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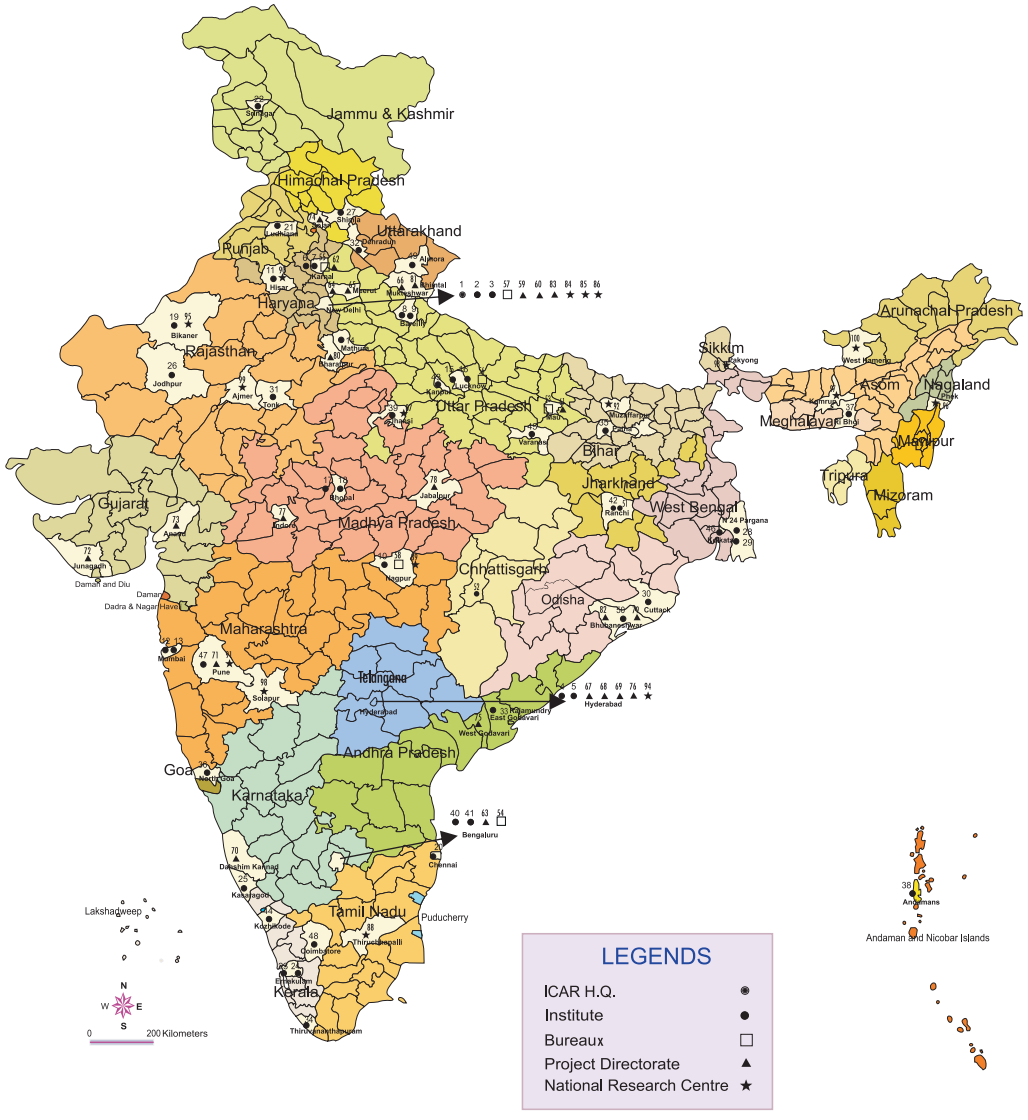

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संदेश

भारतीय सभ्यता कृषि विकास की एक आधार रही है और आज भी हमारे देश में एक सुदृढ़ कृषि व्यवस्था मौजूद है जिसका राष्ट्रीय सकल घरेलू उत्पाद और रोजगार में प्रमुख योगदान है। ग्रामीण युवाओं का बड़े पैमाने पर, विशेष रूप से शहरी क्षेत्रों में प्रवास होने के बावजूद, देश की लगभग दो-तिहाई आबादी के लिए आजीविका के साधन के रूप में, प्रत्यक्ष या अप्रत्यक्ष, कृषि की भूमिका में कोई बदलाव होने की उम्मीद नहीं की जाती है। अतः खाद्य, पोषण, पर्यावरण, आजीविका सुरक्षा के लिए तथा समावेशी विकास हासिल करने के लिए कृषि क्षेत्र में स्थायी विकास बहुत जरूरी है।

पिछले 50 वर्षों के दौरान हमारे कृषि अनुसंधान द्वारा सृजित की गई प्रौद्योगिकियों से भारतीय कृषि में बदलाव आया है। तथापि, भौतिक रूप से (मृदा, जल, जलवायु), बायोलोजिकल रूप से (जैव विविधता, हॉस्ट-परजीवी संबंध), अनुसंधान एवं शिक्षा में बदलाव के चलते तथा सूचना, ज्ञान और नीति एवं निवेश (जो कृषि उत्पादन को प्रभावित करने वाले कारक हैं) आज भी एक चुनौती बने हुए हैं। उत्पादन के परिवेश में बदलाव हमेशा ही होते आए हैं, परन्तु जिस गति से यह हो रहे हैं, वह एक चिंता का विषय है जो उपयुक्त प्रौद्योगिकी विकल्पों के आधार पर कृषि प्रणाली को और अधिक मजबूत करने की मांग करते हैं।

पिछली प्रवृत्तियों से सबक लेते हुए हम निश्चित रूप से भावी बेहतर कृषि परिदृश्य की कल्पना कर सकते हैं, जिसके लिए हमें विभिन्न तकनीकों और आकलनों के मॉडलों का उपयोग करना होगा तथा भविष्य के लिए एक ब्लूप्रिंट तैयार करना होगा। इसमें कोई संदेह नहीं है कि विज्ञान, प्रौद्योगिकी, सूचना, ज्ञान-जानकारी, सक्षम मानव संसाधन और निवेशों का बढ़ता प्रयोग भावी वृद्धि और विकास के प्रमुख निर्धारक होंगे।

इस संदर्भ में, भारतीय कृषि अनुसंधान परिषद के संस्थानों के लिए विजन-2050 की रूपरेखा तैयार की गई है। यह आशा की जाती है कि वर्तमान और उभरते परिदृश्य का बेहतर रूप से किया गया मूल्यांकन, मौजूदा नए अवसर और कृषि क्षेत्र की स्थायी वृद्धि और विकास के लिए आगामी दशकों हेतु प्रासंगिक अनुसंधान संबंधी मुद्दे तथा कार्यनीतिक फ्रेमवर्क काफी उपयोगी साबित होंगे।

(राधा मोहन सिंह)

केन्द्रीय कृषि मंत्री, भारत सरकार

Foreword

Indian Council of Agricultural Research, since inception in the year 1929, is spearheading national programmes on agricultural research, higher education and frontline extension through a network of Research Institutes, Agricultural Universities, All India Coordinated Research Projects and Krishi Vigyan Kendras to develop and demonstrate new technologies, as also to develop competent human resource for strengthening agriculture in all its dimensions, in the country. The science and technology-led development in agriculture has resulted in manifold enhancement in productivity and production of different crops and commodities to match the pace of growth in food demand.

Agricultural production environment, being a dynamic entity, has kept evolving continuously. The present phase of changes being encountered by the agricultural sector, such as reducing availability of quality water, nutrient deficiency in soils, climate change, farm energy availability, loss of biodiversity, emergence of new pest and diseases, fragmentation of farms, rural-urban migration, coupled with new IPRs and trade regulations, are some of the new challenges.

These changes impacting agriculture call for a paradigm shift in our research approach. We have to harness the potential of modern science, encourage innovations in technology generation, and provide for an enabling policy and investment support. Some of the critical areas as genomics, molecular breeding, diagnostics and vaccines, nano technology, secondary agriculture, farm mechanization, energy, and technology dissemination need to be given priority. Multi-disciplinary and multi-institutional research will be of paramount importance, given the fact that technology generation is increasingly getting knowledge and capital intensive. Our institutions of agricultural research and education must attain highest levels of excellence in development of technologies and competent human resource to effectively deal with the changing scenario.

Vision-2050 document of ICAR-Central Agroforestry Research Institute (CAFRI), Jhansi has been prepared, based on a comprehensive assessment of past and present trends in factors that impact agriculture, to visualise scenario 35 years, hence towards science-led sustainable development of agriculture.

We are hopeful that in the years ahead, Vision-2050 would prove to be valuable in guiding our efforts in agricultural R&D and also for the young scientists who would shoulder the responsibility to generate farm technologies in future for food, nutrition, livelihood and environmental security of the billion plus population of the country, for all times to come.

