction in wheat yield was only 5% than sole crop. It was found less competitive than any other horti-silvi combinations. Combination of *P. cineraria* and *Z. mauritiana* showed synergistic effect on the wheat crop yield and exhibited the highest B: C ratio of 1.4 as compared to the sole crop. Soil organic carbon was increased by 8% in top layer and by 13% in lower layer in agroforestry plots as compared to the control plot. Thus agroforestry model was observed to be more beneficial than sole agricultural crop in term of carbon benefits. Cultivation of good quality saplings of khejri and grafted ber (Gola variety) is good combination for higher economic yield. Research institutions and SFDs are developing good quality of khejri seedlings whereas grafted ber is developed by research institutions as well as commercial private nurseries. These quality materials are beneficial when integrated in the farmlands for enhancing total yield per unit area.

9.4.3 Establishment and management of model: A farmland was ploughed and weed removed in collaboration with farmers. Khejri and grafted ber were planted alternate to each other at a spacing of 6x6 m with pit size of 60x60x60 cm. Basal doges of 10 kg FYM, 150 g DAP, 450 g SSP and 25 g forate was applied at the time of plantation. Drip irrigation was provided at 10 days interval in summer season and 15 days interval in winter season. Plantation was maintained through different silvicultural activities viz. irrigation, soil working, weeding, protection, anti-termite treatment, pruning etc. Grafted ber was pruned every year in month of May. Wheat crop was grown each year with this combination. Intercropping is possible up to 10 to12 years of tree age.

9.4.4 Fuel wood and fodder yield from khejri: Production of fodder at 6 year of age was 0.20 tons/ha for *P. cineraria*. Production of utilizable biomass at 6 year of age was 2.18 tons/ha for *Z. mauritiana* and *P. cineraria*.

9.4.5 Economics of model: This model provided additional benefit of Rs. 7184 ha at the age of 6 year as compared to agriculture crop.

9.4.6 Impact and upscaling: Khejri-gafted ber based agri-horti-silvi model provides additional benefit to the farmers in arid region. In addition it also sequesters more carbon and improves soil fertility. The model advances total productivity and has been adopted by farmers of the adjacent village.

Chapter 10

Agroforestry in Coastal Plains and Ghats

Agroforestry in Coastal Plains and Ghats

Coastal plains and ghats cover Coromandel and northern Circar coasts of Andhra Pradesh, Odisha, Malabar coastal plains, Konkan coastal plains and the Sahyadris. States and Union Territories covered under this agro-climatic condition are Tamil Nadu, Kerala, Andaman and Nicobar Islands, Lakshadweep Islands and Puducherry. Following models were developed by Institute of Forest Genetics and Tree Breeding, Coimbatore for these regions:

i. Casuarina (*Casuarina equisetifolia*)- Maize (*Zea mays*) agri-silviculture model
ii. Casuarina (*Casuarina equisetifolia*)-Moringa (*Moringa oleifera*)-Maize (*Zea mays*) agri-silvi-horticulture model
iii. *Acacia auriculiformis*-Napier grass (*Pennisetum purpureum*) silvi-pasture model
iv. Teak (*Tectona grandis*)-Blackgram (*Phaseolus mungo*) agri-silviculture
v. *Acacia mangium*-Beans (*Vigna* species) agri-silviculture model
vi. *Acacia mangium*- Pepper (*Piper nigrum*) silvi-horticulture model
vii. *Casuarina* based windbreak agroforestry model

10.1 Casuarina (*Casuarina equisetifolia*)-Maize (*Zea mays*) agri-silviculture model

10.1.1 Edaphic and environmental requirements of model: This model is suited for areas with average annual rainfall ranging from 600 to 800 mm and average annual temperature from 27-29^{o}C. The soil type suited for the model is yellowish red to dark reddish brown with calcic sub soil horizon. Texture is sandy loam to loamy sand and pH of the soil is alkaline and varies from 8.2 to 8.5.

10.1.2 Significance of model: This model is beneficial to the farmers, who can plant Casuarina trees in their farm fields along with other annual crops especially with maize for higher economic returns. IFGTB has come up with superior clones and hybrids in Casuarina with high wood yield. These superior clones can be planted in this agri-silvi system for higher economic returns. It is also important to note that Casuarina being nitrogen fixer will also help in soil improvement.

10.1.3 Establishment and management of model: Normally the land is prepared for growing agricultural crops just before the onset of southwest monsoon (May-June). Raising of agricultural crop and planting of Casuarina seedlings is carried out simultaneously. Parallel watering channels are taken 7 m apart. Three month old potted seedlings of Casuarina are planted in pits of size 30 cm^3 at 2 m distance between plants in each channel. Thus the density of Casuarina remains as 650 trees/ha. A basal dose of 25 g each of nitrogen, phosphorus and potassium fertilizer and 1 kg FYM is added in each pit at the time of planting. Biofertilizers like Frankia or Azospirillum are mixed with the soil in the pits for better establishment. Application of biofertilizers can also be done in the nursery while raising the seedling. Maize (*Zea mays*) is dibbled at 60x25 cm apart as per package of practices in the interspace between Casuarina rows. Casuarina grows well and fast under irrigated conditions. The seedlings are watered once in a week for the initial two months and later no additional watering to the tree seedlings was given. The seedlings share the water with the agricultural crop as and when the crop is irrigated. However, during the post harvest period and during the dry season, tree rows are irrigated at fortnightly intervals. Casualty replacement is done within a month's period. Periodical cultural operations such as weeding, soil working etc. are to be carried out twice a year. Lower lateral branches of the trees up to nearly half the height of canopy are pruned during the second and third year and the pruned material can be used as fuel wood.

