Introduction

1

Jagdish Chander Dagar, Anil Kumar Singh, and A. Arunachalam

Abstract

Agroforestry is an age-old land use system as the process of human evolution has been from forests when man learnt the art of domesticating plants and animals after leaving the hunting and gathering habit. The hunting and food gathering system gradually gave way to food producing systems. Incidentally, some stray references related to tree plantations occur in different texts of the Vedic literature. Archeological excavations corroborate early tree domestication around the settlements in South Asia. In India, organized research in agroforestry was initiated in early 1970s through industry participation in plantation of commercial tree species through Indian Council of Agricultural Research (ICAR) institutes. As follow up, the All India Coordinated Research Project (AICRP) on Agroforestry was established in 1983 by the ICAR through which research work was carried out through Agricultural Universities situated in different agroclimatic zones. Forest Survey of India has reported that about 25 million ha area in the country (8.2 % of the total reported geographical area) is under agroforestry in both irrigated and rainfed agriculture which also includes trees outside forests and scattered trees on and off the agricultural fields. In this publication, the various chapters are compiled in such a way that a clear picture of various agroforestry systems both traditional and improved found in different agroecological regions is presented. Some systems are present across a number of climatic regions (for example salt-affected and waterlogged areas); but the problems are of different nature in different regions. To deal with such cases, separate chapters are included to present agroforestry approaches dealing with specific problems. Agroforestry systems provide excellent opportunities for carbon sequestration and mitigating climate change, hence it needs a special strategy in policy initiatives.

J. C. Dagar (✉) · A. K. Singh · A. Arunachalam
Natural Resource Management Division, Indian Council of Agricultural Research, Krishi Anusandhan Bhavan-II, New Delhi 110012, India
e-mail: dagarjc@gmail.com

J. C. Dagar et al. (eds.), *Agroforestry Systems in India: Livelihood Security & Ecosystem Services*, Advances in Agroforestry 10,
DOI: 10.1007/978-81-322-1662-9_1,

Early History of Agroforestry in India

Agroforestry is a collective name for land use systems and technologies, where woody perennials are deliberately grown on the same land-management units as agricultural crops and/or animals, either in some form of spatial arrangement or on a temporal sequence. In agroforestry systems, there are both ecological and economical interactions between the different components (Lundgren and Raintree 1982). Historically agroforestry is an age-old land use system as the process of human evolution has been from forests when man learnt the art of domesticating plant and animals after leaving the hunting and gathering habit. In about 700 BC, the hunting and food gathering system gradually gave way to food producing systems. Horticulture as co-existent with agriculture is found to have been prevalent in India from early historic period (500 BC to First century AD) when a certain amount of share in garden crops started to have been enjoyed by the King for providing irrigation. Incidentally, some stray references occur in different texts of the Vedic literature. For example, the cultivation of date palm (*Phoenix dactylifera*), banana (*Musa* x *paradisiaca*), pomegranate (*Punica granatum*), coconut (*Cocos nucifera*), jujube (*Ziziphus mauritiana*), *aonla* (*Emblica officinalis*), *bael* (*Aegle marmelos*), lemon (*Citrus limon*), and many other fruit trees and requirement of livestock in agriculture and mixed economy of agriculture and cattle breeding may be traced in protohistory chalcolithic periods of civilization (Raychaudhuri and Roy 1993). The role of many common trees such as *khejri* or *sami* (*Prosopis cineraria*), *aswattha* (*Ficus religiosa*), *palasa* (*Butea monosperma*), and *varana* (*Crataeva nurvala*) in Indian folk life has been mentioned in ancient literature of Rig Veda, Atharva Veda, and other Indian scriptures (Mann and Saxena 1980).

Archeological excavations corroborate early tree domestication around the settlements in South Asia. The evidences of this dates back to the Mesolithic period (10,000–4000 BC) when fruits of 63 plants including *bael, aonla, ber (Ziziphus* spp.), figs (*Ficus* spp.), *mahua (Madhuca indica)*, mango (*Mangifera indica*), etc., were reportedly consumed in one or the other form and were domesticated near the habitats (Randhawa 1980). Puri and Nair (2004) mentioned that rearing of silkworm (*Bombyx mori*) and lac insect (*Kerria lacca*) was practiced in the Indian sub-continent during the Epic era of Ramayana and Mahabharata (7000 and 4000 BC, respectively). The *Rishi*, *Muni,* and *Guru* (teachers of that time) were residing in forest and derived food in the form of vegetables, dry fruits, sweetening medium, medicine, and gum besides fuel from the forest. Further, they developed *Ashrams* (Institutions of learning) and started growing fruit trees like mango, guava (*Psidium guajava*), *mahua*, and others along with flowers, vegetables, and *Kutoo* (food grains) to meet their needs. Emperor Ashoka, a great Indian ruler (273–232 BC), encouraged a system of arbori-horticulture of banana, mango, jackfruit (*Artocarpus heterophyllus*), and grapes (*Vitis vinifera*). Further, the travelog of Ibn Battuta (Persian traveler, 1325–1354 AD) provides the earliest literary evidence of intensively cultivated landscapes of Malabar coast with coconut (*Cocos nucifera*) along with black pepper (*Piper nigrum*) around the habitats (Randhawa 1980). Warriar (1995) while describing Wayanad in Western Ghats, now in Kerala State, as Green Paradise mentioned that plough agriculture was prevalent in Wayanad as early as in the Megalithic Age (between 400 BC and 400 AD), and spices like black pepper, ginger (*Zingiber officinale*), and cardamom (*Elettaria cardamomum*) were often grown in association with woody perennials—as support or shade trees, since the early Middle Ages (500–1400 AD). The contents of *Krishi Gita*—over 300 year-old book of agricultural verses in Malayalam—also reflect on the need to maintain tree cover on the land scape, plant fruit trees on cleared forests, gardens, and other leftover lands, avenue planting as well as leaving vestiges of forests in the midst of cultivated landscapes (Kumar 2008). Natural history studies during the two previous centuries (Mateer 1883; Logan

1906) also signify that the people in the southern parts of peninsular India traditionally used their homesteads for a variety of needs such as food, energy, shelter, medicines, and other purposes. These evidences show that agroforestry was at the central stage in meeting the livelihood requirements since ancient times in India. Agroforestry practices were also prevalent in other parts of the world as described by Conklin (1957), Hailey (1957), Raghavan (1960), King (1987) and Nair (1993).

In India, organized research in agroforestry was initiated in early 1970s through industry participation in plantation of commercial tree species through Indian Council of Agricultural Research (ICAR) institutes. In 1979, first agroforestry Seminar was conducted at Imphal with participation of International Centre for Research in Agroforestry (ICRAF). As follow up, the All India Coordinated Research Project (AICRP) on Agroforestry was established in April, 1983 by the ICAR. The Council took lead in conducting systematic research in agroforestry initially through several coordinated projects and later by establishing National Research Center for Agroforestry (NRCAF) in 1988 at Jhansi. The Center was established to cater basic, strategic, and applied research needs in the field of agroforestry. The AICRP on Agroforestry—a large agroforestry network operational since 1983 was transferred to NRCAF in 1997 by empowering Director, NRCAF as the Project Coordinator of this big program. At present, the AICRP is being operated at 25 State Agricultural Universities (SAUs), 11 ICAR institutes and one Indian Council of Forestry Research and Education (ICFRE) institute. Since the early 1980s several agroforestry systems have been developed which have gone to farmers' fields and provided livelihood support to poor farmers.

Presently, the NRCAF is recognized worldwide for its research and development capabilities, agroforestry database, and information repository and natural resource management on watershed basis. The center conducts basic and strategic agroforestry research involving forest and fruit trees, shrubs, bamboos, arable crops, pastures, livestock, fish, and their interactions. Equal emphasis is given on tree improvement and human resource development (HRD) research programs.