(S. AYYAPPAN)
Secretary, Department of Agricultural Research & Education (DARE)
and Director-General, Indian Council of Agricultural Research (ICAR)
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New Delhi 110 001

Preface

The Central Agroforestry Research Institute (CAFRI), erstwhile National Research Centre for Agroforestry at Jhansi under the aegis of Indian Council of Agricultural Research is the only institution in the South-Asia representing the integration of agriculture and forestry to increase the productivity and sustainability of farming system to augment farm income and provide livelihood security. The organized research conducted by the CAFRI and AICRP on Agroforestry with its 37 Centres located in different parts of the country have led to notable accomplishments in land use and farm income diversification, natural resource management, climate resilience, secondary agriculture and economic transformation of farmers through technological interventions.

Agroforestry, the practice of introducing trees in farming has played a significant role in enhancing land productivity and improving livelihood in both rainfed and irrigated ecologies. At the same time agroforestry interventions in farmland have far reaching environmental and ecological impacts. The role of agroforestry in soil conservation, bio-amelioration and climate moderation is most widely acclaimed and one of the compelling reasons for including trees on farm lands. It is now a proven fact that the global climate is changing and measures for its mitigation and adaptation are essential to face the new challenges. Agroforestry has the potential to mitigate the climate change through micro-climate moderation and natural resources conservation in short run and through carbon sequestration in long run. Thus, the present challenges of food, nutrition, energy and environment security can be met through different agroforestry systems developed for various agro-climatic zones. Agroforestry has a great potential to provide employment to rural and urban population through industrial application and value addition. With the implementation of recently launched National Agroforestry Policy, it is likely to transform the rural economy by expanding tree plantation in complementarities and integrated manner with crops and livestock to improve productivity, employment, income and livelihoods of rural households, especially the small holder farmers, besides help in mitigating climate change effects.

The systematic efforts to envision the challenges and opportunities, and formulate its own strategy were undertaken in 1997, 2007 and

2011 by preparing 'Vision 2020', 'Perspective Plan 2025', and 'NRCAF Vision 2030', respectively. The present document, articulates the strategies to overcome the present challenges and tap the opportunities by harnessing the power of science and undertaking boundary less partnership with different stakeholders in supply chain at regional, national and international level. I would like to express my gratitude to Dr. S. Ayyappan, Secretary, DARE and Director General, ICAR for his valuable guidance in preparing the document. I am grateful to Dr. A. K. Sikka, Deputy Director General (NRM) and Dr. B. Mohan Kumar, ADG (Agronomy, Agroforestry & Climate Change), ICAR for their keen interest and valuable comments, while reviewing the drafts. I gratefully acknowledge the contribution of Dr. S. K. Dhyani, Ex. Director, CAFRI, in the finalization of VISION 2050. I am also thankful to the Chairman, and Members of QRT and RAC, IMC and other stakeholders for their inputs in finalizing this Document.

I appreciate the efforts of all the scientists and Programme Leaders of the Institute in timely bringing out this Document. I am sure that **CAFRI Vision 2050** would guide all the stakeholders engaged in agroforestry research in achieving higher, sustainable and inclusive agricultural growth.

(Anil Kumar)
Director
ICAR-CAFRI, Jhansi

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Context

INDIAN agriculture is facing diverse challenges and constraints due to growing demographic pressure, increasing food, feed, pulp, fodder and timber needs, natural resource degradation and climate change. Diversification of land use with agroforestry as a component can address some of these challenges. Agroforestry has traditionally been a way of life and livelihood in India for centuries. The country has also been in the forefront since organized agroforestry research started worldwide. It developed robust agroforestry science, innovations and practices that are attracting global interest.

Organized agroforestry research in India began in the late eighties when the Indian Council of Agricultural Research (ICAR) launched the All India Coordinated Research Project (AICRP) on Agroforestry in 1983. Further, Central Agroforestry Research Institute (CAFRI), erstwhile National Research Centre for Agroforestry (NRCAF) was established on 8th May in 1988 at Jhansi to accelerate basic, strategic and applied research in agroforestry. At present there are 37 Centres under AICRP on Agroforestry representing the major agro-ecologies of the country with the project coordinating unit at CAFRI, Jhansi. The significant contributions of agroforestry research include – the Diagnosis and Design of the agroforestry practices, Collection and Evaluation of Multi-Purpose Tree Species (MPTS) and Development and Management of Agroforestry Systems for different agroclimatic regions. The Diagnostic and Design survey by the centres generated valuable information and identified important agroforestry practices in the country. A significant contribution of the project was on Tree Selection and Improvements for species such as poplar, eucalyptus, Dalbergia, Neem, Acacia, Leucaena, Ailanthus, Pongamia, Casuarina, Anogeissus, bamboos and Mangium hybrids. Registration of the elite germplasm of shisham by NRCAF (Bundel-1 and Bundel-2) and GBPUAT (PS 52), poplar clones (L-48/89, L-47/88) by PAU, Ludhiana, teak clone (PDKV/AF/1) by College of Agriculture, Nagpur and eucalyptus (SRY-16) by MPKV, Rahuri are some of the examples. Similarly, in neem, elite germplasm with high yield and high, stable azadirachtin content have been identified. Clonal seed orchards for Dalbergia, Acacia species have been established. Amongst various bamboo species evaluated for growth, productivity and compatibility under agroforestry, *Bambusa vulgaris* has

been found most promising on farmer's field in Bundelkhand region and elsewhere. Agronomic practices for raising the promising MPTS in association with annual crops have been developed and standardized. Morus and Grewia based- system for western Himalayas, alder based- for North-Eastern Hill region, poplar based- for Indo-Gangetic region, aonla and khejri based- for semi-arid and arid regions, teak based- for tropical region and Gmelina and Acacia based-system for Humid and Sub humid regions have been developed. Packages have also been developed for development of wastelands through agroforestry. AICRP on Agroforestry initiated systematic work on biofuel research in 2003 with major emphasis on jatropha and pongamia. A network project on bamboo based agroforestry has also been initiated in 2007 at six centres. In addition, agroforestry practices have been intertwined with the various programs/ schemes like watershed development, rehabilitation of problem soils, treatment of degraded and other wastelands etc. A large private sector industry has already developed around several tree products and there are good examples where agroforestry has made a significant impact on the economy, livelihoods and landscapes. Poplar and Eucalyptus based agroforestry in Indo-Gangetic region; Eucalyptus, Leucaena and Casuarina based agroforestry in Andhra Pradesh and other southern states; Ailanthus based in Gujarat are successful examples to name a few. The multifunctional home-gardens in Kerala and other coastal states promote food security and diversity and provide basic needs of food, fuel-wood, fodder, plant-derived medicines, and cash income from their small holdings. They also provide 70 to 84 per cent of the commercial timber requirements in these states (Kumar and Nair, 2004). Agroforestry is also providing livelihood opportunities through

A multistoried agroforestry system from humid tropics

lac, apiculture and sericulture cultivation. Suitable trees for gum and resin have been identified for development under agroforestry.

Agroforestry systems also provide environmental services in addition to the economic gains and other contributions. Agroforestry systems increase and conserve aboveground and soil carbon stocks. Agroforestry thus contributes to the resilience of agriculture by adaptation and mitigation of climate change effects. In India, evidence is now emerging that agroforestry systems are promising land use system to increase and conserve aboveground and soil carbon stocks to mitigate climate change (Dhyani *et al.*, 2009). Average sequestration potential in agroforestry in India has been estimated to be 25 t C ha^{-1} over 96 million ha (Sathaye and Ravindranath, 1998). In another estimate agroforestry contributes 19.30% of total C stock under different land uses. The potential of agroforestry systems as carbon sink varies depending upon the species composition, age of trees, geographic location, local climatic factors and management regimes. The growing body of literature indicates that agroforestry systems has the potential to sequester large amounts of above and below ground carbon in addition to SOC enhancement, as compared to treeless farming systems (Ajit *et al.*, 2013). Agroforestry is contributing to achieve the national goal as desired tree cover from present less than 25 per cent to 33 per cent in the country can only be achieved by planting trees on farm field/bunds, especially in states that have low tree cover.

However, increasing demand of household and wood based industries and changing priorities in bio-fuels, bio-energy, tree borne oil seeds (TBOs), value addition, crop diversification, employment generation, watershed protection, carbon sequestration, ecosystem services and mitigating climate change effects call for new thrust in agroforestry research and development.

Central Agroforestry Research Institute (CAFRI), erstwhile NRC for Agroforestry prepared its first Perspective Plan in 1997 to conceptualize, visualize and achieve the targets and programmes for agroforestry research in the country by preparing 'Vision 2020'. This was followed by preparing 'Perspective Plan 2025' in 2007 to address the changes that had taken place and to address emerging issues and challenges. In view of rapid changes during the last one decade mainly due to climate change which affected agriculture in a big way, a 'NRCAF Vision 2030' document was prepared in 2011. The document highlighted key challenges and opportunities in the agriculture sector in general and agroforestry sector in particular in the coming two decades for development of an appropriate strategy and roadmap to define

the role of CAFRI in shaping the future of the Indian agricultural research for growth, development and equity. However, as there is a considerable time gap between initiation of research and significant output, dissemination and adoption of technology particularly with tree based system, hence long term planning is required to meet future challenges. The 'CAFRI Vision 2050' is prepared keeping in view the future challenges and opportunities and will help in long term planning of agroforestry research in the country.