Fig. 33 Casuarina -Maize agri-silviculture model

10.1.4. Rotation period and yield: Casuarina trees will be felled/harvested in the age of 4 years for pole purpose (average height 8.1 m and 34.2 cm girth, 650 poles can be harvested per ha and sold at Rs.45 per pole). Maize yield was 2.0 t per ha per year.

10.1.5 Economics of the model: Total expenditure for whole model was Rs.6,238 (inclusive of all operation from sowing to harvest). Income generated from maize was Rs.8,000 per ha per year for Rs 4,000 per ton. Income generated from Casuarina poles was Rs.29,250 at Rs.45 per pole and Rs 1,820 from fuel wood. Net income from this model was Rs 32,832.

10.1.6 Impact and upscaling: Casuarina-maize based agri-silvi model gives short rotation tree harvest and soil fertility improvement through nitrogen fixation. The upscaling of this model can be done through establishing of demonstration plots with high yielding clones released by IFGTB.

10.2 Casuarina (*Casuarina equisetifolia)*-Moringa (*Moringa oleifera*)-Maize (*Zea mays*) agri-silvi-horticulture model

10.2.1 Edaphic and environmental requirements of model: This model is suited for areas with average annual rainfall ranging from 600 to 800 mm and average annual temperature may vary from 27-29^{o}C. The soil type suited for the model is yellowish red to dark reddish brown soil with calcic sub soil horizon. Texture is from sandy loam to loamy sand and pH of the soil is alkaline and varies from 8.2 to 8.5.

10.2.2 Significance of model: This model is beneficial to the farmers who can plant Casuarina trees in their farm fields along with Moringa for higher economic returns. The superior clones of Casuarina can be planted in this silvi-horticulture system for higher economic returns. It is also important to note that Casuarina being nitrogen fixer will also help in soil improvement.

10.2.3 Establishment and management of model: Raising of agricultural crop by the onset of monsoon (May-June) and planting of Casuarina and Moringa seedlings in the field is carried out simultaneously. Parallel watering channels are taken 7 m apart. Three month old potted seedlings of Casuarina and one month old potted seedlings of Moringa (var: PKM-1) are planted alternately in pits of size 30 cm^3 at 2 m distance between plants in each channel. Thus the density of Casuarina and Moringa remains as 325 trees/ha. A basal dose of 25 gm each of N, P & K fertilizers is added to each pit at the time of planting for Casuarina. For Moringa plants, 100 gm each of Urea and SSP and 50 gm MOP are added to the pit in the third month. At the end of sixth month an additional dose of 100 gm urea is added for better establishment. Biofertilizers like *Frankia* or *Azospirillum* can also be mixed with the soil in the pits for better establishment. During the initial two months weeding is essential. Maize (*Zea mays*) is dibbled at 60x25 cm apart as per package of practices in the interspace between Casuarina-Moringa rows.

10.2.4 Rotation period and yield: Casuarina trees will be felled/harvested in the age of 4 years for pole purpose (average height 8.1 m and 34.2 cm girth, 650 poles can be harvested per ha and sold at Rs.45 per pole). Maize yield was 2.0 t per ha per year. Moringa yield is 68,250 number of drumsticks per ha in 3 years at Rs 60 per 100 fruits. The income earned was Rs. 40,950 from sale of Moringa.

10.2.5 Economics of the model: Total expenditure for whole model was Rs.7,264 (inclusive of all operation from sowing to harvest). Income generated from maize was Rs.8,000 per ha per year for Rs 4,000 per ton. Income generated from Casuarina poles was Rs.29,250 at Rs.45 per pole and Rs.1820 from fuel wood. Income from Moringa was Rs.40,950 at Rs 60 per 100 fruits. Net Income generated from this model was Rs 57,971.

10.2.6 Impact and upscaling: Casuarina-Moringa-maize based agri-silvi-horti model gives short rotation tree harvest and soil fertility improvement through nitrogen fixation. The upscaling of this model can be done through establishing of demonstration plots with high yielding clones released by IFGTB.

10.3 *Acacia auriculiformis*-Napier grass (*Pennisetum purpureum*) silvi-pasture model

10.3.1. Edaphic and environmental requirements of model: Average annual rainfall required is ranging from 600 to 800 mm. Average annual temperature may vary from 27-29°C. Soil is yellowish red to dark reddish brown with calcic sub-soil horizon. Texture range from sandy loam to loamy sand. The soil pH is alkaline and varies from 8.2 to 8.5.

10.3.2 Significance of the model: This model is suited to the class IV-VIII lands to meet the fuel and fodder demand. The class IV-VIII lands are not put under any use and lie as fallow land mostly and occaionally put under rainfed agriculture. Class IV lands in the micro-watershed are unproductive due to many reasons. Establishment of silvipasture was one of the options adopted to convert these lands productive. Therefore, various technologies like formation of contour bunds, rain water harvesting structures, moisture conservation measures and planting drought resistant species (like *Acacia* spp. *Eucalyptus*, *Gliricidia* etc.) were adopted depending on site conditions.