Major Agroforestry Systems and Practices in India

In agroforestry literature the words "systems" and "practices" are often used as synonyms. In real sense agroforestry system is a specific local example of a practice, characterized by environment, plant species, and their arrangement, management, and socio-economic functioning. An agroforestry practice in turn denotes a distinctive arrangement of components in space and time (Nair 1993). Although hundreds of agroforestry systems have been recorded, they all consist of about 20 distinct agroforestry practices. In other words, the same or similar practices are found in various systems in different situations.

Nair (1993) classified agroforestry systems based on nature and arrangement of components (structural classification), function of the systems, ecological classification, and socio-economic criteria. In actual sense none of the system can be followed as such because most of the categories of agroforestry systems are found in all agroecological zones. In Indian literature, several terms for different systems such as agri(o)silviculture, agri(o)silvipasture, agri(o)horticulture, agri-silvi-horticulture, agri-silvi-hortipasture, hortiagriculture, horti-silvi(o)agriculture, horti-silvipasture, silvipasture, sylvopastoral, etc., are frequently used but the rationale and criteria for using or defining such terms have seldom been explained. While classifying agroforestry systems based on the type of components Nair (1989, 1993) classified agroforestry systems as agrisilviculture, silvopastoral, and agrosilvopastoral. He preferred using term agrisilviculture (rather than agrosilviculture) to denote the combination of trees and crops, whereas agrosilvopastoral (rather than agrisilvipastoral) was used for crops + animals/pasture + trees. His intention was to limit the use of the word agrisilviculture only to those combinations involving agricultural crops and trees. He

has argued that the word agrosilviculture can encompass all forms of agriculture (including animal husbandry) with trees, and would thus be another word for agroforestry. That again was the reasoning behind the use of all-inclusive "agro" prefix agrosilvipastoral.

In this classification, the word tree was probably commonly used for forest as well as fruit trees, hence later the word "horti" was used as prefix for fruit trees. In this publication, more common classifications adopted broadly in agroforestry literature involving all categories explained by Nair (1993) has been followed; furthermore, when the tree included is a fruit tree, it is referred to as a "horti"-system, and the term tree is used to encompass all trees other than fruit trees.

With the above background, agroforestry systems in India are categorized/classified as follows:

(a) Trees with arable crops or tree-based systems—includes scattered trees on farm land, boundary plantations, shelter belts and wind breaks, and wood lots.
(b) Trees on pasture lands (silvopastoral systems)—trees + pastures/grasses + animals.
(c) Fruit tree-based cropping systems—arable crops or grasses as intercrops with fruit trees.
(d) Commercial tree-based cropping systems—including commercial trees like *Populus* and *Eucalyptus* along arable crops.
(e) Plantations on rangeland or grazing/pasture land—plantations such as coconut, rubber, red oil palm, etc. + grasses/legume fodders + animals.
(f) Plantation based multi-storey cropping system—plantations including clove, cardamom, coconut, coffee, etc., + forest trees/shrubs + pine apple + shade tolerant crops + grasses + vines + vegetables, etc.
(g) Others—such as home gardens, multi-enterprise farming systems, biodrainage plantations, aquaforestry, apiculture with forestry, etc.

Some of these systems are traditional (Pathak and Dagar 2000) while in many research efforts have been made. In some modern systems such as alley cropping (hedgerow intercropping), sand dune stabilization, reclamation of degraded lands including salt-affected lands, biodrainage plantations, even home gardens, improved fallows, watershed management, and multi-enterprise farming system much research inputs (technologies) have been incorporated in the recent past. The major agroforestry systems/practices found/identified in different regions of India are mentioned in Table 1.1.

Description of the systems and practices in different agroecological regions are included in specific chapters in this book. Some location-specific aspects of general nature of agroforestry systems that are not described in the specific chapters for different agroecological regions are briefly described here.

Shifting Cultivation

Shifting cultivation, one of the most primitive traditional agroforestry practices, refers to farming system in tropics and subtropics in which land under natural vegetation (usually forests) is cleared by the slash and burn method, cropped with common arable crops for a few years, and then left unattended while the natural vegetation regenerates. Traditionally, the fallow period used to be 10–20 years but now it is reduced to 3–5 years. In India, about 600 thousand families in 48 districts are cultivating 2.27 million ha area (Table 1.2) as shifting cultivation (FSI 1997; North Eastern Council 1997).

It is evident that shifting cultivation has become unsustainable primarily due to reduced *jhum* cycle owing to the increase in population pressure. Many workers (Borthakur 1992; Ramakrishnan 1992; Tripathy and Barik 2003; Tomar et al. 2012) suggested alternatives or improvements to shifting cultivation.

Nair (1993) has included about 44 species of perennial legumes used in Asian farming systems which may help in improving the fallow. These include species of *Acacia, Albizia, Alnus, Cajanus, Calliandra, Casuarina, Erythrina, Faidherbia, Flemingia, Gliricidia, Inga, Leucaena, Parkinsonia, Pithecelobium, Prosopis, Robinia,*

Table 1.1 Common agroforestry systems/practices found in India

Agroforestry practice	Arrangement of major components	Agroecological adaptations/distribution and special remarks
1. Shifting cultivation (Traditional as well as improved fallows)	Fast growing trees planted after clearing forest and left to grow in fallow period + arable crops	Tribal areas of Northeastern states, Orissa, Andhra Pradesh (enough scope of improvement)
2. Taungya (Traditional)	Combined stand of woody and arable crops during early stages of establishment	In all regions mainly tribal belts (enough scope of improvement)
3. Multi-purpose trees on crop lands (Traditional and improved)	Trees scattered on fields, boundary plantations, live hedges (forest and fruit trees + arable crops)	All regions especially in subsistence farming, also integrated with animals mainly in dry regions (Many improved MPTs are available)
4. Plantation-based cropping systems (Improved)	(i) Integrated multi-storey mixture of plantation crops	Plantations like coffee, cacao, coconut + fruit trees + spices like clove, cardamom + vines (black pepper) + shade crops, etc., in humid and sub-humid tropical regions
	(ii) Commercial plantation crops with shade trees scattered on field or dense in boundaries	Tea plantations + shade trees in hilly regions
	(iii) Tree plantations with arable crops	Commercial plantations (Poplar, Eucalyptus, bamboo) in Indo-Gangetic Plains on crop fields
	(iv) Fruit orchards and arable intercrops or fodder crops	All regions including temperate hilly regions
	(v) Plantations on pastures/grazing lands	In humid and sub-humid tropical regions, mainly coastal regions
5. Alley cropping (Hedgerow intercropping) (Improved systems)	Leguminous trees/shrubs trained in rows as alleys + arable crops/ grasses	In humid and sub-humid regions, mostly on sloping lands to conserve soil
6. Home gardens (Improved home gardens also available)	Multi-storey combination of MPTs (mainly fruit & plantation trees, shrubs), vines, shade crops, vegetables, spices, etc., poultry, ducks, and livestock around homesteads	All regions especially in hilly regions and coastal highly populated regions
7. Trees on grazing/pasture lands	Scattered trees/shrubs (used as fodder + shade) on grazing lands (involves livestock)	In all hilly and dry regions; also nearby forests
8. Afforestation for land reclamation and soil conservation (Improved)	Trees, shrubs, and grasses on highly degraded lands including eroded, mined, salt-affected, and waterlogged area (improved systems)	In all arid and semi-arid regions to rehabilitate ravine lands, mined areas, salt-affected lands, biodrainage plantations along canals and crop fields, and sand dunes stabilization

(continued)

Table 1.1 (continued)

Agroforestry practice	Arrangement of major components	Agroecological adaptations/distribution and special remarks
9. Shelter belts, wind breaks, and live hedges	Trees and shrubs sometimes succulent cactus, etc., as live hedges	In all regions
10. Woodlots	Mostly on common property lands, along roads, railway lines, avenue trees, sacred groves, etc.	In all regions
11. Cut and carry systems (protein banks)	Usually leguminous fodder and fuel-wood trees/shrubs and fodder grasses and legumes on *Panchayat* lands	In many progressive villages throughout country
12. Multi-enterprise farming systems (Improved)	Forest and fruit trees + food crops + vegetables + fodder crops + live stock + poultry + duckry + piggery + fish in pond + floriculture + apiculture + natural gas/solar energy	Improved and highly remunerative; size of enterprise depends on the size of land holding of the farmer; being adopted in all regions
13. Others (Improved)	Aquaforestry, apiculture, and cultivation of medicinal and aromatic plants with forest and fruit trees; fish culture with mangroves; domestication of ornamental plants from forests and wild places, grazing in forests, etc.	New adventures but being followed at many places