❑

Challenges

INDIAN agriculture is facing diverse challenges and constraints due to growing demographic pressure, increasing food, feed, pulp, fodder and timber needs, natural resource degradation and climate change. Diversification of land use with agroforestry as a component can address some of these challenges. Agroforestry has traditionally been a way of life and livelihood in India for centuries. The country has also been in the forefront since organized agroforestry research started worldwide. It developed robust agroforestry science, innovations and practices that are attracting global interest.

India faces a critical imbalance in its natural resource base with about 18 per cent human and 15 per cent of livestock population of the world being supported only on 2.4 per cent of geographical area, 1.5 per cent of forest and pasture lands and 4.2 per cent of water resources. Agriculture sector contributes about 15 per cent of the national GDP, employs 56 per cent of the total workforce and supports about 58 per cent of the total population. Thus, this sector is very vital not only to provide income support, but also to ensure livelihood security for majority of the people. However, there are some serious concerns which of late, have emerged. The foremost among them is global warming. The Intergovernmental Panel on Climate Change (IPCC, 2007), in its Fourth Assessment Report concluded that the increasing Greenhouse Gases (GHG) have resulted in global warming by 0.74°C over the last 100 years. The IPCC have predicted an increase of 1.8 to 4.0°C by the end of this century. Such changes are expected to adversely affect agriculture covering crops, trees, soils, livestock and fisheries. The indirect effects of climate change on water resources are likely to be very critical. Likewise, soil organic carbon and other basic soil processes will be affected. The adverse effects of climatic change are expected to be relatively high in India due to dependence of large population on agriculture, degradation of natural resources, increasing human and livestock population, wide range of pests and diseases, low levels of technology and changing patterns in land use. A serious threat is being predicted in meeting the food, fibre, fuel and fodder requirements of the growing population.

It is estimated that India will be the most populous country in the world by 2028 surpassing China (The World Population Prospects- The

2012 Revision, UN, The Hindu, June 13, 2013). Population of the country will touch 1.4 billion mark by 2025 and 1.6 billion by 2050. Thus, there will be an increase of about 33 per cent in population of the country, but the per capita surface water availability and per capita utilizable surface water will decline by about 30 per cent by 2050 as compared to present. These all effects will result in low agricultural and livestock productivity, less industrial output and degradation of natural resources, which ultimately raise the concerns for livelihood opportunities, employment generation and natural resource conservation (Figure 1).

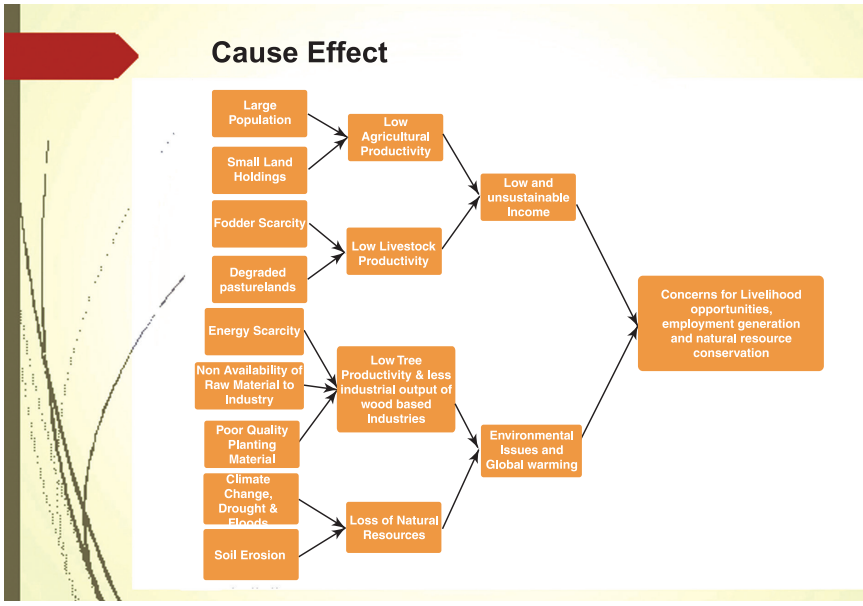

Fig. 1 Cause effect of challenges faced by agriculture

Presently, in India, about 60 per cent of the cropped area is rainfed, which contribute about 44 per cent of food-grain production. Its contribution in coarse cereals & pulses is about 90 per cent, in oilseeds 60 per cent and in case of cotton it is about 80 per cent. Significant proportion (66 per cent) of livestock population is also in the rainfed areas. However, these areas are characterized by low input use and low yield levels. The yield levels are highly prone to variety of risks. As such, rainfed agriculture is quite complex and needs to be tackled with a much more sensitivity and systematic approach. For such areas, diversification of landuse systems with agroforestry is a necessary strategy for providing variety of products for meeting requirements of the people, insurance

against risks caused by weather aberrations, controlling erosion hazards and ensuring sustainable production on a long-term basis. Besides, 90 per cent of the forests in the country are performing the critical functions of protecting fragile watersheds and are not fit for commercial exploitation (Dhyani *et al*., 2007).

Agroforestry is playing the greatest role in maintaining the resource base and increasing overall productivity in the rainfed areas in general and the arid and semi-arid regions in particular. Agroforestry land use increases livelihood security and reduces vulnerability to climate and environmental change. There are ample evidences to show that the overall (biomass) productivity, soil fertility improvement, soil conservation, nutrient cycling, microclimate improvement, and carbon sequestration potential of an agroforestry system is generally greater than that of an annual system (Dhyani *et al*., 2009). Agroforestry has an important role in reducing vulnerability, increasing resilience of farming systems and buffering households against climate related risks. It also provides for ecosystem services - water, soil health and biodiversity. Therefore, agroforestry will be required to contribute substantially to meet the demands of rising population for food, fruits, fuel wood, timber, fodder, bio-fuel and bio-energy as well as for its perceived ecological services (Figure 2).

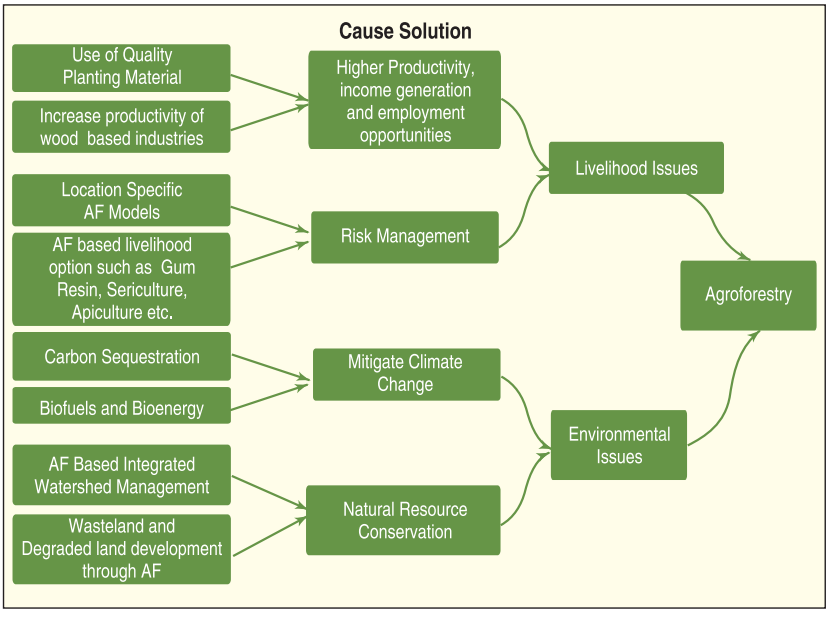

Fig. 2 Agroforestry as the solution to the challenges faced by agriculture

Table 1. Total Domestic Demand for Various Commodities

Items	Present 2010-11	Projected for 2025	Projected for 2050	Contribution from Agroforestry in 2050
Food grains (million t)	218.20	320.00	457.1	41.14*
Fruits (million t)	71.20	106.00	305.3	47.74*
Fodder (million t)	1061.00	1170.00	1545	154.50
Fuel wood (million t)	308.00	479.00	629	308.00
Timber (million t)	120.00	171.00	347	295.00
Biodiesel (million t) required for 20% blending of diesel	12.94	22.21	37.92	30.34
Area (million ha) required for TBOS	12.32	15.86	21.67	17.34

*Food-grains/fruits production from systematic agroforestry systems *viz.* agri-silviculture/ agri-horticulture only considered

In order to meet the requirement of the population in 2050 an increase by 1.5 times in fodder, two times in food grains and fuel wood and three times in timber production will be required (Table 1). Also, to meet the energy requirement from bio-diesel and achieve 20% blending in diesel, a three-fold increase in production of biodiesel will be required (Dhyani *et al.*, 2013).

Agroforestry has the potential to provide most or all the ecosystem services. The Millennium Ecosystem Assessment (2005) has categorized the ecosystem services into provisioning service (e.g., fuel-wood, fodder, timber, poles etc.), regulating service (hydrological benefits, micro-climatic modifications), supporting service (nutrient cycling, agro-biodiversity conservation), and cultural service (recreation, aesthetics).