10.3.3. Establishment and management of model: The model was established by planting *Acacia auriculiformis* seedlings raised in the poly bags (4 months old) at 4 m spacing between plants and 7 m between rows in pits of size 30 cm^3 (Shanmughavel *et al.,* 2003). A basal dose of 50 g of diammonium phosphate (DAP), 50g of muriate of potash and 1 kg of farmyard manure (FYM) was applied at the time of planting to boost up growth of the seedlings. Slips of Napier grass *(Pennicetum purpureum)* were planted in the inter space between the rows with spacing of 50x50 cm. At the time of planting 50 kg/ha of N, 50 kg/ha of P_2O_5 and 40 kg/ha of K_2O was applied and watered once in a week. Casualty replacements of trees is carried out within a month's period and a density of 325 trees/ha maintained. Other periodical cultural operations such as weeding, soil working and fertilizer application were carried out time to time as per standard practice.

10.3.4 Rotation period and yield: During the second and third year, lateral branches of the trees were pruned to ward off any shade effect to the grass. The pruned material (2.8 t/ha) formed the biomass for fuel wood. At four years of age the tree attains an average height of 8.5 m and girth of 24.70 cm at breast height. The entire biomass available at this time can be utilized as fuel wood. The fuel wood biomass amounted to 18.44 t/ha which included the main bole, branch wood and pruned material.

10.3.5 Economics of the model: Total expenditure for model was Rs.21,088 (inclusive of all operation from sowing to harvest) for year 2000. Income from Napier grass is Rs.80,000 per ha. Income from Acacia fuel wood was Rs. 14,752 at Rs. 800 per/t. Net income generated from this model was Rs 73,664.

10.3.6 Impact and upscaling: This model holds potential for farmers where the primary consideration is for fodder and fuel wood. Moreover there was no significant reduction in the fodder yield when intercropped with *Acacia auriculiformis*.

10.4. Teak (*Tectona grandis*) - blackgram (*Phaseolus mungo*) agri-silviculture model

10.4.1 Edaphic and environmental requirements of model: This model is suited for areas with average annual rainfall ranging from 600 to 800 mm and average annual temperature may vary from 27-29^{o}C. Texture of soil is sandy loam to loamy sand and pH of the soil is 6.5 to 7.5.

10.4.2 Significance of model: This model is beneficial to the farmers, who can plant teak trees in their farm fields along with other annual crops especially with maize for higher economic returns. Teak can be planted in wide rows of 8x4 m and the alley can be used for cultivation of black gram upto 5 years as inter-crop in this Teak based agri-silvi system. The tree component will have minimal effect on yield on intercrop.

10.4.3 Establishment and management of model: Teak stumps were planted 4 m apart in the channels formed at 8 m wide and the density remained as 325 trees/ha. As soon as the stumps were established, 3 to 4 irrigations were given to tree component during first three months to maintain better survival percentage and later no irrigation was given to the trees. Agricultural crops were grown every year with this combination.

Fig. 34 Teak- blackgram agri-silviculture model

10.4.4 Rotation period and yield: The girth and height of the trees increased steadily as age increased and attained a girth at breast height of 46 cm and height of 11 m at the end of fifth year. The volume produced at five years age was 50.4 m^3/ha with an average productivity of 10.1 m^3/ha/yr.

10.4.5 Economics of the model: Total expenditure for whole model was Rs. 12,275 (inclusive of all operation from sowing to harvest) for year 2004. Income generated from Black gram was Rs.10,400 per ha per year at Rs.16 per kg.

Income from Teak poles was Rs. 65,000 at Rs.200 per pole and Rs 2250 from fuel wood. Net income generated from this model was Rs 65,375.

10.4.6 Impact and upscaling: Under Teak-black gram model, the trees attained an average productivity of 10.1 m^3/ha/yr, which is almost double that normally attained under forest plantations. Further it was also found that teak based agroforestry improves fertility status of the soil and facilitates to recycle nutrients from deeper layer to topsoil and in turn sustains the productivity of the system.

10.5 *Acacia mangium* - Beans (*Vigna* species) agri-silviculture model

10.5.1 Edaphic and environmental requirements of model: The annual average rainfall required is 776 mm. The temperature ranges from 20^0C to 37.5^0C. Red sandy loam soil is suited for this model.

10.5.2 Significance of model: This model is beneficial to the farmers, who can plant *Acacia mangium* trees in their farm fields along with other annual crops especially with beans for higher economic returns. Mangium being nitrogen fixing tree will help in enhancing soil fertility. Farmers are practicing beans cultivation without incorporation of tree components like Mangium. Mangium is also being cultivated as sole pulpwood plantation. Quality planting stocks of *A. mangium* raised from seeds collected from seed orchards will help in attaining higher productivity under agroforestry systems.

10.5.3 Establishment and management of model: The model was established with superior seedling stocks of *Accaia mangium* with 4.5 x 4.5 m spacing. Intercropping activities was carried out up to third year with Onion, Beans and Horse gram. Pruning, weeding and soil working were carried out in the established agroforestry plot.

Fig. 35 *Acacia mangium* - Beans agri-silviculture model

10.5.4 Rotation period and yield: At the end of third year, the girth and height of *A. mangium* was recorded 30 cm and 6.1 m respectively. In turn, volume production was 10.64 m^3 per ha and wood yield on fresh weight basis was 9.0 MT per ha. Besides better performance in terms of growth and wood yield, there exits a greater possibility of cultivation of agricultural crops up to the harvest age of six years. The yield reduction observed up to three years period was mainly due to the difference in the total number of plants under open and under *A.mangium* plot and not due to the suppression effect of tree component over the agricultural crops. Among different agricultural crops intercropped with *A. mangium* viz. tomato (*Lycopersicon esculentum*), black gram (*Vigna mungo*), horse gram (*Macrotyloma uniflorum*), fodder sorghum (*Sorghum bicolor*) and beans (*Phaseolus vulgaris)* were found to be compatible. Finally *Acacia mangium* pulp yield estimated is 18 MT per ha and fuel wood yield is 2.0 MT per ha from branches after the rotation period of 6 years. Green beans yield is estimated 24 MT per ha for 6 years.