Table 1.2 Area under shifting cultivation in India

States	Total area (000 ha)	Families involved (No.)	Districts (No.)
Arunachal Pradesh	261	54,000	10
Assam	310	58,000	3
Manipur	360	70,000	5
Meghalaya	265	52,290	5
Mizoram	45	50,000	3
Nagaland	633	1,16,046	7
Tripura	108	43,000	3
Andhra Pradesh	103	23,200	4
Orissa	184	1,41,000	8
All India	2,269	6,07,536	48

Source FSI (1997), North Eastern Council (1997)

and *Sesbania.* The intercropping between the fast growing leguminous trees during fallow phase is one of the approaches while finding alternative to shifting cultivation. Besides technical inputs socio-economic considerations are also important in solving the problems related to shifting cultivation. There is urgent need of settling the land tenureship issue educating the people about the adverse impacts of short *jhum* cycles. There is need to provide employment opportunities and regular income through proper utilization of natural resources and by equitable distribution of wasteland among the tribal people. The cooperative efforts should be encouraged for carrying out forest-based activities such as basket making (bamboo-based cottage industry), rope making, cane furniture, processing of minor forest produce, honey collection, etc. For these activities, efforts should be made to create viable market for sailing the products on remunerative prices. The local administration must ensure the implementation of total literacy campaign, which due to remoteness and un-supportive attitude of tribal people has not been successful so far. For awareness and educating specially the women and children, services of various non-governmental organizations and voluntary agencies, besides the regular government machinery, are required on regular basis. Eco-development plans for areas under shifting cultivation should be developed on priority on site-specific basis involving sustainable agroforestry practices. Determining the population supporting capacity of a *jhum* stand may be one of the major aspects for checking the degradation of the environment and depletion of the resources. Overall strategy should be developed which ensures improving livelihood of people by efficient utilization of natural resources including land, water, biodiversity, and external input in a practical and profitable manner enhancing the environmental safety. Integrated approach involving arable crops, fruits, animal husbandry, fishery, and forestry with appropriate conservation measures for natural resources would be most effective in overall development of the shifting cultivation areas.

Taungya

The *taungya* system in the tropics is like an organized and scientifically managed shifting cultivation, a forerunner to agroforestry. The word is reported (Blanford 1958) to have originated in Myanmar (earlier Burma); *tauang* means hill and *ya* means cultivation. Earlier it was a local name for shifting cultivation and later subsequently used to describe afforestation as well. Today the system is known by different names such as *Tumpangsari* in Indonesia; *Kainginning* in the Philippines; *Lading* in Malaysia; *Chena* in Sri Lanka; *Kumri, Jhooming, Poonam, Taila* and *Tackle* in different parts of India; *Shamba* in East Africa; *Parcelero* in Puerto Rico; and *Consorciarcao* in Brazil (Nair 1993).

Essentially, the system consists of growing annual agricultural crops along with the forestry species during the early years of establishment of the forestry plantation. The important tree species grown in this system include *Shorea robusta, Tectona grandis, Dalbergia sissoo, Acacia catechu, Eucalyptus globulus, Populus deltoides*, and *Pinus patula.* The land basically belongs to the forestry department and upon their large-scale lease, allowed the subsistence farmers to raise their crops and in turn the farmers protect the tree saplings. It can be considered a step in the process of transformation from shifting cultivation. It is not merely the temporary use of a piece of land and a poverty level wage, but a chance to participate equitably in diversified and sustainable agroforestry economy. There are numerous reports describing *taungya* practices of different regions but research data on changes of the soil fertility and management aspects are, however, scarce. Alexander et al. (1980) based on 2 years data on the Oxisols of Kerala mentioned disadvantage of *taungya* causing erosion hazard caused by soil preparation during cultivation for the agricultural crops. The surface horizons became partly eroded and subsurface horizons were gradually exposed. The addition of crop residues to the soil surface was found to be a very effective way of minimizing soil loss and exposure. The farmers may manage the system in more sustainable way as is the case in watersheds if they are leased the land for longer period.

Home Gardens

Home gardens depict a transition stage between tropical forest ecosystem and arable cropping that mutually supports the sustainable agriculture and forest ecosystems. It also preserves the biodiversity. Much has been written about home gardens and numerous terms have been used by various workers. These include mixed-garden horticulture, house garden, Javanese home gardens, compound farm, kitchen garden, household garden, and homestead agroforestry (Nair 1993). Plantation crops such as coconut (*Cocos nucifera*), cacao (*Theobroma cacao*), coffee (*Coffea arabica*), arecanut (*Areca catechu*), and vine black pepper (*Piper nigrum*) often are the dominant components of many home gardens of humid tropics. Fruits such as banana (*Musa paradisiaca*), papaya (*Carica papaya*), mango (*Mangifera indica*), guava (*Psidium guajava*), custard apple (*Annona squamosa*), and jackfruit (*Artocarpus heterophyllus*) are the major components of some tropical home gardens including coastal regions of India. Dagar (1995), Kumar (2006, 2010), Pandey et al. (2007) and Kumar and Kunhamu (2011) have given comprehensive account of home gardens in coastal and Island regions of India.

Plantation Based Cropping Systems

During the recent past in India a sizeable data has been generated from coconut-based cropping systems and is related to intercropping under coconut plantations and fruit tree orchards, integrated mixed farming in small holdings, grazing under coconut, factors favoring intensification of land use with coconut, and multi-storey tree gardens. Important crops—plantation combinations include cereals (rice-*Oryza sativa*, finger millet-*Eleusine coracana,* and maize-*Zea mays*); pulses (pigeon pea-*Cajanus cajan*, green gram-*Vigna radiata*, black gram-*Vigna mungo*, gram-*Cicer arietinum*, soybean-*Glycine max*, cowpea-*Vigna unguiculata*, etc.); oil seeds (groundnut- *Arachis hypogaea*, mustard-*Brassica juncea, B. nicra, B. napus*, sesame-*Sesamum indicum*, safflower-*Carthamus tinctorius*, sunflower-*Helianthus annuus*, etc.); root crops (sweet potato-*Ipomoea batatas*, tapioca-*Manihot esculenta*, yams-*Dioscorea* spp., and taro-*Colocasia esculenta*, etc.); spices and condiments (ginger-*Zingiber officinale*, turmeric-*Curcuma domestica*, cardamom-*Elettaria cardamomum*, cinnamon-*Cinnamomum zeylanicum*, clove-*Syzygium aromaticum*, nut meg-*Myristica fragrans*, chilies-*Capsicum acuminatum, C. annuum*, and black pepper-*Piper*

nigrum); fruits like pineapple-*Ananas comosus*, mango-*Mangifera indica*, banana-*Musa* x *paradisiaca*, papaya-*Carica papaya*, and bread fruit-*Artocarpus altilis*); other crops (cotton-*Gossypium herbaceum, G. arboretum, G. hirsutum*, sugarcane- *Saccharum officinarum*, potato-*Solanum tuberosum*, abaca-*Musa textilis* and several vegetables); tree crops (areca nut-*Areca catechu*, cacao (*Theobroma cacao*, tea-*Camellia sinensis*, and coffee-*Coffea arabica*); improved pasture grasses include species of *Brachiaria*, *Dichanthium*, *Panicum*, *Setaria*, *Paspalum,* and *Pennisetum*; while improved forage legumes include species of *Stylosanthes*, *Desmodium*, *Glycine*, *Pueraria*, *Phseolus, Leucaena,* and *Macroptilium*. Many trees such as species of *Populus, Eucalyptus, Moringa, Erythrina*, *Ficus, Tamarindus, Gliricidia*, *Ceiba,* and *Cordia* also find the place in these systems.