Agroforestry systems on the boundary of ponds/lakes improve microclimate

Apart from fuel wood, fodder, fibre, fruits and medicine, other key advantages from agroforestry include the following:

- Land rehabilitation and land reclamation.
  - Rehabilitation of saline, alkaline and water-logged soils through bio-drainage by planting suitable species. Surface mined areas are reclaimed through bioremediation;
  - New self-nourishing systems of stand management (e.g. nitrogen-fixing/fertilizer trees) that mimic the natural ecosystem, where significant quantities of nitrogen are added via the biological fixation pathway in the low fertility sites;

Prosopis cineraria, Albizia, Acacia and other fertilizer (N-fixing) trees in agroforestry help in fertility build up

- Agricultural non-point source pollution (NPSP) is a significant cause of stream and lake contamination in many parts of the country. NPSP owing to agricultural intensification constitutes a major environmental problem, where agricultural chemicals such as fertilizers, manures, and pesticides continue to add chemical ions (mainly high NO_3 levels and other major anions and cations) in stream water (Kumar *et al*., 2012). In addition, runoff from animal husbandry units, which contain predominantly high levels of organic compounds, is another source of pollutants. Lateral inflows (water that is added to the stream due to effluent seepage from ground water, overland flow, inter-flow, or via small springs and seeps) transport such solute mass to the streams and rivers. Agroforestry emerges as a promising option to ameliorate and rehabilitate such degradation.
- Diversity of products provides opportunities for development of industries and for creating off-farm employment and marketing opportunities.

- Environmental services such as climate change mitigation (carbon sequestration), phytoremediation, watershed protection, amelioration of problem soils, and biodiversity conservation.
- Integrating trees on the fields act as natural sump for nutrients from deeper layers of soil, add bio-fertilizer, conserve moisture and enhance productivity of the system.

Agroforestry systems on arable lands envisage growing of trees and woody perennials on terrace risers, terrace edges, field bunds, as intercrops and as alley cropping. Agroforestry practices for non-arable degraded lands such as bouldery riverbeds, torrents, landslide, shifting cultivation areas, waterlogged soils, control of desertification, mine spoil rehabilitation and treatment of saline and alkaline lands have been developed and demonstrated. The technologies need to be adopted and disseminated by the concerned departments in affected areas. A long term comprehensive research program is therefore required, which should address natural resource management issues, diversification of land use particularly with agroforestry in the context of changing climate. Agroforestry land use in conjunction with soil and water conservation and animal husbandry needs to be emphasized in future. CAFRI Vision 2050 intends to address these issues in a comprehensive manner by giving highest priority to farmers and wood/agri-based industries for uplifting rural economy, mitigating environmental deterioration, stabilizing productivity and meeting diverse needs of people.

Agroforestry has high potential of C sequestration- *Albizia* based system

Operating Environment

Global scenario

Agroforestry is practiced in all continents of the world. A high percentage of tree cover is found in nearly all continents of the world, highest being in Central America and southeast Asia. There is now general agreement about the magnitude and scale of the integration of trees into agricultural lands and their active management by farmers and pastoralists. Dixon (1995) estimated a total 585-1215 million ha of land in Africa, Asia and the Americas under agroforestry, while Nair *et al.* (2009) estimated a land area of 1,023 million ha under agroforestry worldwide. Almost half of the world's agricultural lands have at least a 10 per cent tree cover, suggesting that agroforestry, an integrated system of trees, crops and /or livestock within a managed farm or agricultural landscape, is widespread (Zomer *et al.*, 2009). Agroforestry is contributing substantially in economic growth of various countries. The economic importance of agroforestry can be partly understood by examining data on the export value of major tree products. FAOSTAT (2011) shows that conservative estimates of international trade of this list of tree products was valued at a whopping US$140 billion in 2009. The actual production levels are much higher, considering that the list includes only well known and common tree products and that many tree products in developing countries are not marketed internationally (e.g. firewood, fodder, medicinal uses) and for products such as fruit, as much as 90% of production is consumed domestically. In addition, the positive externalities (or ecosystem services) represented by trees (e.g. carbon sequestration, nutrient cycling, provision of shade, etc.) are not counted.

Agroforestry research at the international level is conducted by the International Centre for Research in Agroforestry (ICRAF), now named as World Agroforestry Centre, which was started in 1978 at Nairobi in Kenya. Now it is a CGIAR Consortium Research Centre with five regional offices located in Cameroon, India, Indonesia, Kenya and Peru. The Centre's aim is to increase use of trees in agricultural landscapes to improve their food security, nutrition, income, health, shelter, social cohesion, energy resources and environmental sustainability of small holders.

In India, organized research in agroforestry conducted by National Agricultural Research & Education System (NARES) and ICFRE institutions during last more than three decades resulted in development and demonstration of many agroforestry technologies. But most of them have not reached to farmers' field for want of awareness, inadequate infrastructure and lack of policy support. Small land holdings, grazing pressure and resource-poor situations constitute other constraints in this respect. The agroforestry technologies have been successful in the areas where quality planting material and assured market are available for example poplar and eucalyptus in Indo-Gangetic region. Similarly, inclusion of fruit plants such as aonla, guava, ber, bael, citrus etc. as component of agroforestry in arid and semi-arid region has also been quite successful.

Fodder trees are playing an important role in reducing the fodder shortage problem in India. In most parts of our country after the end of rainy season, animals suffer badly due to lack of protein rich diet since availability of fodder become scarce. The situation becomes serious during the dry season under rain-fed conditions, when generally no crop can be grown, and natural pasture, grasses, and weeds become unproductive. Farmers either feed their animals with the low-quality hay of the stored crop residues or they travel long distances to gather green grasses or fodders. In such circumstance, shrubs and fodder trees are able to withstand the drought, stay green, and provide a nutritious fodder for livestock (Dhyani, 2003). Alarming shortages of forage in our country can be solved partially by planting fodder trees capable of sustained production of palatable forage high in protein and Total Digestible Nutrients (TDN). Through the plantation of these species on degraded lands under silvipasture systems and in farmer's fields under various agroforestry systems, fodder availability can be enhanced. Oaks, *Grewia optiva, Celtis australis* in Western Himalaya, and *Ficus* spp., *Alnus nepalensis* and *Bauhinia* spp., in Eastern Himalayas have been used as important fodder trees. Lopping of *Prosopis cineraria* (Khejri) in western Rajasthan, *Albizia lebbeck*, *A procera*, *Azadirachta indica* in northern and central India for leaf fodder, use of pods of *Acacia niloitca* and *Prosopis juliflora* for fodder are common practices since old days. Most of these species are important source of fodder during lean period as well. Advantages of tree fodder are that trees can be grown on steep, rocky mountain slopes, in arid, saline, or water-logged soils, and in areas with severe climatic conditions. Also, trees do not need heavy inputs of fertilizer, irrigation, labour, pesticides, etc., as are generally needed to grow conventional fodder crops. Trees use and recycle nutrients that

are beyond the reach of grasses and other herbaceous plants. Trees that accumulate nitrogen enhance forage quality. Their relative deep root system can exploit deep moisture resources and, using this and other strategies, trees are more tolerant to dry periods than pastures.

The success of industrial agroforestry be attributed to short gestation period, improved planting material, regular and high returns, readily available market and no restrictions on transportation. Availability of quality planting material is therefore, one of the major concerns that needs to be addressed urgently. Understanding of the biophysical issues related to productivity, water resource sharing, soil fertility and plant interactions in mixed communities are also inadequate because research has been mostly observational in nature rather than process oriented. Methods to value and assess the social, cultural and economic benefits of agroforestry systems are not available and the socio-economic processes involved in the success and failure of agroforestry have to be fully investigated. The successful practices of wasteland reclamation and poplar-based agroforestry showed that these technologies were widely adopted when their socio-economic benefits appeared convincing.

Policy on tree felling from agroforestry systems holds the key to large-scale agroforestry adoption. Industries have taken up poplar, *Eucalyptus,* bamboos*, Acacia, Casuarina, Ailanthus* and teak for commercial agroforestry due to their great market potential. Genetically improved clonal planting stock of eucalyptus, poplars and acacias has transformed the productivity and profitability of plantations. Average yields from such clonal plantations are 20 to 25 times higher compared to the average productivity of forests in India. Almost 50 million plants of improved eucalyptus are being planted every year. However, indigenous species like shisham, babul, neem, ber, palash in spite of

Aonla based agroforestry system- a boon for rainfed farmers in semi-arid, arid regions

their scattered presence on farmers' field could not pick up ground on commercial scale due to long rotation, harvesting and marketing hurdles and adverse effects on crops particularly under rainfed conditions and the non-availability of improved material.

Continuous emphasis on tree plantation by government through various schemes (MGNREGs, RKVY, National Horticulture Mission, Bamboo Mission, special plantation drive as in Uttar Pradesh etc.) and watershed program such as IWMP in tandem with available knowledge on agroforestry from ICAR institutions, SAUs, Private players like WIMCO, ITC etc. has started bearing fruits and farmers are coming forward for plantation on private lands.