10.5.5 Economics of the model: Total expenditure for whole model was Rs. 89,000 (inclusive of all operation from sowing to harvest, year 2009). Income generated from beans was Rs.1,44,000/- per ha in 6 year at Rs 6 per kg. Income from mangium pulp wood was Rs. 36,000 at Rs. 2000 per MT of pulp wood and Rs 2000 from fuel wood. Net income generated from this model was Rs. 93,000.

10.5.6 Impact and upscaling: By considering of growth, wood yield and greater possibility of cultivation of agricultural crops up to the harvest age of six years. *Acacia mangium* can be a tree component under agroforestry system in farm fields receiving high rainfall of 1000 mm or having irrigation system.

10.6 *Acacia mangium*-Pepper (*Piper nigrum*) silvi-horticulture model

10.6.1 Edaphic and Environmental requirements of model: The average annual temperature of 27.5 °C and rainfall of 2604 mm is suited for this model.

10.6.2 Significance of model: This model is beneficial to the farmers who can plant *Acacia mangium* trees in their farm fields and the *A. mangium* trees can serve as support for pepper cultivation. *A. mangium* being nitrogen fixing tree will help in enhancing soil fertility. Farmers are practicing pepper cultivation using *Erythrina* or *Gliricidia. A. mangium* is also being cultivated as sole pulpwood plantation. Quality planting stocks of *A. mangium* raised from seeds collected from seed orchards will help in attaining higher productivity of *A. mangium* under agroforestry systems.

10.6.3 Establishment and management of model: This model is established with superior seedling stocks of *Accaia mangium* with 4x3 m spacing. Pruning, weeding and soil working were carried out in the established agroforestry plot. At the end of first year, pepper was introduced at two vines per tree. Elephant foot yam (*Amorphophallus paeoniifolius*) or tapioca (*Manihot esculenta*) was the optional inter crop during first and second year. The yield from pepper is expected to be realized from fourth year onwards of planting and can be retained as yearly harvest of pepper is continued up to 20 years period.

Fig. 36 *Acacia mangium*- Pepper silvi-horticulture model

10.6.4 Rotation period and yield: At the end of third year, the girth and height of Mangium recorded was 36 cm and 15 m respectively. In turn, volume production was 79.12 m^3 per ha and wood yield on fresh weight basis was 54 MT per ha. Besides better performance in terms of growth and wood yield, there exits a greater possibility of cultivation of Pepper up to 20 years. *Acacia mangium* pulp yield estimated is 160 MT per ha and fuel wood yield was 30 MT per ha from branches after the rotation period of 20 years. Pepper yield estimated were 14.6 MT per ha for 17 years (as yield starts from fourth year onwards).

10.6.5 Economics of the model: Total expenditure for whole model was Rs. 3,78,500 (inclusive of all operation from sowing to harvest (Year 2009). Income generated from pepper was Rs.8,76,000/- per ha for 17 years for Rs 60 per kg. Income generated from Mangium pulp wood was Rs. 3,20,000 at Rs. 2000 per MT of pulp wood and Rs 30,000 from fuel wood. Net income from the model was of Rs 8,48,000.

10.6.6 Impact and upscaling: By considering the growth, wood yield and greater possibility of cultivation of pepper up to 20 years, *Acacia mangium* can be a tree component under agroforestry system in farm fields receiving high rainfall more than 1000 mm in Kerala.

10.7 Casuarina (*Casuarina equisetifolia*) based windbreak agroforestry model

10.7.1 Edaphic and environmental requirements of model: The average annual temperature of 21-35°C and the rainfall averages of 700 mm are suited for this model.

10.7.2 Significance of model: Annual crop loss worth crores of rupees is reported in the country due to windstorms. This crop loss due to heavy wind is more frequently being reported in banana plantations. To efficiently manage this recurrent problem, IFGTB has released five superior clones of *Casuarina junghuhniana* for providing protection against windstorms to horticultural and agricultural crops like banana, citrus crops, red gram, etc. This casuarina based windbreak tree varieties planted on the periphery of farm lands can help slow down the speed of wind and minimize the damage to cash crops. These clonal windbreaks also reduce evaporation from the soil and water loss through transpiration from the crops inside. This in turn increases productivity of agriculture crops from 10 to 30%.

Banana and other horticultural crops are being cultivated as sole crops without windbreaks. Some farmers use plastic strips to tie together the banana plants to protect from wind damage, which is not cost effective and also labour intensive. Windbreak tree varieties of *Casuarina* can be in three rows as windbreaks. These windbreak tree varieties of IFGTB show high level of branch persistence with 40 to 50 thick and horizontal branches within 3 m height from the base of the tree. The other superior chractersties of these clones are: i) greater branch thickness, ii) wider branch angle, iii) greater height growth rate (2.5 to 3 m per year) and iv) faster diametrical growth rate of main stem (1.5 to 2 cm per year).

Fig. 37 IFGTB windbreak tree varieties with cow pea

10.7.3 Establishment and management of model: After land preparation by ploughing and formation of three channels at distance of 0.5 m or 1 m all along the boundary within each channel, superior clones of Casuarina are planted at 2 m interval within the rows in 'Quincunxs' or 'Zig-zag' pattern. Thus the tree density will be around 380 trees per acre.