In North-eastern Himalayan regions domestication of large cardamom (*Ammomum subulatum*) plantations under *alder* (*Alnus nepalensis)* and its collection from the natural forests by indigenous Lepcha and Limbu tribes is an age-old agroforestry practice. Besides *Alnus nepalensis*, there are 29 other tree species, supporting this plantation crop. Tree management practices by farmers involve harvesting trees above 16 cm basal diameter to assist natural regeneration of younger tree seedlings and open canopy to regulate light at the ground. This tree management system provides continuous supply of fodder and fuel wood. The nitrogen fixing trees help site improvement and better growth of cardamom. Alder is also grown to enhance soil fertility particularly by the tribal people for growing maize, millet, potato, chilies, barley, vegetables, etc. This tree is main component of coffee and cardamom at lower and higher altitudes as a shade tree.

In Punjab and Haryana farmers are growing poplar (*Populus deltoides*) and *Eucalyptus* (particularly in areas with high water table) in rows on their cultivated fields having rice-wheat cropping system or sugarcane. This is more prevalent in irrigated situations.

Scattered Trees on Farmlands

The practice of growing agricultural crops under scattered trees on farmlands is quite old and seems to have scarcely changed for centuries. In ancient India, trees were given more importance than crops in tree-crop mixed cropping. Today also the trees are found grown scattered in agricultural fields for many uses such as shade, fodder, fuel wood, fruit, small timber, vegetables, and medicinal uses. Some of the practices are very extensive and highly developed. For example, growing of *Prosopis cineraria* and *Ziziphus nummularia* in arid areas; *Dalbergia sissoo*, *Acacia nilotica*, and mango in Indo-Gangetic plains; *Grewia optiva, Quercus* spp, and many other tree species in the Himachal Pradesh; *Eucalyptus globulus* in the southern hills of Tamil Nadu; and *Borassus flabellifer* in peninsular coastal regions. Nair and Dagar (1991) documented a profile of numerous tree species found growing in different agroclimatic regions of India. There are strong convictions for the acceptance of these trees on agricultural fields since time immemorial. The very fact that Khejri (*Prosopis cineraria*) is omnipresent in dry regions and its occurrence is encouraged in all the cultivated fields and village grazing grounds. It shows that its usefulness is generally and widely accepted by land owners who have a strong conviction that the tree does not hinder crop productivity in the adjoining areas. Moreover, studies conducted have shown that the soil under *P. cineraria* has more organic matter, total nitrogen, total and available phosphorus and potassium, and micronutrients (Zn, Mn, Cu, and Fe). Similarly *Ziziphus nummularia* is preferred and is a favorite bush in arid Rajasthan.

In the foot hills of Shivaliks, Grewal (1992) reported that growing Bhabar grass (*Eulaliopsis binata*) with *Eucalyptus* and *Acacia catechu* is highly economical system. In Indo-Gangetic plains the farmers retain trees of *Acacia nilotica*, *Acacia catechu, Azadirachta indica, Butea monosperma, Dalbergia sissoo, Gmelina arborea, Morus alba*, *Mangifera indica, Syzygium*

cuminii, and *Ziziphus mauritiana*. Farmers in sub-humid *terai* region of Indo-Gangetic plains, prefer *Dalbergia sissoo*, *Psidium guajava, Mangifera indica, Morus alba*, *Syzyzium cuminii*, and *Grewia nudiflora*. In Bihar *Dalbergia sissoo, Litchi chinensis,* and *Mangifera indica* are frequently grown on fields. Farmers in northeastern region prefer *Alnus nepalensis*, *Artocarpus chaplasha*, and species of *Bambusa*, *Dendrocalamus*, and fruit trees like *Mangifera indica, Emblica officinalis*, and *Parkia roxburghii*. In coastal areas of peninsular India, *Borrasus flabellifer* is found scattered in the fields of groundnut, rice, and green gram. Other most common trees found on farmers' fields are *Moringa oleifera, Tamarindus indica, Ceiba pentendra, Anacardium occidentale, Cocos nucifera* palm, and fruits like banana, custard apple, guava, and pomegranate.

Trees on Farm Boundaries

Trees, which are grown in agricultural fields or on field bunds, are also often and usually grown on farm boundaries. In northern parts of India particularly in Haryana and Punjab, both *Eucalyptus* and *Populus* are commonly grown along field boundaries or bunds of paddy fields. Other trees, which are found grown as boundary plantations or live-hedge, include *Acacia nilotica*, *Dalbergia sissoo,* and *Prosopis juliflora*. Farmers of Sikkim grow bamboo (*Dendrocalamus*) all along irrigation channels. In coastal areas of Andhra Pradesh, *Borassus* is most frequent palm. In Andamans, *Gliricidia sepium*, *Jatropha* spp, *Ficus sp., Ceiba pentendra, Vitex trifoliata,* and *Erythrina indica* are grown frequently as live-hedges. At many places succulents like *Agave* and many cactoids are grown as common live fence.

Many of the boundary plantations also help as shelterbelts and wind breaks particularly in fruit orchards. In Bihar, *Dalbergia sissoo* and *Wendlandia exserta* are most common plantations. *Casuarina equisetifolia* and *Acacia auriculaeformis* are extensively planted on field bunds and along sandy coastal areas in Orissa.

Woodlots

In many parts, farmers grow trees in separate blocks as woodlots along with agricultural fields. Now the practice is expanding fast due to shortage of fuel wood and demand of poles or pulpwood in industry. For example, bamboo poles are in great demand for orange orchards in Nagpur area and *Eucalyptus* and *Populus* for WIMCO Industries. Woodlots are being raised mostly on large farms due to the increase of labor costs and labor management, lack of irrigation facilities, and risk of crop investments. Woodlots of *Casuarina equesitifolia*, bamboo, *Populus deltoides*, *Eucalyptus,* red sanders (*Pterocarpus santalinus*), *Dalbergia sissoo*, *Grewia nudiflora,* and many others have become popular in many parts of the country. In recent times, these woodlots have shrunk at a fast rate due to increase in population pressure.

Systems for Soil Conservation/ Amelioration/Reclamation

About 121 million ha of land in India is suffering from different degradation problems (NAAS 2010) including serious wind and water erosion and salinity. The deep and narrow gullies are best controlled by putting them to permanent vegetation after closure to grazing. Afforestation with suitable tree species like *Acacia nilotica, A. eburnea, Azadirachta indica, Butea monosperma, Prosopis juliflora, Dalbergia sissoo, Tectona grandis*, species of *Bambusa* and *Dendrocalamus* helps in stabilizing the gullies and ravines. Other adaptable species include grasses like Dichanth*ium annulatum, Bothriochloa pertusa, Iseilema laxum, Cynodon dactylon, Dactyloctenium aegyptium, D. sindicum, Heteropogon contortus, Themeda quadrivalvis, Sehima nervosum,* and *Cenchrus ciliaris* which will besides providing fodder will also help in checking soil erosion. Grasses such as *Vetiveria zizanioides* and *Saccharum benghalensis* along with trees like *Terminalia arjuna*, *Eucalyptus*, and *Casuarina equisetifolia* help in stabilizing the coastal sand dunes.