With the rapid urbanization and economic growth in the country, farming community have witnessed unprecedented opportunities for moving beyond subsistence farming to supplying products needed by urban dwellers. Agroforestry products such as timber, fruit, food, fibre, fodder, medicine and others are progressively meeting the subsistence needs of households and providing the platform for greater and sustained productivity. Now due to change in dietary habits and consumption patterns, it is estimated that there will be less demand for cereals and many times more demand for animal products like milk, meat, pulses and edible oils by 2050. In addition, there will be due emphasis on bio-fuel, bio-energy, bio-fertilizers, bio-pesticides, bio-remediation, bio-fortification, bio-industrial watersheds and applications of nano technology to enhance nutrient and water use efficiency, plant based medicines and increasing demands for wood for house construction. This requires a matching reallocation of lands in favour of agroforestry. It is in this context that agroforestry systems offer opportunities to farmers for diversifying their income and to increase farm production. Agroforestry can improve soil fertility, provide fodder, produce tree fruits, expand fuel wood supplies, and produce a variety of wood products for farmers' own use and sale without demanding additional land. Research results from different agro-climatic regions of the country show that financial returns generated from agroforestry systems vary greatly but are generally much higher than returns from continuous unfertilized food crops. The higher returns associated with agroforestry can translate into improved household nutrition and health, particularly when women control the income (NRCAF 2007, 2011). However, monitoring and impact assessment studies need to pay higher attention to understand how agroforestry affects household resource allocation, consumption patterns, nutrition status of household members, and health.

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CAFRI and Agroforestry Network

CENTRAL Agroforestry Research Institute (CAFRI), erstwhile National Research Centre for Agroforestry (NRCAF) was established at Jhansi on 8th May, 1988 under the aegis of Indian Council of Agricultural Research (ICAR), New Delhi to cater to basic, strategic and applied research needs in the field of Agroforestry. All India Coordinated Research Project on Agroforestry – a large agroforestry network, which was operational since April, 1983 was transferred to CAFRI in 1997 with empowerment of Director, CAFRI as Coordinator of the programme. At present, AICRPAF is running at 27 SAUs, 09 ICAR Institutes and one ICFRE institute. CAFRI and AICRP on Agroforestry in the last more than two decades has developed several Agroforestry systems that have gone to farmer's field and provided livelihood support to small and marginal farmers. CAFRI is recognized worldwide for its research and development capabilities, Agroforestry data-base & information repository and natural resource management on watershed basis. The institute conducts basic and strategic research through four programmes *viz*. Natural Resource and Environment Management; System Research; Tree Improvement, Post Harvest and Value Addition, and HRD, Technology Transfer & Refinement.

CAFRI is striving hard to meet the technological challenges and gearing up to become global leader in the field of Agroforestry research and development. By 2050, CAFRI aims to establish itself as focal organization in dovetailing researchers, farmers, wood-based industrialists, consumers and other stakeholders. The efforts are in full swing to develop adoption friendly agroforestry techniques for covering 60 per cent non-arable, non forest lands and 40 per cent arable lands under Agroforestry system and increase number of trees outside the forest by at least 50 per cent so that micro-climate mediation is achieved and degradation of natural resources halted.

Vision

Integration of woody perennials in the farming system to improve land productivity through natural resource conservation, restoration of ecological balance, alleviation of poverty and risk mitigation.

Mission

To improve quality of life of people through integration of trees in farming system.

Focus

To achieve the vision and mission of CAFRI, it gives highest priority to farmers and wood-based industries for uplifting rural economy, apprehending deteriorating environment, stabilizing productivity and meeting diverse needs of people.

Mandate of CAFRI

- To undertake basic and applied research for developing and delivering technologies based on sustainable agroforestry practices for farms, marginal land and wastelands in different agroclimatic zones in India.
- To coordinate network research with the State Agricultural Universities/ICAR Institutes/other related research Institutes for identifying technologies which can be transferred from one region to another.
- To provide training in (a) research methodologies and (b) use and application of technologies developed, at various levels.
- To develop technological packages of different agroforestry practices for various agroclimatic zones for transfer to farm, field and wastelands.
- To act as repository of information on the subject.
- To collaborate with relevant national and international agencies for achieving the mandate.
- To provide consultancy.

Mandate of AICRP on Agroforestry

- Screening and genetic upgrading of different plant species for their compatibility under different agroforestry systems.
- To study the effect of trees on legumes/trees/suitable orchard species, while growing mixed with suitable species of grasses and fodder commercial plants.
- Performance of the local predominant grasses/local crops and
- Refining the technology for proper propagation and management of the species.

Infrastructure requirement

The ICAR has recently upgraded the NRCAF as Central Agroforestry Research Institute (CAFRI), which is still developing its

infrastructural facilities. It will require strengthening scientific, technical and administrative manpower, infrastructure for farm, laboratories and offices with Regional Centres having all facilities to carry out research and innovations and to develop location specific agroforestry technologies.

Human Resource requirement

Trained human resources are needed in agroforestry sector for targeted growth. Agroforestry sector will need human resources with higher skills than before to ensure technology generation, its dissemination to all stakeholders particularly at the grass root level. Further, agricultural human resources with diverse skills is today required by a wide ranging and fast expanding wood based industry, post harvest and value addition of agroforestry products industry, public, corporate as well as unorganized sector. In general, there is substantial gap between demand and supply of trained human resources. This is true for agricultural sector, though the shortfall is likely to be high in this sector with the implementation of National Agroforestry Policy, which is aimed to mainstream the trees grown on farms. Agroforestry with its contribution in carbon sequestration and mitigation of climate change effects as well as increasing the vegetation cover may become future engines of growth which would have a bearing on trained human resource requirements. The thematic areas identified for human resource training are,

- Geospatial technologies for mapping agroforestry area in the country.
- Digital spectral library for agroforestry systems.
- Valuation of agroforestry based ecological services
- Agroforestry tree products- value addition through post harvest technologies.
- Carbon sequestration potential and ecosystem services of agroforestry.
- Biofuel R&D- germplasm exchange and technologies for lingo-cellulosic biomass.

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New Opportunities

THE potential of agroforestry to contribute to sustainable development has been well recognized world over. The United Framework Convention on Climate Change (UNFCCC) and the Intergovernmental Panel on Climate Change (IPCC) increasingly acknowledge it as a component of climate-smart agriculture. During the 2011 Conference of the Parties (COP)17 meeting in Durban, agroforestry was frequently mentioned as having a strong potential for climate change adaptation and mitigation. Furthermore, National Adaptation Plans of Action (NAPAs) and Nationally Appropriate Mitigation Actions (NAMAs) talk of agroforetry as an important component in agriculture sector actions. In addition, the United Nations Convention to Combat Desertification (UNCCD) acknowledges agroforestry's potential to control desertification and rehabilitation. It is also seen as an important practice in the ecosystem approach promoted by the Convention on Biological Diversity (CBD) and contributes to its global Strategy for Plant Conservation (FAO, 2013).

Agroforestry has high potential for simultaneously satisfying three important objectives *viz*., protecting and stabilizing the ecosystems; producing a high level of output of economic goods; and improving income and raw materials to rural population. Further, agroforestry is capable of conserving natural resources under different agro-climatic regions and only viable option to increase the forest cover of the country. Agroforestry systems also help in build-up of rhizosphere micro-organisms. In a scenario of decreasing availability of arable lands for agriculture, degradation of soil and water resources, increasing pollution hazards and threats to environment and ecosystem from global warming and climate change, new approaches in farming systems are needed to meet food, fodder, fibre, firewood and timber demands of the increasing population. Of late, shortage of LPG and kerosene, reduced population of animals/ household is once again forcing rural population towards use of fuel wood for meeting its energy needs. Agroforestry interventions *i.e.,* integration of trees, crops and livestock in an already existing land use system is one option to fulfill fuel wood needs.

In fact, **a**groforestry has proven as an important tool for crop diversification. National Agriculture Policy, 2000 recommends agroforestry for sustainable agriculture and advocates bringing up agroforestry in areas

currently under shifting cultivation. National Forest Policy, 1988 sets a goal of increasing forest cover on one-third geographical area of the country. Major Policy initiatives including National Forest Policy 1952, 1988 and the National Agriculture Policy 2000, Task Force on Greening India- 2001 and National Bamboo Mission-2002 emphasized the role of agroforestry for efficient nutrient cycling, organic matter addition for sustainable agriculture and for improving forest cover.

India launched the much-needed National Agroforestry Policy in 2014. The National Agroforestry Policy is a path-breaker in making agroforestry an instrument for transforming lives of rural farming population, protecting ecosystem and ensuring food security through sustainable means. The major highlights of the Policy are: establishment of Institutional setup at National level to promote Agroforestry under the mandate of Ministry of Agriculture; simplify regulations related to harvesting, felling and transportation of trees grown on farmlands; ensuring security of land tenure and creating a sound base of land records and data for developing an Market Information System (MIS) for agroforestry; investing in research, extension and capacity building and related services; access to quality planting material; institutional credit and insurance cover to agroforestry practitioners; increased participation of industries dealing with agroforestry produce; strengthening marketing information system for tree products.