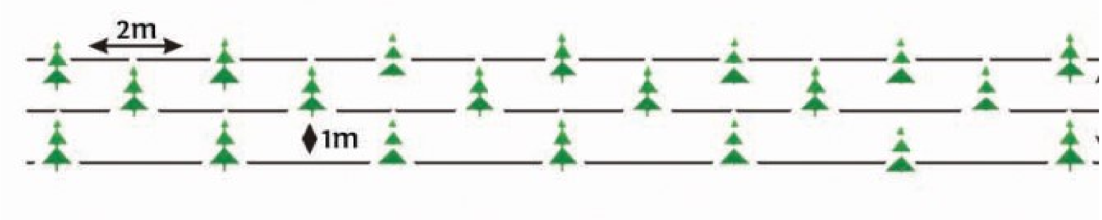


Fig. 38 Casuarina (*Casuarina equisetifolia*) based windbreak agroforestry Model

10.7.4 Rotation period and Yield: On an average, 20 MT of wood can be harvested from four years onwards. Windbreaks were planted in field boundaries of one ha land. The windbreak clones gave about 40% more yield when compared to other clones in the market. Farmers can get an additional income of up to Rs. 1,00,000 per ha, besides the protection of agriculture and horticulture crops from the wind damages.

Fig. 39 Poles harvested from 4 year old clonal windbreaks in banana field

10.7.5 Economics of the model: Total expenditure for whole model for the year 2013 was Rs 31,500 (inclusive of all operation from sowing to harvest). Income generated from banana was Rs.51, 450 per ha for per year. Income generated from Casuarina pulp wood was Rs. 1, 00,000 at Rs. 5000 per MT of pulp wood at the 4th year. Net income from this model was Rs 1, 19,950.

10.7.6 Impact and upscaling: Scientific study has demonstrated that red gram variety (CO-8) suffered no crop lodging when planted inside windbreaks and recorded a 1.5 times higher yield compared to crop cultivated in open field without windbreaks. Hence, the windbreaks not only protect the crops but also enhance its productivity substantially. Windbreaks can be also used for fruit orchards as windbreaks enhance the orchard microclimate, thus improving conditions for pollination and fruit set which in turn result in greater yields.

Fig. 40 Crop lodging prevented by windbreaks established with IFGTB-windbreak Clones

Chapter 11

Agroforestry way ahead

Agroforestry way ahead

Trees and forests were always considered as an integral part of the Indian culture. With increasing population and huge gap between demand and supply, forests were ruthlessly exploited to meet the increasing demand of fuel, fodder, timber and NTFPs. Competing uses of land for agricultural, forestry pastures, human settlement and industries exerts tremendous pressure on the country's finite land resources. Despite pressures to part away forest land for development purposes, India is also pursuing its goal of having 33% of its geographical area under forest and tree cover. Added to this are the targets of nationally determined contribution (NDC) committed by the country under the Paris agreement of UNFCC. The forestry sector in India needs to gear up through inter-sectoral linkages and convergence to meet the future challenges. To overcome this huge burden upon our existing forests some alternative steps are essential to meet the increasing demand of forest produce. Actions on forest and non-forest land become important. Improving forest areas and rehabilitating degraded forests alone will not serve the purpose. Greening non-forest lands by creating additional tree cover through agroforestry, farm forestry, urban and peri-urban forests, roadside avenues etc., needs to be developed. Concept of multiple use of land with multipurpose tree species has become important. In this context, agroforestry, which is a form of multiple land use system, needs to be adopted and encouraged. Under agroforestry system one could achieve greater efficiency of tree species for photosynthesis, improved soil structure and fertility with increasing effects on crop yield. Development of improved varieties of fast grown species and farmers taking up plantation activities has led to the demand for timbers shift from forest resources to trees grown outside forest (TOF). Agroforestry as multiple land use system also reduces losses from soil erosion and more closed cycling of organic matter and nutrients. It has yielded in creating better micro climatic conditions for the growth of agricultural crops.

Agroforestry Promotion

National Agriculture Policy (2000) clearly states, "Agriculture has become a relatively unrewarding profession due to generally unfavorable price regime and low value addition, causing abandoning of farming and increasing migration from rural areas". Hence the policy stresses, "Farmers will be encouraged to take up farm/agroforestry for higher income generation by evolving technology, extension and credit support packages and removing constraints to development of agroforestry". Rural people have been practicing tree planting in their farms and homesteads to meet household requirements of fuel, poles, timber and medicinal plants. With the advent of agroforestry, diversification in agriculture was encouraged to generate high income and minimize risks in cropping enterprises.

Planning Commission has recommended following suggestions for promoting agroforestry (Anonymous 2001):