Tree species such as *Acacia tortilis, A. nilotica, A. senegal, Prosopis cineraria, P. juliflora, Azadirachta indica, Tecomella undulata, Salvadora oleoides, Capparis decidua, Cordia rothii, Albizia lebbeck*, and *Cassia siamea* are suitable for growing on sand dunes in arid regions along with shrubs like *Calligonium polygonoides*, *Acacia jacquimontii,* and *Ziziphus nummularia*; and grasses like *Cenchrus ciliaris, Lasiurus scindicus,* and *Saccharum benghalensis*. These have been found effective in arresting drifting of soil/sand, as high as 1,450 t ha^{-1} (Hirekerur et al. 1991). Comprehensive results on afforestation of the salt-affected highly degraded soils with suitable species have been published by Dagar and Singh (1993), Singh et al. (1993), Tomar et al. (2003a, b, 2010) and Dagar (2012). The salt tolerant tree species are used for fodder, fuel wood, timber, and shade. Tree plantation techniques have been evolved for planting trees on highly sodic soils using auger-hole technique (Singh et al. 1993; Dagar et al. 2001a, b); on saline soils by furrow method (Tomar et al. 1998); on calcareous degraded lands using saline water (Tomar et al. 2003b); and on waterlogged farmers' fields (Ram et al. 2011). Several species have been identified for these situations. Tree species such as *Acacia nilotica*, *A. farnesiana, Parkinsonia aculeata*, *Prosopis juliflora,* and *Tamarix articulata* are the ideal for both alkali and saline soils while *Casuarina glauca* is an additional tool for saline waterlogged situations. *Azadirachta indica, Salvadora persica, Acacia nilotica*, and *Prosopis juliflora* are successful plants in black cotton saline vertisols. *Salicornia bigonia, Terminalia catappa, Pandanus* spp., and *Salvadora persica* (all oil yielding plants) have been assessed as the ideal choice for planting along with sandy coastal regions. In canal command areas where salinity and waterlogging are created due to seepage *Eucalyptus camaldulensis, E. tereticornis,Casuarina equisetifolia, C. glauca*, *Acacia nilotica*, and *Acacia ampleceps* are grown with success to check the seepage and salinity.

Shelter Belts

Arid regions witness very high wind velocity throughout the year and sand can initiate movement of particles even at 12–14 km h^{-1} wind velocity. Farmers build kind of obstacles to stop sand movements called *kana bandi* (e.g., in Rajasthan) either by using pieces of small dead wood or local vegetation to check wind velocity within safer limits (Mathur 1995). *Crotalaria burhia, Leptadenia pyrotechnica,* and Ae*rva javanica* are planted in 20–25 m wide rows across the wind direction. Between the lines of these under shrubs, grasses such as *Cenchrus ciliaris, C. setigerus*, and *Lasiurus scindicus* are planted on leeward side of each break. This permanent vegetation helps accumulating sand near them which is again spread in the field. This also helps increased crop yields along the lines.

Trees on Rangelands

As pointed earlier *Salvadora oleoides, S. persica, Capparis decidua, Tecomella undulata, Acacia nilotica, A. leucophloea, Prosopis cineraria*, and now *Prosopis juliflora* are the most frequent trees on common community grazing lands in dry regions. In coastal areas, coconut is most common tree on pasture lands. Sometimes trees like *Trema tomentosa, Moringa oleifera, Morinda citrifolia, Gliricidia sepium, Albizia lebbeck, Pongamia pinnata*, and *Ficus* spp. are grown and lopped for fodder. A cattle rearing usually involves grazing on these pastures. An organized form of silvopastoral system assures 10 t $ha^{-1}year^{-1}$ forage biomass production (as against 1 t $ha^{-1}year^{-1}$ from natural stands) at 10 year rotation in dry zones (Pathak et al. 1995) besides assuring soil conservation, carbon sequestration, and employment generation. While explaining the nature of grassland dynamics and their management Dagar and Pathak (2005) have cited several examples of trees playing crucial role in management of grazing lands in different agroecological regions. Based on long-term studies Rai (2012) reported the

importance of *Ailanthus excelsa, Acacia tortilis, Acacia nilotica, Hardwickia binata,* and *Leucaena leucocephala* based silvopastoral systems for live stock production.

Aquaforestry

Throughout the coastal regions particularly along the Andhra coast farmers are cultivating fish and prawn in saline water and growing coconut and other trees on bunds of ponds. These trees help in producing feed in the form of litter to fishery and generating extra income to the farmer. Now the fish culture in association of the mangroves is also advocated which are proved to be rich source of nutrition to the aquatic life and breeding ground for juvenile fish, prawn, muscles, turtles and variety of other animals (Dagar et al. 1991; Dagar 1995, 2003). Poultry is another adventure in some of these regions. A well-balanced system of animal husbandry including goat farming, poultry, ducky, turtles, and fishes in the small ponds in home gardens make a balanced system of high moisture, energy, and nutrient use efficiency per unit area The leaves of many trees such as *Gliricidia sepium, Leucaena leucocephala*, and *Moringa oliefera* have been found to serve as fish feed when offered as pallets and improved the productivity of fish pond. In many parts of the country, farmers are raising forest and fruit trees and vegetables on the dykes of fish ponds on their farms in multi-enterprise mode and are generating nutrition rich food for the family and good income.

Apiculture with Trees

The coastal population has been harvesting honey from the bees-making-hives on trees. Apiculture is now considered a profitable profession throughout the country. Many farmers are interested to go for this business by selecting different kinds of plantations. Eventually, the scopes of bee keeping are more prominent in the agroforestry systems due to high floral diversity. Apiculture in farming system mode is a sustainable component for generating regular income.

Improved Agroforestry Practices and Systems in India

It has been possible to conduct a Diagnosis and Design (D&D) exercise for existing agroforestry practices in India, generate valuable information, and identify important agroforestry practices from different parts of the country through the (AICRP) on Agroforestry. The collection and evaluation of multi-purpose trees (MPTs) resulted in establishment of arboretum in each coordinating center of AICRP. A collection of 184 species was made by these coordinating centers. This was followed by identification of important tree species for agroforestry research for various agroclimatic conditions. Each center was allocated two tree species for seed/germplasm collection and conducting provenance trials. A significant contribution of the project was tree selection and improvement of species such as *Populus deltoides, Eucalyptus tereticornis, Dalbergia sissoo, Azadirachta indica, Acacia nilotica, Leucaena leucocephala, Ailanthus excelsa, Pongamia pinnata*, and *Casuarina equisetifolia*. Clonal orchards for *Dalbergia sissoo, Acacia nilotica*, and *Azadirachta indica* have been established. Under National Agricultural Technology Project a program "Agroforestry BASE"—an online database has been developed at National Center for Agroforestry Research (NCAF), Jhansi which is being updated periodically.

Agronomic practices such as planting methods, irrigation, filling mixture composition, fertilization, spacing, and pruning schedules for raising some of the promising MPTs in association with annual crops have been developed and standardized. The suitable crops and cropping sequences which can be grown successfully (without significant reduction in yield) through agronomic manipulations and tree canopy management practices in combination with different forest and fruit trees have been identified. *Morus*

alba and *Grewia optiva*-based agroforestry systems for western Himalayas, *Alnus nepalensis*-based system for North Eastern Hill region, *Populus deltoides*-based system for Indo-Gangetic region, *Emblica officinalis*, and *Prosopis cineraria*-based systems for semi-arid and arid regions, *Tectona grandis*-based system for tropical region, and *Gmelina* and *Acacia*-based systems for humid and sub-humid regions have been developed. Packages have also been developed for rehabilitation of different wastelands through suitable agroforestry models.

The 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 systems has also been initiated in 2007 at six centers. Keeping in view the present day challenges, the project is now focusing on role of agroforestry in meeting the environmental challenges, value addition for creating livelihood opportunities, and application of modern tools and technologies in agroforestry research.

In recent times, substantial research inputs have been put into alley cropping (hedge row intercropping) system in which usually arable crops are grown in alleys formed by hedge rows of trees or shrubs, particularly in high rainfall areas. The hedge rows are cut back at crop planting time and kept pruned during the cropping season to prevent shading and to reduce competition with food crops. The hedge rows are allowed to grow when there are no crops and normally pruned during the season and the pruned material is either used as mulch, fodder, or source of nitrogen for crops. Tree species such as *Leucaena*, *Gliricidia*, *Sesbania,* and *Cassia* have widely tested in alley cropping system. Short duration rainy crops such as pearl millet and sorghum were found to be compatible with *Leucaena leucocephala* and *Gliricidia sepium.* In high rainfall areas like Andamans *Gliricidia sepium* has been found very successful on sloping lands and forage grasses such as hybrid napier (*Pennisetum purpureum*), thin napier (*Pennisetum polystachyon*), *Setaria anceps*, and legume *Stylosanthes guianensis* could be grown for fodder as alley crops which in turn also helped in checking erosion. Other crops such as turmeric (*Curcuma domestica*), ginger (*Zingiber officinale*), *Colocasia esculenta*, etc., also can be grown with hedge row crops. Wider alleys and low cutting heights were found to give higher intercrop yields in *Leucaena* system in semi-arid conditions.