The current area under agroforestry in India is estimated as 25.32 million hectares (Mha) (Dhyani *et al*., 2013) or 8.2 per cent of the total geographical area of the country. There is further scope of increasing the area under agroforestry in future by another 28.0 Mha. The major share of the land to be brought under agroforestry will come from fallows, cultivable fallows, pastures, groves and rehabilitation of problem soils. Thus, a total of 53.32 Mha (Table 2), representing about 17.5 per cent of the total reported geographical area (TRGA) of the country, could

Table 2. Land use (million ha) scenario at present and projected for 2050.

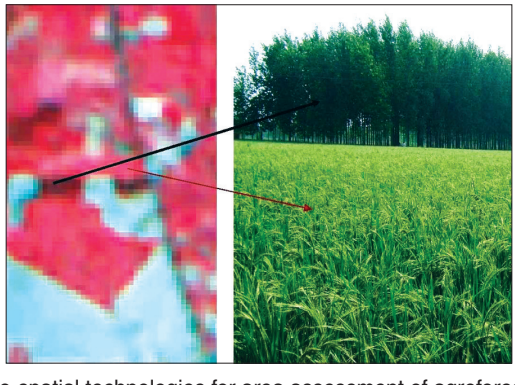
Classification	1970*	2010*	2050
1. Forest cover#	63.83	69.63	69.63
2. Net area sown	140.86	140.86	142.60
3. Other uncultivated land (Fallow, pastures, cultivable waste, misc. tree crops and groves)	54.46	55.18	53.44
4. Not available for cultivation	44.60	40.00	40.00
Reporting area	303.75	305.67	305.67
Agroforestry	-	25.32[$]	53.00[$]

*Source: *Agricultural Statistics at a Glance, 2010,* Directorate of Economics and Statistics, Ministry of Agriculture, Govt. of India. #Forest Survey of India, State of Forest Report 2009.

[$]Dhyani *et al*., 2013.

potentially be brought under agroforestry in the near future, which will make agroforestry a major land-use activity, after agriculture (140.86 Mha, 46.08 % of the TRGA) and forestry (69.63 Mha, 22.78% of the TRGA) in India (Dhyani *et al*., 2013).

With the increase in area from 25.32 million ha to 53.0 million ha in next thirty five years, agroforestry will be contributing substantially in meeting the basic needs of the society through increased production and providing environmental benefits (Dhyani *et al*., 2013). In terms of specific empirical evidence, the area under forest will not change much in future in view of the developmental needs of the country, though it has increased by 8.24% from 63.83 million ha to 69.09 million ha in last 40 years (Table 2). In next 35 years it is expected that there will be substantial increase in area under tree cover *i.e.* Tree Outside Forest and a large portion of it will be devoted to agroforestry. This is possible as Task Force on Greening India (Planning Commission, 2001) projected that additional 28 million ha area can be brought under plantation through agroforestry to meet the national goal of increasing forest cover on one-third of the total geographical area. For this purpose, 10 million ha of irrigated lands which are suffering from water logging, salinity and water erosion and another 18 million ha of rainfed lands have been ear-marked for agroforestry development. A sizeable area will also be contributed from barren and uncultivable land, permanent pastures and other grazing land, culturable waste land and fallow land. In addition, out of the Prime minister's eight National Mission (NM) under National Action Plan on Climate Change, agroforestry is likely to play proactive role in the NM on Greening India, NM on Energy, NM on Sustainable Agriculture and NM for Sustaining the Himalayan Ecosystem. Under the National Mission for Greening India a target of 3.0 million ha of degraded lands and fallows are to be brought under



Geo-spatial technologies for area assessment of agroforestry

Poplar based AFS in Indo-gangetic region – a successful model

agro/social forestry. Such climate change mitigation strategies through agroforestry would also ensure greater synergy with the Convention on Biological Diversity in view of the ability to maintain high biodiversity.

Tree crop combinations for different edapho-climatic conditions have been identified for arable lands. Technology for rehabilitation of degraded lands through silvipasture has been standardized. Bio-fuel species for energy production have been identified and variability in germplasm for agroforestry traits and productivity are being studied. Mass multiplication techniques for quality planting material have been perfected in number of species, while many more are in pipeline. DNA finger printing techniques for characterization of promising germplasm is being attempted. GIS and RS techniques for computing area under agroforestry system have been developed. The same is being used for mapping of agroforestry area in different parts of country. A preliminary estimate of the agroforestry area in India through use of geospatial technologies has been estimated to be 17.45 million ha (Rizvi *et al.*, 2014). Agroforestry database has been developed and web-site has been created. More number of species being added to the data-base. Thus, frontier technologies are playing their role in agroforestry research.

Agroforestry products particularly wood based were henceforth either locally being consumed or traded conventionally and market was highly un-organized. Commercial Agroforestry in tandem with wood based industries have shown immense potential as they are exempted from the felling restrictions. Poplar, *Eucalyptus*, *Casuarina, Leucaena* based commercial agroforestry systems could flourish in different regions of the country when promoted by industries. Similarly, fruit based industries coupled with food supply chain and creation of infrastructural facility like refrigerated storage and transport facilities have changed marketing of fruits, vegetables, medicinal and aromatic plants. Industries (wood based or crop based) can join hands together to process variety of products from agroforestry system. Growing awareness towards valuation of environmental services and carbon trading will provide an

opportunity for more plantations under agroforestry systems on privately owned lands. There is a vast potential for investments and creation of employment in agroforestry sector through involvement of corporate sector. Bio-fuel, TBOs and bio-energy are yet other areas, where industry can play an important role to meet the requirements for energy as well as for employment generation.

Hydrological monitoring of agroforestry systems

Agroforestry research is committed to enhance farmer's productivity per unit area and time, bring in self reliance amongst farming community, enhance returns from limited resources, reduce input cost and combat changing climate by integrating conventional knowledge and practices with latest scientific knowledge and tools. The agroforestry network has large collections of neem, babul, shisham, jatropha and karanj besides many other tree species of agroforestry significance. These are being evaluated for their integration in agroforestry system. Biotechnological tools are being used to establish genetic variability in germplasm. Plant multiplication techniques using conventional methods and tissue culture are on the cards for production of true to the type quality planting material on large scale.

Integration of AF technologies with NRM in participatory mode ensures livelihood opportunities and drought mitigation strategies for the region

Agroforestry is an important tool to manage natural resources *viz*., land, water, vegetation and environment. Watershed projects implemented by the Institute have shown potential in rainfed areas and enhanced surface water availability throughout the year, besides plentiful ground water recharge. Improved soil, water and agroforestry interventions in Gadkundar-Dabar watershed of Bundelkhand region enhanced biomass production by three folds besides drought proofing. Farmers' income and stability improved and forest wealth saved and

fortified (NRCAF, 2012). Scaling-up of agroforestry based integrated watershed management in drought prone rainfed areas with enabling policy and institutional support would promote equity and livelihood along with strengthening various ecosystem services, while reducing poverty and building resilience in semi-arid tropics.

Post-harvest losses contribute to 5-25% loss of productivity and value addition has potential to increase returns by several folds. Due to un-organized marketing of agricultural produce, farmers often face glut of production and crashing prices. Many potential crops are not grown by farmers for want of readily available market. However, by integrating minor forest products such as natural gums & resins, lac cultivation, sericulture, apiculture, medicinal and aromatic plants in agroforestry additional opportunity for earning livelihood can be created. Value addition in such produces can help farmers in getting high remuneration. Research and development of value added products, acceptable to common man, can change agriculture production scenario and consumer behavior as well.