i. Rather than having a uniform strategy for the whole country commercial agroforestry should be adopted in irrigated districts of the country.
ii. A separate strategy should be developed for rainfed areas for environmental security, sustainable agriculture and food accessibility.
iii. Suitable species for commercial agroforestry may include *Acacia nilotica*, Bamboo species, *Casuarina equisetifolia, Eucalyptus* species, *Populus deltoides* and *Prosopis cineraria* for different climatic, edaphic and agricultural conditions.
iv. Specific institutes have been identified for tree improvement and development of clones of specified species.
v. Corporate private sectors may be encouraged to take up research and development in tree improvement, development of better clones and micro/macro propagation of quality planting material.
vi. About 100 NGOs may be identified to carry out clonal propagation of seedlings for distribution to farmers at appropriate price and carrying out extension work. Extension activities should include organizing farmers, providing them training in planting techniques, protection measures and other silvicultural operations.
vii. Technological development to diversify usage of agroforestry species will help to ensure a ready market for example bamboo is getting rediscovered as a potential raw material for the development of bamboo composites suitable for use in place of wood and wood composites.
viii. Bamboo technology mission should be started keeping in view the impending gregarious flowering followed by mass mortality of bamboo, forest fire famine and insurgency.
ix. As more and more farmers are taking up agroforestry, export/import policies should be modified to encourage agroforestry products marketing.
x. A system of market regulation to be put in place including a mechanism of periodic review in order to protect the interest of both producer and consumer of agroforestry produce.
xi. A suitable market information system needs to be introduced to inform farmers about major buyers, prevailing prices trends and procedures etc.
xii. All existing laws and executive orders related to tree felling, transport, processing and sale should be amended to facilitate agroforestry.
xiii. Commercial agroforestry may be planned in irrigated districts covering 10 million hectare. On annual basis one million ha should be brought under multipurpose tree species identified by the Task Force. The scheme of NABARD for farm agroforestry should be expanded and investment of Rs. 100 crores per year should be ensured.

xiv. It is proposed to cover 18 million ha of rainfed areas on watershed basis under agroforestry for conservation of soil/water and plantation of hardy species such as Eucalyptus, Bamboo and Babul. On annual basis 1.8 million ha is proposed for afforestation under various schemes of Rural Development, NAEB and 'Food for Work' scheme. An investment of Rs. 2700 crores will be required on yearly basis.

xv. Major states may establish Agroforestry Cooperative Federation for increasing bargaining powers of farmers in marketing of agroforestry products.

xvi. Wood based industries should continue supply of quality planting material to farmers and ensure suitable buy back arrangement.

A study by the International Union of Forest Research Organizations in 2016 reported that India is the third largest importer of illegally logged timber in the world (Anonymous 2016). Between 2010 and 2018 India imported Rs 388 billion worth of wood and wood products from around the world. The World Bank study says this market is expected to grow at 20% every year for the next few years. It makes economic and ecological sense for the Indian farmers to tap into this market. It will have a huge positive impact on the foreign exchange. These trees will act as insurance during exigencies for the farmer reducing dependence on high interest loans. By planting high value trees on a portion of their farmland along with their existing crop, farmers will have a lucrative additional source of income. It is ludicrous to expect a farmer who can barely save himself to save ecology. Hence, agroforestry as an economic plan with a profound ecological impact addressing soil health, water sequestration, farmer economics and biodiversity revival all in one go. This will set an example that ‘profitability’ is not the enemy of ecology rather environmentalism has to become profitable for both to be sustainable.

Agroforestry has promoted polyculture with a variety of trees, shrubs, herbs and bushes. It has kept soil fertile and water plentiful and allowed economics and ecology to benefit from each other in complementary ways. This practice has sparked a new revolution in the agricultural sector and the Indian economy. National Agroforestry Policy (2014) emphasis on the environmental contribution of agroforerty through preventing deforestation, promoting carbon storage, conservation of biological diversity and reducing pressure on natural forests.

In order to formulate a strategy to increase the green cover/tree cover outside recorded forest areas (Trees Outside Forests) and particularly agroforestry, Ministry of Enviornment, Forest and Climate Change constituted a committee in January 2018 under the Chairmanship of Shri Abhijit Ghose, Foremer PCCF (HoFF), Rajasthan to suggest ways to increase green cover that will help both agriculture and forestry sector. The important points emerging from all the recommendations of various committees are:

- Availability of quality planting material
- Developing high yielding varieties and clones

- Development of economically viable demonstrable agroforestry models suitable to different agro-climatic zone
- Rationalization of regulatory regimes
- Training and capacity building of farmers and tree growers
- Documenting and popularizing success stories
- Building network of certified nurseries
- Policies for management of TOF
- Supplementing government finances
- Realizing the importance of agroforestry in supplementing income, providing forest resource and combating environmental challenges

Many initiatives have already been taken but much more is required to be done. Many states have taken initiatives to de-regularize common agroforestry species but more is required to be done. Change in definition of bamboo crop in Indian Forest Act 1927 is widely appreciated by the farmers. Research organizations like ICFRE and ICAR are continuously working towards development of high yielding varieties of tree crop which are disease and pest resistant and give higher returns to farmers. Testing performance of these varieties through combination of different agroforestry models is encouraging farmers to introduce tree crop in farming systems. Today many successful models are available in farm forestry but more is required to be done. Success stories of private sector companies yielding higher returns by developing high yielding varieties are many now.

In agroforestry the major thrust has been on tree selection and improvement. In this aspect some significant contributions has been made for species such as Poplar, *Eucalyptus* spp., *Acacia* spp., *Leucaena* spp., *Ailanthus* spp., *Pongamia* spp., *Casuarina* spp., *Mangium* hybrids and Bamboos. Indigenous species which were priority for selection and improvement work included *Dalbergia* spp., Neem, *Prosopis*, *Pongamia* spp., *Simarouba*, Teak, *Anthocephalus cadamba*, *Grewia*, *Hardwickia* spp., *Melia*, *Prosopis cineraria*, Jatropha, Salix and *Gmelina arborea*. The selection and improvement work got varied success depending upon the species and its distribution. Clonal and seedling seed orchards for *Dalbergia* spp., *Acacia* spp., *Prosopis* spp., *Pongamia* spp., *Simarouba* and other species have been established. Amongst various bamboo species evaluated for growth, productivity and compatibility under agroforestry *Bambusa vulgaris* has been found most promising on farmers field. ICFRE introduced number of species to agroforestry. The present works being carried out by ICFRE institutes will further widen the scope of tree species as more and more clones and varieties of diverse species will be available.