Recently, farmers are adopting multi-enterprise farming systems to ensure perennial and sustainable round the year income from the farm involving many components such as fruit and forest trees, cereal crops, vegetables, fish (if there is pond), live stock, fodder, poultry birds, mushroom, and bee keeping. Live stock component is very important in this enterprise. Due to climate aberration if some component fails then the farmer can get some returns from remaining components. This farming system is most viable and remunerative.

Area Under Agroforestry in India

India has a large number of agroforestry systems and practices of various forms and types so it is very difficult to assess or estimate the extent of the area under agroforestry in the country. However, the Forest Survey of India (FSI) has been engaged in assessing the Trees Outside Forest (TOF) wealth of the country since 1991. In general, trees outside forests mean the trees available on agricultural land, along road side, railways, canals, ponds, orchards, parks, gardens, and homestead. These categories broadly fall under agroforestry. From 1991 onwards, the organization has been trying to improve the methodology of TOF assessment which has so far been based on field inventory methods, by incorporating satellite data of IRS LISS III, PAN, and fused image from these two for editing and refinement of classified images (Rawat et al. 2004; FSI 2011). At the national level, an attempt is being made in the National Carbon Project (NCP) to estimate the total phytomass and carbon density for plants/trees inside and outside the forest through a project taken up by the Indian Space Research Organization (ISRO), Government of India under its ISRO-Geosphere

and Biosphere Program in the 11th-Five-Year Plan. Inventories of non-forest areas were also designed to generate information at the state level. For example, the Kerala Forest Research Institute carried out a systematic survey using small villages as sample unit and estimated that the home gardens of Kerala had a total of 440 million trees equivalent to an estimated growing stock of 134.13 million m^3, of which 8.15 million m^3 meet the substantial portion of the total fuel wood requirement in the state (Singh and Chand 2012). Similarly a systematic study was conducted in the state of Madhya Pradesh by the Indian Institute of Forest Management, Bhopal, and highlighted the special distribution and importance of TOF in relation to livelihood of local people. In arid and semi-arid areas of less forest cover such as Rajasthan, Haryana, Punjab, Maharashtra, and Central India, nearly the entire total fuel wood requirements of rural people are met from non-forest resources like TOF. Recently, Singh and Chand (2012) developed a methodology and reported that in Haryana aboveground TOF phytomass varied from 1.26 t/ha in the scattered trees in the rural/urban area to 91.5 t/ha in the dense linear TOF along the irrigation canals. The total aboveground TOF phytomass and carbon content was calculated as 367.04 and 107.34 t/ha, respectively. These studies concluded that the classification of TOF and estimation of phytomass and carbon content in TOF can be successfully achieved through the combined approach of Remote Sensing and GIS-based spatial technique with the supplement of field data.

The forest cover assessment carried out by FSI using satellite data included all lands comprising area of one hectare and more, with a tree canopy density of more than 10 %, irrespective of their land use and ownership. The small patches of trees which are less than one hectare in extent, such as trees in village woodlots, homestead, urban areas, scattered trees, trees along roads, canals, railway lines and trees in block, and linear formation are excluded from the forest cover due to technical limitations of the procedures used. The contribution of such trees/patches to overall cover is estimated statistically using a sampling based methodology and is termed as tree cover. Thus, tree cover comprises tree patches outside the recorded forest area which are not captured by remote sensing satellite during forest cover assessment having area less than the minimum worth mapping area of one hectare. These blocks or linear patches between 0.1 and 1.0 ha are usually scattered trees.

Based on combined approach, the FSI has estimated the total forest and tree cover of India to be 78.3 million ha (including 4,662 km^2 mangrove area), which is 23.81 % of geographical area (FSI 2011). Of this, Trees Outside-Forest consist of about 5.07 % of total forest cover, i.e., 3.51 million ha (Mha) area. Thus, total TOF and tree cover make 12.59 Mha (Table 1.3), which may be considered as under agroforestry systems. FSI (FSI 2011) has reported that 25.31 Mha area in the country (8.2 % of the total reported geographical area of the country) is under agroforestry in both irrigated and rainfed agriculture (Table 1.4) which also includes TOF, scattered trees on and off the agricultural fields, 2.27 Mha area under shifting cultivation (North Eastern Council 1997), and 2.42 Mha home gardens (Kumar 2006).

As per this estimation, 7.0 Mha area is under irrigated agroforestry with commercial/industrial plantations under agrisilviculture (2.63 Mha), fruit orchards or fruit-based cropping systems (2.79 Mha), and trees on boundaries or bunds of agricultural fields (1.58 Mha) through social forestry. About 10.6 Mha area in rainfed agriculture is under agrisilviculture (2.4 Mha), agrihorticulture or fruit trees based cropping systems (1.86 Mha), and trees on grazing/range lands and field boundaries (6.32 Mha). Besides this, about 3 Mha area is under tree cover due to rehabilitation of salt-affected lands, mined wastelands, and trees on common property/community lands.

Considering the importance of agroforestry in India, the Planning Commission of India, the apex planning body for the country, in its report stated that there is a scope for bringing 10 Mha irrigated and 18 Mha rainfed additional area under agroforestry (Planning Commission 2001). Out of this a total of about 7.73 Mha (3.80 Mha

Table 1.3 Area under trees outside forest and tree cover (scattered trees) of India in 2011

Category	Area (000 ha)	Percent of geographical area
Trees outside forest	3,509	1.07
Tree cover (scattered trees)	9,084	2.76
Total	12,593	3.83

Source FSI (2011)

Table 1.4 Estimated agroforestry area in the country

Category	Area (million ha)	Remarks
Agroforestry in irrigated areas		
Agrisilviculture	2.63	Industrial use
Agrihorticulture	2.79	Fruit orchards/fruit trees based cropping systems
Trees on field boundary or bunds	1.58	Social forestry, live fences, etc.
Sub-total (A)	**7.00**	
Agroforestry in rainfed areas		
Agrisilviculture	2.40	Scattered trees on fields, bunds, boundaries
Agrihorticulture	1.86	Fruit orchards/plantation-based cropping systems
Trees on field boundary/bunds	0.74	Social forestry, deliberate live fences, etc.
Silvo-pastoral	5.58	Trees on grazing/range lands
Sub-total (B)	**10.58**	
Other land uses		
Home gardens	2.42[a]	Mostly in coastal areas and North-Eastern states
Shifting cultivation	2.27[b]	Mostly in NEH States, Orissa, Andhra Pradesh
Afforestation of problem soils	2.12	Plantations on salty soils, mine areas, etc.
Trees on community/common lands	0.92	On Panchayat lands, along roads, railways, etc.
Sub-total (C)	**7.73**	
Total agroforestry area **(A + B + C)**	**25.31**[c]	

Source NRCAF (2013)
[a] Kumar (2006)
[b] North Eastern Council (1997)
[c] FSI (2011)

irrigated and 3.93 Mha rainfed land) has been brought under agroforestry through various schemes during the past 10 years. There is further scope of increasing the area under agroforestry in future by another 28.0 Mha which may include the remaining 20.27 Mha area earlier earmarked by the Planning Commission (2001). The major share of the land to be brought under agroforestry will be from fallows, cultivable fallows, pastures, groves, and rehabilitation of problem soils. Thus, a total of 53.31 Mha area (about 17.5 % of the total reported geographical area-TRGA), could potentially be under agroforestry in the near future (NRCAF 2013), making the agroforestry a major activity in India in terms of area occupied after agriculture with 141 Mha, 46 % of the TRGA (Ministry of Agriculture 2010), and forestry with 69.63 Mha, 22.8 % of the TRGA (FSI 2011).