Tasar sericulture on arjun (*Terminalia arjuna*) – a livelihood option

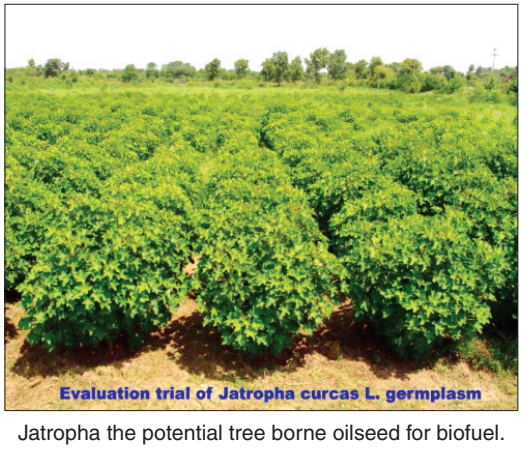
Apiculture provides additional income to farmers

Goals and Targets

At present agroforestry meets almost half of the demand of fuel wood, 2/3 of the small timber, 70-80 per cent wood for plywood, 60 per cent raw material for paper pulp and 9-11 per cent of the green fodder requirement of livestock, besides meeting the subsistence needs of households for food, fruit, fibre, medicine, timber etc. However, ccurrent biomass productivity per unit area and time is less than 2 t $ha^{-1}y^{-1}$. Agroforestry practices have demonstrated that this could be safely enhanced to 10 t $ha^{-1}y^{-1}$ by carefully selecting tree-crop combinations. Area under forest is degrading due to tremendous demographic pressure and infrastructure growth needs, while agricultural area is almost stable. In India, nearly 120.72 million ha land or 37 per cent of the total geographical area is under one or the other forms of soil degradation (e.g., water erosion: 93 million ha, wind erosion: 11 million ha, salt affected soils: 6.74 million ha, and 16.53 million ha of open forest area; ICAR, 2010). Up to March 2007, 56.54 million ha area has been treated under various watershed development programmes, however a sizeable area is yet to be treated. Trees are known to grow even in areas polluted by heavy metals and other hazardous industrial chemicals. In fact, there are trees, which can absorb and tolerate such pollutants, which not only reduce crop yields but also impair quality of crop produce. A number of agroforestry tree species e.g. *Terminalia arjuna, Eucalyptus* hybrid, *Morus alba* and *Syzygium cummini* etc. have been evaluated and identified for their potential for phytoremediation (Dhillon *et al*., 2008). In India, 24.68 million ha area is affected by chemical pollution. These areas can be brought under cultivation through biological amelioration. Agroforestry can play vital role in such endeavours. Meeting diverse needs of people and livestock from limited land resources is only possible, when Agroforestry becomes common land use on majority of arable and non-arable lands. This will not only avert degradation, but also enhance total productivity and restore eco-balance simultaneously. Agroforestry answers many problems that are faced by today's agriculture in terms of stability in production, regular returns, restoration of fertility, indiscriminate deforestation, drought mitigation and environmental pollution. Some points which will have bearing on the ongoing as well future research programmes are highlighted below;

In India, the energy demand is expected to grow at 4.8%. Further in

view of the increasing gap between demand and domestically produced petroleum, the dependence on import of oil will increase in the near future. To meet the growing needs of energy in the country, bio-fuel and bio-energy are being emphasized. Bio-fuels being renewable liquid fuels are gaining worldwide acceptance as a solution for problems of environmental degradation, energy security, restricting imports, rural employment and agricultural economy. The potential tree borne oilseeds (TBOs) holding promise for biofuel are *Jatropha curcas*, *Pongamia pinnata*, *Azadiracta indica*, *Calophyllum* and others, while *Simarouba, Madhuca, Garcinia* spp., etc. are good sources of edible oils. In agroforestry system, TBOs have been intercropped with annual crops such as cowpea, sesame, sunflower, French bean, blackgram, greengram and groundnut etc. at various places. In addition, lignocellulosic biomass *i.e.* plant dry matter (biomass), in the form of wood fuel, has a long history as a source of energy. Biomass is a carbon-neutral source of energy: since it comes from plants, the combustion of lignocellulosic material produces no net carbon dioxide into the earth's atmosphere. It is the most abundantly available raw material on the Earth for the production of bio-fuels, mainly bio-ethanol. This lignocellulosic biomass can be grouped into four main categories: agricultural residues (including corn stover and sugarcane bagasse), dedicated energy crops, wood residues (including saw mill and paper mill discards), and municipal paper waste. Under agroforestry systems many tree species are of interest for their ability to provide high yields of biomass and can be harvested multiple times each year. These include poplar, leucaena, jatropha and other species. The promotion of bio fuels could also provide a poverty alleviation option in the rural areas. Farmers can use fallow, waste and marginally used land for growing such trees and benefit from the annual produce, which will add to their income. With the increased green cover the environment will also benefit greatly. The use of oils is also CO_2 neutral, which would mitigate greenhouse effect. However, bio-fuel research is still at the beginning with respect to genetic improvement for increasing



Jatropha the potential tree borne oilseed for biofuel.

seed and oil yield of TBOs, and this will require concerted efforts from all quarters (Dhyani *et al*., 2011).

- In rural areas 70-80% energy comes through biomass from trees and shrubs. Due to agroforestry initiatives large amount of woods are now being produced from outside the conventional forestlands. Small landholdings and marginal farmers, through short rotation forestry and agroforestry practices are now providing the bulk of country's domestically produced wood products. *Prosopis juliflora* is the major source of fuel for the boilers of the power generation plants in Andhra Pradesh. The fuel wood potential of indigenous (*Acacia nilotica, Azadirachta indica, Casuarina equisetifolia, Dalbergia sissoo, Prosopis cineraria and Ziziphus mauritiana*) and exotic (*Acacia auriculiformis, A. tortilis, Eucalyptus camaldulensis* and *E. tereticornis*) trees revealed that calorific values range from 18.7 to 20.8 MJ kg^{-1} for indigenous tree species and 17.3 to19.3 MJ kg^{-1} for exotics. Species such as *Casuarina equisetifolia, Prosopis juliflora, Leuceana leucocephala* and *Calliandra calothyrsus* have become prominent due to their potential for providing wood energy at the highest efficiency, shorter rotation and also their high adaptability to diverse habitats and climates. Agroforestry plantations on community land and live fence on farm boundaries have immense potential in this regards. The option of biomass based power plant where electricity generation can be aimed from crop/plant residue is yet another option.
- Success in agroforestry, however will depend upon making available quality planting material, hence tree improvement and production of quality planting material should get priority in future as well.
- Capacity building of all stakeholders (producer, processor and consumer) needs due emphasis.
- Agroforestry extension services are grossly lacking. There is no dedicated extension support service for agroforestry. Institutions like KVK should be strengthened for the purpose. Although, agriculture is the state subject, the concerned state should be pursued to include agroforestry as a subject in its development and extension agenda.
- Non-timber produce from agroforestry trees like fruit, flower, honey, gum, resin, silk, raw medicine, etc. are source of income and health for tribal and other rural people. However, marketing hurdles for agroforestry produce are altogether different than that of agriculture. There are state to state variations for felling, harvesting and transportation of the tree produce and often linked with state forest laws. In order to facilitate adoption of agroforestry in the

country, there is an urgent need to implement the recommendations of the recently launched National Agroforestry Policy.

- A major role for agroforestry in near future will be in the domain of environmental services. This will need the development of mechanism to reward the rural poor for the environmental services such as biodiversity conservation, watershed protection and carbon sequestration that they provide to society. Therefore, strategy to formulate "ecosystem service pricing" needs urgent attention as agroforestry systems as such have long gestation period and majority farmers in India are small to marginal, who need quick and regular income from any venture. Such a system of "ecosystem service pricing" will help quick adoption of agroforestry and in turn conserve natural resources and provide sustained productivity. This can be done through carbon trading, surface water availability reward etc.

On the basis of above points, goals/target to be achieved in the next thirty five years are envisaged as below. To achieve the goals, long term planning along with adequate funds, suitable extension strategies, harvest-process technology, development of new products and market infrastructure and removing legal barriers in felling, transportation and marketing of agroforestry produce are the key issues.

Goal	Approach	Performance Measure
Enhance biomass productivity per unit area and time through agroforestry interventions	Development and evaluation of agroforestry systems for arable and non-arable lands and problem soils	Number of system developed. No. of compatible crops/plants identified. Increase in biomass productivity. The national goal to have a minimum of one-third of the country under forest or tree cover achieved.
	Integration of medicinal, aromatic and ornamental plants in agroforestry	
	Study on diversity of pests, pathogens and other microbes and their interactions	
	Growth and process modeling	
	Study on structure, biomass and productivity of agroforestry components	
Agroforestry for environmental amelioration, resource conservation, mitigation of climate change effects and management of stresses	Agroforestry interventions on watershed scale-Assessment of system productivity	Long term impact of identified agroforestry systems assessed in terms of employment generation, livelihood support, conservation of land and water, quality of produce and increase in biomass productivity and micro-climate improvement. Agroforestry based climate resilient agriculture promoted. Improving ecosystem services and increasing farmers' income (National Mission for a Greening India, NAP 2014).
	Agroforestry in improvement of ecosystem services	
	Effect of microclimate under agroforestry systems and evaluation for shade tolerance/ resilience of crops/ varieties/types/accessions	
	Development of soil quality index for assessing soil health and sustainability of agroforestry systems	
	Agroforestry strategies for mitigation of climate change and management of stresses	

Tree improvement, post-harvest & value addition	Collection, evaluation, characterization and conservation of germplasm of important agroforestry species including TBOs	Improved cultivars/varieties identified and released. Seed orchard of selected agroforestry species established. Elite planting material available on mass scale. Biofuel and bioenergy production enhanced for coping with climate change and meeting energy requirement. Remunerative livelihood options available. Agroforestry Information System available online.
	Standardization of clonal propagation techniques and mass multiplication of elite planting material	
	Harvest and post-harvest processing and value addition of natural gums, resins etc.	
	Development and evaluation of livelihood options by integrating lac cultivation, apiculture, sericulture etc. in agroforestry systems.	
Participatory development of agroforestry models, HRD, refinement and transfer of technology	Promotion for wider technology adoption among farmers and other target groups, feedback and refinement.	Adoption of agroforestry in terms of area and density. Number of stakeholders trained or exposed to agroforestry. Livelihood and employment avenues enhanced. Sufficient raw material for wood based industries available. An effective market mechanism would be created for generating income to growers from agroforestry produce. Agroforestry product research, new product development, new designs and quality standards would be evolved for downstream processing.
	Capacity building of stakeholders through training, workshop, meeting, *Kisan Mela* etc.	
	Evaluation of adoption pattern of agroforestry interventions	
	Trends in marketing of agroforestry products and services including market intelligence	
	Exchange of material and technology through collaborative research programs and networking	
	Agroforestry role in poverty alleviation; women empowerment and livelihood support- an analysis	