ICFRE institutes has done tree improvement on *Dalbergia* spp., *Populus* spp., *Tectona granids, Casuarina equisetifolia, C. junghuhniana, Eucalyptus* spp., *Neem, Melia dubia, Ailanthus* spp., *Gmelina arborea, Neolamarckia cadamba, Calophyllum inophyllum, Tamarindus indica* and *Corymbia* spp. ICFRE also took new initiative on international provenance testing program in collaboration with

CSIRO, Australia and exchange of new germplasm of *Casuarina* spp., *Eucalyptus* 'mallees', *Grevillea robusta, Acacia mangium* and *Acacia melaxylon* from Australia.

Agroforestry is bound to play a major role in near future, not only for its importance in food and livelihood security but also for its role in combating the environmental challenges. 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 National Agroforestry Policy made several recommendations which will go a long way in stimulating large scale adoption of the agroforestry by the farmers and will provide the required raw material to wood based industries on one hand and play its role in energy and environmental security on the other. 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 eco-systems such as Himalayan region and Coastal eco-system to sustain these areas for higher productivity and natural resource management.

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Annexures

Annexure-I

List of Principal Investigators/ Contributors of Agroforestry models, ICFRE Institutes

S.No.	Name of Agroforestry Model	Principal Investigator/s	Name of the Institute
1	*Hardwickia binata* based agroforestry model	Dr. Bilas Singh, Scientist	Arid Forest Research Institute, Jodhpur (Rajasthan)
2	*Emblica officinalis* (Aonla) based agroforestry model		
3	*Colophospermum mopane* based agroforestry model		
4	*Prosopis cineraria – Zizyphus mauritiana* (grafted Ber) agroforestry model		
5	Poplar based agroforestry system	Dr. Aditya Kumar Scientist	Institute of Forest Productivity, Ranchi (Jharkhand)
6	Bamboo based agroforestry system	Dr. Animesh Sinha, Scientist	
7	Poplar-Wheat Agri-Silviculture model	Dr. Aditya Kumar, Scientist	
8	Poplar-Maize Agri-Silviculture model		
9	Poplar-Banana Silvi-Horticulture model		
10	Poplar-Turmeric agri-Silviculture model		
11	Poplar-Amorphophallus Silvi-Horticulture model		
12	Casuarina - Maize Agri-Silviculture model	Dr. M. George, Scientist (Retd.) & Dr. Syam Viswanath, Scientist	Institute of Forest Genetics and Tree Breeding, Coimbtore (Tamil Nadu)
13	Casuarina – Moringa - Maize Agri-Silvi-Horticulture model		
14	*Acacia auriculiformis* – Napier grass - Silvi-Pasture model		
15	Teak - blackgram Agri - Silviculture model	Dr. M. George, Scientist & Dr. C. Buvaneswaran, Scientist	
16	*Acacia mangium* - Beans Agri-Silviculture model		
17	*Acacia mangium* - Pepper Silvi-Horticulture model		
18	*Casuarina* based Windbreak agroforestry model	Dr. C. Buvaneswaran, Scientist 'F' & Dr.A.Nicodemous, Scientist	

19	Sandalwood -Aonla-Arhar Silvi-Horti-Agri model	Dr. Syam Vishwnath, Scientist	Institute of Wood Science & Technology, Bengaluru (Karnataka)
20	*Santalum album, Pterocarpus santalinus, Eucalyptus* species and *Tectona grandis*	Dr.GRS Reddy, Scientist	Institute of Forest Biodiversity, Hyderabad (Telangana)
21	*G.arborea-* Sorghum-Red gram silvi-agri model	Mr.M.B.Honnuri, Scientist	
22	Apple based Horti-medi model	Dr. Jagdish Singh, Scientist	Himalayan Research Institute, Shimla (Himachal Pradesh)
23	Poplar- Wheat-turmeric Silvi-agri-medi model	Shri K.K Sharma, Scientist	Forest Research Institute, Dehradun (Uttarakhand)
24	Poplar – Wheat agroforestry model		
25	Eucalyptus-wheat/paddy silvi-block model	Dr. Charan Singh, Scientist	
26	Poplar based Silvi-medicinal models		
27	Melia-Aonla based Agri-silvi-medicinal model	Dr. Rambir Singh Scientist & Dr. Charan Singh Scientist	
28	Melia based Agri-silviculture model		
29	King chilli – Arecanut Agroforestry model (Horti-spice model)	Shri Pawan K Kaushik, Scientist	Rain Forest Research Institute, Jorhat (Assam)
30	Agri-Lac model	Dr. Nanita Berry, Scientist	Tropical Forest Research Institute, Jabalpur (M.P.)
31	Teak-turmeric silvi-medicinal model		
32	Bamboo based silvi-agri model	Dr. Nanita Berry, Scientist & Shri R.S.Pal	
33	Flemingia based silvi-agri-lac model	Dr. Nanita Berry, Scientist	
34	Babul-Paddy agroforestry model	Dr. Syam Viswanath, Scientist	
35	Bach- Paddy agroforestry model	Dr.G.R.S.Reddy, Scientist & Shri Pushkar Shrivastava	

Annexure-II

Source and contact address for Quality Planting Material of selected agroforestry tree species used for agroforestry models

Choice of species in agroforestry is extremely important. Farmers prefer those tree species which are suitable to the site and can grow in combination with agricultural crops without adversely affecting the productivity of the crops. The species should also give quick and high return in addition to the return from agricultural crops. Sometimes farmers may decide to choose species with high value long rotation like. Teak, Shisham etc. to give return at the time of dire need. Farmers interested in agroforestry may contact ICFRE institutes for their requirements of Quality Planting Material of forestry trees.