Need and Scope of Agroforestry in India

It is worth mentioning here that agroforestry systems are probably the only means for getting the desired tree cover in the country, especially in states that have low forest area. Agroforestry

is not only a technique for growing food crops in association with woody perennials and livestock to optimize the use of natural resources but also a source of renewable energy resource and a means of reducing the risk of environmental degradation and climate change. The livelihood security through agroforestry and its potential in meeting basic needs viz., food, fuel, fodder, and employment generation are well known. By virtue of diversity of the components of the agroforestry systems like food grains, vegetables and fruits, and the nutritional security to the communities could be ensured. The fodder cultivation under agroforestry land use will ensure production of milk, meat, and animal products. Wide range of food crops, pulses, and oil seeds can meet diverse needs of the society. Tree domestication and the commercial processing and marketing of tree products and services, is a new frontier for agroforestry research and or development. Multi-enterprise farming systems have to go long way for bringing sustainability and livelihood security among small and marginal stakeholders. A major role is also emerging in the domain of environmental services, particularly the development of mechanisms to reward the rural poor for the watershed protection, biodiversity conservation, and carbon sequestration that they provide to the society. Agroforestry has the greatest potential to mitigate climate change through adaptation. It is the tested mechanism to tolerate diversified climate through adaptations toward variety of climate aberrations.

Some of the main socio-economic and environmental outcomes/successes of agroforestry development programs in the country have been summarized in a separate chapter dealing with utilization and benefits of agroforestry. The economic analysis of more than 30 agroforestry models practiced in different agroclimatic conditions of the country reveal a high benefit: cost ratio (1.5–3) and Internal Rate of Return (15–40 %). Thus, agroforestry has to play a decisive role not only in supply of timber products, thus saving the forest, but also to be extremely effective in meeting the other requirements including food security and requirements of day today life and also to mitigate climate change.

Agroforestry Research and Technology Development

India has been at the forefront of agroforestry research but still there is a long way to go. Agroforestry research in the ICAR system and other Indian institutes and universities has been in progress since early 1950s. As mentioned earlier, the ICAR launched the AICRP on agroforestry in 1983 representing all agroclimatic zones in the country. Besides ICAR Institutes and SAUs, the ICFRE also supports agroforestry research in education in various parts of the country. Private sector initiatives in agroforestry such as those by WIMCO, Bharatia Agro-Industries Foundation (BAIF), Indian Farms Forestry Development Cooperative (IFFDC), and Imperial Tobacco Company (ITC) are also worth mentioning. Some of the important research and development outcomes in agroforestry in India since organized research in agroforestry began in the early 1980s are listed below:

- ***Characterization of agroforestry systems*** in different agroclimatic zones of the country: By developing a D&D approach and using them for survey, a bench mark information base for major agroforestry systems has been prepared.
- ***Collection and evaluation of multipurpose tree*** species: Creation of arboretums in different agroclimatic zones.
- ***Tree selection and improvement***: Tree species on which tree improvement has focused include poplar (*Populus deltoides*), shisham (*Dalbergia sissoo*), neem (*Azadirechta indica*), semal (*Bombax ceiba*), subabul (*Leucaena leucocephala*), and species of *Casuarina* and *Eucalyptus*.
- Identification of preferred agroforestry tree species for different agroclimatic regions.
- Management practices for different agroforestry systems; Packages of practices have been standardized and their efficacies and economic returns (B:C ratios) worked out to show the

usefulness of the systems under specified agroecological and socio-economic settings.

- ***Development of site-specific agroforestry technologies***: Tree species must suited for rehabilitating problem areas such as degraded lands including salt—affected, waterlogged, and eroded lands, have been identified and management technologies for each developed.
- Design and testing of multi-enterprise farming system models for different agroclimatic situations for livelihood security of small and marginal farmers.
- Identification and development of climate resilient agroforestry systems involving diversified cropping systems and livestock population directly on farmers' fields.

The major thrust area on which agroforestry has focused today in India includes:

– Increased production of wood resources to meet the growing needs of households and industries.
– Environmental amelioration through the C-sequestration, bioremediation, and resource conservation.
– Enhancement of livelihood and employment avenues.
– Promotion of agroforestry adoption through developing decision support systems and other appropriate means.
– Exploration of new and under exploited species of high economic value, such as medicinal, aromatic, oil-yielding, etc.
– Testing and evaluation of marine algae or seaweeds for food, medicine and green manure in identified agroforestry systems.
– Rehabilitation of degraded salt-affected areas using good quality forages, MPTs, plantation crops, and plants of industrial application with due attention to quality assessment of the products obtained from the saline habitats.
– Development of halophytic crops involving fish, shrimp culture, and poultry with agroforestry systems, genetic improvement of salt-tolerant plants, raising nursery with saline water, and multiplication and conservation of useful genetic material.
– Development of sustainable and remunerative multi-enterprise farming systems for marginal and small farmers of different agroclimatic regions working under different stresses, through value addition and policy initiatives.
– Promotion of agroforestry-based industries.
– Transfer of technology transfer.
– Capacity building/human resource development.
– Support and linkages among national and international collaborative research programs.

Based on three decades of experience with agroforestry research and development we have also identified major constraints to the promotion of agroforestry in India which include:

- Lack of an enabling Agroforestry Policy.
- Long gestation periods of tree species.
- Lack of high yielding genetic planting material and silvicultural practices for indigenous tree species.
- Lack of access to credit against agroforestry plantations.
- Absence of marketing institutions.
- Absence of any organized agroforestry extension service.
- Restrictions in harvesting of some timber trees; the cumbersome procedures involved in getting permission for harvesting trees on private lands.

In this publication, the various chapters are compiled in such a way that a clear picture of various agroforestry systems found in different agroecological regions is presented. The regional system descriptions in the chapters present both little studied traditional practices as well as improved systems. Some systems are present across a number of climatic regions; for example salt-affected and waterlogged areas are present in all agroecological regions but the problems are of different nature in different regions. To deal with such cases, a separate chapter is included to present agroforestry approaches to dealing with salinity problems. Similarly, other problematic areas such as mines and ravine lands covered in separate chapter. Most of the degraded lands including salt-affected and

waterlogged areas can be brought under vegetation through agroforetsry practices which control erosion, reduce runoff, improve *in situ* soil-moisture conservation, increase water-table, and also improve productivity and profitability. Agroforestry systems that provide excellent opportunities for carbon sequestration are a valuable climate change mitigation strategy, which needs to be incorporated into major policy documents. Concerted efforts are required to identify practical and cost-effective means through changes in land use practices using agroforestry as an option. These issues are discussed in a separate chapter on policy initiatives. Finally a synthesis chapter highlights the important initiatives taken at the level of researchers and policy makers, constraints faced, and directions for future efforts in agroforestry research.

This publication may prove quite useful for different stakeholders interested in agroforestry at global level in general and at country level in particular.