Strategy to Achieve the Objectives and the Outputs

The roadmap for achieving the objectives and the expected outputs, outcomes and the beneficiaries are presented here below,

- Recurrent Diagnosis and Design (D&D) survey of the different agro-climatic regions periodically to assess the status of agroforestry and to further refine the agroforestry technologies based on the findings of recurrent D & D exercises.
- Molecular characterization and DNA finger printing of germplasm of important MPTS for application in tree improvement progarmmes.
- State of the art nurseries for producing quality planting material of important MPTS in different regions.
- Promotion of nitrogen fixing/ fertilizer trees based agroforestry systems in degraded or low fertility lands for rehabilitation of such lands.
- Use of geospatial technologies in identifying and assessing the area under agroforestry in the country.
- Development of digital library of spectral signatures for major agroforestry systems.
- Assessing potential of agroforestry in carbon sequestration and mitigating climate change.
- Developing mechanism for the benefit of carbon sequestration reaching to small holders.
- Screening and evaluation of selected multipurpose trees (MPT) for higher thermo-tolerance and better Photosystem-II activity for coping with climate change to increase dry land productivity.
- Standardization, refinement and dissemination of agroforestry based amelioration technologies for problem soils.
- Genetic improvement *of Jatropha curcas, Pongamia pinnata* and other TBOs for maximizing yield, productivity and oil content for biofuel programme.
- Development, standardization and adoption of agroforestry models linked with market for enhancing productivity and profitability of small holding farmers.
- Development of decision support systems for micro level planning.
- Development of an online comprehensive data base on agroforestry for predicting yield and pricing of agroforestry produce.

- Capacity building of the scientists and technical personals in the field of carbon trading/ carbon sequestration/ climate change, genome resource conservation, molecular diagnostics, nano technology, physiology at cellular level etc.
- Government of India has accorded highest priority to the holistic and sustainable development of rainfed areas through watershed development program, therefore for research as well as extension of technologies, linkages with these programs will be established. In order to augment funds for technology dissemination, the schemes such as MGNREGS, RKVY, BGREI (Bringing Green Revolution to Eastern India- a sub-scheme of RKVY from 2010-11), BRGF, NFSM and other flagship programs of Govt. of India for agroforestry development particularly in rainfed areas will also be tapped.
- Integration of rural development schemes, afforestation programme, rural employment and rural industrialization programme with agroforestry and linkages with different National Missions and Programs of national importance are needed. Vast resources of innovative schemes such as MGNREGS, RKVY, NFSM, NHM, NBM, Backward Region Grant Fund (BRGF), Compensatory Afforestation Fund (CAMPA), etc. could be networked for improving productivity, efficiency, income and employment. MGNRGES has great potential and vast opportunity for convergence with watershed development programmes, water resource development and afforestation programmes and can be extended for agroforestry activities.
- For technology dissemination strong linkages with the network of KVKs will be established. The approach will be development of consortium with improved inter-institutional linkages along with wide stakeholder consultations.

Outputs

- Agroforestry systems with compatible tree-crop combinations identified for different edaphic and climatic conditions including degraded lands and problem soils across the agro-ecological zones of the country.
- Estimation of area under agroforestry in the country.
- Agroforestry land use plans at district level.
- Package of practices for agroforestry systems.
- Tree-crop interactions with respect to insect pest-disease and studies on micro-organisms for bringing synergy in the system.
- Impact assessment of agroforestry systems on protection of land, water, environment and socio economic status.

- Estimating carbon sequestration potential of agroforestry systems and scope of C trading in small holder situation identified.
- High quality germplasm of preferred species including TBOs will be available. Elite clones and technology will be available to smallholders for increasing productivity and production.
- Agroforestry product research, new product development, new designs and quality standards evolved for downstream processing.
- Assessment of long-term impact of agroforestry systems in terms of employment generation, livelihood support, conservation of land and water, quality of produce and increase in biomass productivity and micro-climate improvement.
- On-farm trials and demonstrations providing the feedback from farmers and other stakeholders to refine the systems.
- Valuation of environmental services of agroforestry for developing mechanism for payment to the practitioners.
- Well trained man-power available to take forward agroforestry land use.
- Quantified data available in respect of productivity, profitability and long term sustainability of the agroforestry systems.

The research output will help in meeting societal goals such as:

- Information on conservation value of tree (species wise, age wise, edapho-climatic condition wise) will help in pricing for environmental services offered by trees.
- Tree and crop improvement will further enhance productivity per unit area and time. Intensive use of land for tree and crop will generate year round employment in farming sector. This will lead to social amenity in the country and overall living status will improve for common men/women.
- Commercial agroforestry in line of that of Poplar, Eucalyptus and *Casuarina* can be promoted through PPP model. This will need facilitation by state governments in establishing food/wood processing units, minor forest produce, value addition etc.

Outcomes

- Use efficiency of both natural and external resources expected to be increased by developing and promoting appropriate agroforestry systems in various agro-climatic conditions for sustainable agriculture and environmental benefits.
- Poverty alleviation through improved agroforestry systems with reduced cost of cultivation, judicious use of resources and ensuring environmental safeguard.

- Enhanced capability and skill of scientific team to carry out participatory research and to conduct skill oriented trainings for local manufacturers.
- Information flow between farmer-researcher-industry and between collaborating Centres for appropriate agroforestry systems.

Beneficiaries and impact

- Self sufficiency in production of timber, NWFP and other forest products. Forest-based industries will start optimum production generating employment and reducing import thus benefiting farmers and wood-industries both.
- High quality germplasm of preferred species will be available. Elite clones and technology will be available to smallholders for increasing productivity and production.
- Initiation of full-fledged extension programme on agroforestry on the lines of agriculture extension.
- An effective market mechanism would be created for generating income to growers from all agroforest produce.
- Agroforestry product research, new product development, new designs and quality standards would be evolved for downstream processing.
- Desired quantity of quality tree fodder will be obtained through agroforestry for the livestock.
- Bio-fuel and bio-energy production would be encouraged for coping with climate change and meeting energy requirement.
- Introduction of improved agroforestry technologies will have profound impact on rain fed agriculture and degraded lands, where there is great scope for its implementation.
- Agroforestry will act as social fence for protecting the national forests.
- Intensively cultivated areas with moderate to high technological assets are expected to be benefited through innovative, need based and location-specific agroforestry technologies.
- Wood based industries will get the desired quantity of raw materials and the country will achieve self sufficiency in wood production.
- Widespread adoption of agroforestry technologies will bring significant environmental benefits and help in mitigation of climate change effects.
- The country will achieve the desired goal of 33 per cent tree cover as per the National Forest Policy.

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Way Forward

AGROFORESTRY is bound to play a major role by 2050, not only for its importance in food and livelihood security, but also for its role in combating the environmental challenges because country's land area cannot be stretched. Agroforestry and trees outside forest will be a key issue in providing a solution to global warming, climate change and enhancing the per unit productivity of the land and converting degraded and marginal lands into productive areas. The major focus of research in the coming years will be on developing agroforestry technologies for critical areas like arid and semi arid zones and other fragile ecosystems such as Himalayan region and Coastal eco-system to sustain these areas for higher productivity and natural resource management. Therefore, the need is for,

- Development and demonstration for adoption of AF models linked with market for enhancing productivity and profitability of small holding farmers.
- Developing AF technologies for critical areas like arid and semi arid zones and other fragile ecosystems for higher productivity and natural resource management.
- AFs for mitigation of climate change effects and management of stresses.
- Demonstration of AF technologies through on farm trials, strategic alliances with corporate sector and other agencies.
- Developing mechanism for the benefit of carbon sequestration reaching to small holders.

With appropriate research interventions, adequate investment, suitable extension strategies and marketing infrastructure, agroforestry area may increase to 53.0 million ha. This will ensure augmentation and stabilization of production and productivity, meeting basic needs of the society, minimize ecological degradations and sustainable management of land, water and biodiversity. Bio-fuel and biomass based agroforestry systems in rainfed areas and wastelands will be helpful in meeting the energy needs as well as for environmental protection. The agroforestry interventions as such will create opportunities for employment generation and livelihood support. A major role for agroforestry in near future will be in the domain of environmental services, such as climate change mitigation (carbon sequestration), phytoremediation, watershed

protection, amelioration of NPS, and biodiversity conservation. However, this will need the development of mechanism to reward the rural poor for the environmental services that they provide to society (NRCAF 2007).

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