S. No.	Quality Planting Material	Name of the institutes
i.	*Casuarina equisetifolia*	**Director** Institute of Forest Genetics and Tree Breeding P.B. No. 1061, R.S. Puram P.O., Coimbatore-641002, India Phone: +91 422 2484100, 2484101 Fax: +91 422 2430549 Email:dir.ifgtb@gmail.com dir_ifgtb@icfre.org Website : http://ifgtb.icfre.gov.in/ **Group Coordinator Research** Tel No : 0091-422-2431942 ; Fax No :0091-422-2430549 E-mail: groupco_ifgtb@icfre.org
ii.	*Casuarina junghuhniana*	
iii.	*Casuarina* hybrid	
iv.	*Eucalyptus* species	
v.	*Acaia auriculiformis*	
vi.	*Acaia mangium*	
vii.	*Tectona grandis*	
viii.	*Bamboo* species	
ix.	*Santalum album*	
x.	*Melia dubia*	
xi.	*Gmelina arborea*	
xii.	*Eucalyptus* species	**Director** Forest Research Institute, P.O. New Forest, Dehradun-248006 (India) Fax :+91 135-2756865 Telephone : +91 135-2755277 Email : dir_fri@icfre.org Website: http://fri.icfre.gov.in/ **Group Coordinator Research** Phone: 0135-2752670 01352224316 Email: groupco_fri@icfre.org
xiii.	*Dalbergia sissoo*	
xiv.	*Melia dubia*	
xv.	*Populus deltoides*	
xvi.	*Bamboo* species	
xvii.	*Azadirachta indica*	
xviii.	*Salix alba*	**Director** Himalayan Forest Research Institute Conifer Campus, Panthaghati, Shimla, HP Phone: 0177- 2626778
xix.	*Bamboo* species	

<table>
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Website: http://hfri.icfre.gov.in/
Group Coordinator Research
Phone: 0177- 2626801
Fax: 0177-2626779
Email: groupco_hfri@icfre.org</td></tr>
<tr><td>xx.</td><td>Tectona grandis</td><td rowspan="4">Director
Tropical Forest Research Institute,
P.O.: R.F.R.C., Mandla Road,
Jabalpur- 482 021, Madhya Pradesh
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Fax :- +91-761-2840484
Email :- dir_tfri@icfre.org
Website :- http://tfri.icfre.gov.in
Group Coordinator Research
Phone: 0761-2840799, 2744103 (O)
Email: groupco_tfri@icfre.org</td></tr>
<tr><td>xxi.</td><td>Bamboo species</td></tr>
<tr><td>xxii.</td><td>Acacia nilotica</td></tr>
<tr><td>xxiii.</td><td>Gmelina arborea</td></tr>
<tr><td>xxiv.</td><td>Bamboo species</td><td rowspan="3">Director
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Phone:-91-0376-2305101
Fax- 91-0376-2305130
email:dir_rfri@icfre.org,
Website: http://rfri.icfre.gov.in/
Group Coordinator Research
Phone: 9435051669
Fax: 0376-2305130
Email: groupco_rfri@icfre.org</td></tr>
<tr><td>xxv.</td><td>Gmelina arborea</td></tr>
<tr><td>xxvi.</td><td>Areca catechu</td></tr>
<tr><td>xxvii.</td><td>Santalum album</td><td rowspan="2">Director
Institute of Wood Science and Technology
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080- 23341731
Fax: 080-23340529
Email: dir_iwst@icfre.org
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Phone: 080-22190105
Email: groupco_iwst@icfre.org</td></tr>
<tr><td>xxviii.</td><td>Bamboo species</td></tr>
<tr><td>xxix.</td><td>Populus deltoides</td><td rowspan="2">Director
Institute of Forest Productivity
NH 23, Gumla Road, Lalgutwa
Ranchi - 835303
Fax: 0651-2526006,
Telephone: 0651-2948505, 2948515
Email: dir_ifp@icfre.org</td></tr>
<tr><td>xxx.</td><td>Bamboo species</td></tr>
</table>

		Website: http://ifp.icfre.gov.in/ **Group Coordinator Research** Phone: 0651-2526028 Email: groupco_ifp@icfre.org
xxxi.	*Hardwickia binata*	**Director** Arid Forest Research Institute P.O. Krishi upaz Mandi, New Pali Road, Jodhpur- 342005 Fax: 0291-2722764 Telephone: 0291-2722549 Email: dir_afri@icfre.org Website: http://afri.icfre.org/ **Group Coordinator Research** Phone: 0291-2729104 Email: groupco_afri@icfre.org
xxxii.	*Emblica officinalis*	
xxxiii.	*Prosopis cineraria*	
xxxiv.	*Colophospermum mopane*	
xxxv.	*Pterocarpus santalinus*	**Director** Institute of Forest Biodiversity Dulapally, Kompally (SO), Hyderabad-500 100 Fax: 040-66309521 Telephone: 040-66309501 Email: director_ifb@icfre.org Website: http://ifb.icfre.gov.in/ **Group Coordinator Research** Phone: 040-66309523 Email: groupco_ifb@icfre.org
xxxvi.	*Santalum album*	

Layout & Design : Amol k. Raut (FRI)

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(An Autonomous body of Ministry of Environment,
Forest and Climate Change, Government of India, New Delhi)