References

Alexander TG, Sobhana K, Balagopalan M, Mary MV (1980) Taungya in relation to soil properties, soil degradation and soil management. Research report 4. Kerala Forest Research Institute, Peechi

Blanford HR (1958) Highlights of one hundred years of forestry in Burma. Empire For Rev 37(1):33–42

Borthakur DN (1992) Agriculture of the North Eastern region with special reference to hill agriculture. Beece Prakashan, Guwahati

Conklin HC (1957) Hununoo agriculture. FAO Forestry Development Paper No.12. Rome, Italy

Dagar JC (1995) Agroforestry systems for the Andaman & Nicobar Islands. Int Tree Crops J 8:107–128

Dagar JC (2003) Biodiversity of Indian saline habitats and management and utilization of high salinity tolerant plants with industrial application for rehabilitation of saline areas. In: Alsharhan AA, Wood WW, Gouie AS, Fowler A, Abdellatif EM (eds) Desertification in the third millennium. Swets and Zeitlinger Publishers, Lisse, pp 151–172

Dagar JC (2012) Utilization of degraded lands/habitats and poor quality water for livelihood security and mitigating climate change. Indian J Agrofor 14(1):1–16

Dagar JC, Pathak PS (2005) Grassland dynamics and their management. Range Manag Agrofor 26(1):7–31

Dagar JC, Mongia AD, Bandyopadhyaya AK (1991) Mangrooves of Andaman and Nicobar Islands. Oxford and IBH Publishing Co. Pvt. Ltd, New Delhi, pp 166

Dagar JC, Sharma HB, Shukla YK (2001a) Raised and sunken bed technique for agroforestry on alkali soils of northwest India. Land Degrad Dev 12:107–118

Dagar JC, Singh G (1993) Afforestration and agroforestry for salt affected soils. Indian Rev Life Sci 13:21–24

Dagar JC, Singh G, Singh NT (2001b) Evaluation of forest and fruit trees used for rehabilitation of semi-arid alkali/sodic soils in India. Arid Land Res Manag 15:115–133

FSI (1997) State of Forest Report. Forest Survey of India, Dehradun, Ministry of Environment and Forests, Government of India

FSI (2011) State of Forest Report. Forest Survey of India, Dehradun, Ministry of Environment and Forests, Government of India

Grewal SS (1992) Watersheds management project, Relmajra (Punjab). Annual Report, 1991–92, CSWCRTI, Dehra Dun, pp 142–143

Hailey L (1957) An African survey. Oxford University Press, Oxford

Hirekerur LR, Lal S, Pofali RM (1991) Approaches to development planning for degraded lands. In: Abrol IP, Dhruvanarayana VV (eds) Technologies for wasteland development ICAR, New Delhi, pp 43–58

King KFS (1987) The history of agroforestry. In: Nair PKR, Stepler HA (eds) Agroforestry: a decade of development. ICRAF, Nairobi, pp 1–11

Kumar BM (2006) Carbon sequestration potential of tropical homegardens. In: Kumar BM, Nair PKR (eds) Tropical homegardens: a time tested example of sustainable agroforestry. Springer, The Netherlands, pp 185–204

Kumar BM (2008) Krishi gita (agricultural verses – trans) A treatise on indigenous farming practices with special reference to malayalam desam (Kerala). Asian Agri-History Foundation, Secunderabad, p 111

Kumar BM (2010) Species richness and aboveground carbon stocks in the homegardens of central Kerala, India. Agric Ecosyst Environ 140:430–440

Kumar BM, Kunhamu TK (eds) (2011) Quarter century of agroforestry research in Kerala: a compendium of research publication. Kerala Agricultural University, Thrissur, p 404

Logan W (1906) Molabar Mannual, vol 2, 2nd edn. Asian Educational Services, Madras, p 772

Lundgren BO, Raintree JB (1982) Sustained agroforestry. In: Nestel B (ed) Agricultural research for development: potentials and challenges in Asia. ISNAR, The Hague, pp 37–49

Mann HS, Saxena SK (1980) Khejri (*Prosopis cineraria*) in the Indian desert: its role in agroforestry. CAZRI, Jodhpur

Mateer (1883) Native life in Travancore. WH Allen, London, pp 450

Mathur BL (1995) Kana bundi indigenous method of controlling wind erosion, Honey Bee (12):7

Ministry of Agriculture (2010) Agricultural statistics at a glance. Directorate of Economics and Statistics, Ministry of Agriculture, Government of India

NAAS (2010) Degraded and wastelands of India: status and spatial distribution. National Academy of Agricultural Sciences (NAAS), New Delhi, pp 158

Nair PKR (ed) (1989) Agroforestry systems in the tropics. Kluwer, Dordrecht

Nair PKR (1993) An introduction to agroforestry. Kluwer Academic Publishers, The Netherlands

Nair PKR, Dagar JC (1991) An approach to developing methodologies for evaluating agroforestry systems in India. Agrofor Syst 16:55–81

North Eastern Council (1997) Basic statistics for north eastern region. North Eastern Council, Shillong, Meghalaya, India

NRCAF (2013) NRCAF Vision 2050. National Research Centre for Agroforestry, Jhansi

Pandey CB, Rai BR, Singh L, Singh A (2007) Homegardens of Andaman and Nicobar, India. Agric Syst 92:1–22

Pathak PS, Dagar JC (2000). Traditional agroforestry sytems: an overview. In:Soni P, Srivastava AK (eds) Landmarks of botany in India. Suriya International Pub., Dehradun, pp 26–49

Pathak PS, Gupta SK, Singh P (1995) IGFRI approaches: rehabilitation of degraded lands. Bulletin Indian Grassland and Fodder Research Institute, Jhansi, pp 1–23

Planning Commission (2001) Report of the Task Force on Greening India for Livelihood Security and Sustainable Development. Planning Commission, Government of India, New Delhi, pp 254

Puri S, Nair PKR (2004) Agroforestry research for development in India: 25 years of experiences of a national program. Agrofor Syst 61:437–452

Raghavan MS (1960) Genesis and history of the kumari system of cultivation. In: Proceedings of the 9th silviculture conference 1956 Forestry Research Insitute (FRI), Dehradun

Rai P (2012) Sylvipastoral system for livestock production: performance of small ruminants. Indian J Agrofor 14(1):23–28

Ram J, Dagar JC, Lal K, Singh G, Toky OP, Tanwar RS, Dar SR, Mukesh K (2011) Biodrainage to combat water logging, increase farm productivity and sequester carbon in canal command area of north-west India. Curr Sci 100 (11): 1673–1680

Ramakrishnan PS (1992) Shifting agriculture and sustainable development: an interdisciplinary study from north eastern India. UNESCO MAB series, Parthenon Publ, Carnforth, Lanes, Paris (Republished by Oxford Univ Press, New Delhi in 1993)

Randhawa MS (1980) A history of Indian agriculture: eighth to eighteenth century, vol 2. Indian Council of Agricultural Research, New Delhi, p 358

Rawat JK, Dasgupta SS, Kumar RS (2004) Assessment of trees outside forest based on remote sensing satellite data. Forest Survey of India, Dehradun, p 9

Raychaudhuri SP, Roy M (1993) Agriculture in ancient India. ICAR, New Delhi

Singh G, Singh NT, Tomar OS (1993). Agroforestry in salt affected soils. Technical Bulletin No.17, CSSRI, Karnal

Singh K, Chand P (2012) Above-ground outside forest (TOF) phytomass and carbon estimation in the semi-arid region of southern Haryana: a synthesis approach of remote sensing and field data. J Earth Syst Sci 121(6):1469–1482

Tomar OS, Gupta RK, Dagar JC (1998) Afforestation techniques and evaluation of different tree species for waterlogged saline soils in semiarid tropics. Arid Soil Res Rehabil 12(4):301–316

Tomar OS, Minhas PS, Sharma VK, Gupta RK (2003a) Response of nine forage grasses to saline irrigation and its schedules in a semi-arid climate of north-west India. J Arid Environ 55:533–544

Tomar OS, Minhas PS, Sharma VK, Singh YP, Gupta RK (2003b) Performance of 31 tree species and soil condition in a plantation established with saline irrigation. For Ecol Manag 177:333–346

Tomar OS, Dagar JC, Minhas PS (2010) Evaluation of sowing methods, irrigation schedules, chemical fertilizer doses and varieties of *Plantago ovata* Forsk to rehabilitate degraded calcareous lands irrigated with saline water in dry regions of north western India. Arid Land Res Manag 24:133–151

Tomar JMS, Das A, Puni L, Chaturvedi OP, Munda GC (2012) Shifting cultivation in northeastern region of India—status and strategies for sustainable development. Indian For 138(1):52–62

Tripathy RS, Barik SK (2003) Shifting cultivation in North East India. In: Bhat BP, Bujarbaruah KM, Sharma YP, Patiram (eds) Proceeding of approaches for increasing agricultural productivity in hill and mountain eco system, ICAR Resaerch Complex for NEH Region, Umiam, Meghalaya, pp 317–322

Warriar MRR (1995) Wayanad in the middle ages. In:Johny KP (ed) Discover Wayanad – the green paradise. District Tourism Promotion Council, Kalpetta, pp 68–69