11 Agroforestry in India and its Potential for Ecosystem Services

S. K. Dhyani and A. K. Handa

Abstract

India has a long tradition of agroforestry and many different types of indigenous agroforestry systems are found in different parts of the country. Most of these systems are location specific, and information on them is mostly anecdotal. The situation is now changing and a lot of research inputs have been at place since the existence of All India Coordinated Project on Agroforestry and establishment of National Centre for Agroforestry at Jhansi. Many technologies for rehabilitation of degraded lands including salt-affected and eroded lands have been developed and benefits of these technologies are reaching to the stake holders. Some of these issues and ecosystem services rendered through agroforestry systems, which are otherwise not highlighted, are discussed in this chapter. The need of separate agroforestry policy at place has been felt.

Introduction

Forests played crucial role in the human evolution. Man learnt the art of domesticating plants and animals after leaving the hunting and gathering habit. Man's desire to live in co-existence in a community created settled agriculture. Increase in human and live stock population necessitated acquiring more and more land under cultivation to meet the ever increasing demand for food, fodder, vegetables, fuel wood, timber, medicines, etc. Further, demographic pressure has forced man to seek unconventional methods of agriculture to utilize land to the maximum extent. Therefore, in the quest of optimizing productivity, the multitier system came into existence. The origin of agroforestry practices in India, i.e., growing trees with food crops, grasses, and other components is believed to have started during *Vedic* era, though agroforestry as a science evolved in recent years. Agroforestry as is now understood as a science of designing and developing integrated self sustainable land management systems which involve introduction and/or retention of woody components such as trees, shrubs, bamboos, canes, palms along with agricultural crops including pasture/animals, simultaneously or sequentially on the same unit of land and time, to satisfy the ecological as well as socio-economic needs of the people.

However, referring to the recent literature, agroforestry combines agriculture and forestry technologies to create more integrated, diverse,

S. K. Dhyani (✉) · A. K. Handa
National Research Centre for Agroforestry, Jhansi, 284003, UP, India
e-mail:
shivkdhyani@gmail.comskdhyani@nrcaf.ernet.in

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_11,

productive, profitable, healthy, and sustainable land use systems. Some important agroforestry practices include: agrisilviculture, agrihorticulture, silvopasture, alley cropping, etc. According to the Association for Temperate Agroforestry—"Agroforestry practices are *intentional* combinations of trees with crops and/or livestock that involve *intensive* management of the *interactions* between the components as an *integrated* agroecosystem." These key characteristics are the essence of agroforestry and are what distinguish it from other farming or forestry practices. To be called agroforestry, a land use practice must satisfy all of these criteria:

- *Intentional*: Combination of trees, crops, and/or animals are intentionally designed and managed as a whole unit, rather than as individual elements that may occur in close proximity but are controlled separately.
- *Intensive*: Agroforestry practices are intensively managed to maintain their productive and protective functions; these practices often involve annual operations such as cultivation and fertilization.
- *Interactive*: Agroforestry management seeks to actively manipulate the biological and physical interactions between tree, crop, and animal components. The goal is to enhance the production of more than one harvestable component at a time, while also providing conservation benefits.
- *Integrated*: The tree, crop, and/or livestock components are structurally and functionally combined into a single, integrated management unit. Integration may be horizontal or vertical, and above or below ground. Such interaction utilizes more of the productive capacity of the land and helps balance economic production with resource conservation.

Traditional Agroforestry Systems

Scanty information is available on the historical aspect of agroforestry in the country, however, it is more in the form of anecdotes and narration without much backing from authentic literature. Though some information is cited under Introduction of this publication a periodic historic information is included under this section. The following text is based on the published papers such as Tejwani (1994), Pathak and Dagar (2000), Dhyani et al. (2006, 2009a, b, 2011), and Kareemulla et al. (2007, 2009).

Agroforestry During Vedic Era

Man was basically a food collector during *Vedic* era, who gradually acquired the knowledge of plant species yielding food, fruits, vegetables, medicines, etc. The origin of agroforestry practice, i.e., growing trees with food crops and grasses believed to have occurred during the Vedic and Pre-Vedic period in India. The God's prime *Rishi* and *Muni* and *Guru* 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* and started growing fruit trees like mango, jackfruit, guava, mahua, and others along with flowers, vegetables and *Kutoo* (food grain) to meet their needs. Man gradually developed settled farming with the passage of time. However, there were many who moved with receding forests, entirely depending on forest for food and shelter. They came to be known as tribal people who cleared some forest area and started growing agricultural crops without any input such as fertilizer and water. They cultivated agricultural crop for 3–5 years thereafter the practice kept on rotation. This practice was coined as shifting cultivation and became popular in Madhya Pradesh, Orissa, Andhra Pradesh, Bihar, North Eastern States, and Andaman Nicobar Islands.

Agroforestry During Epic Era

The period of Indian history during which two great epics (Ramayana and Mahabharata) were composed is known as epic era. Ramayana was composed by great poet Maharishi Valmiki. In this epic, he illustrated that *Rishi* and *Muni* were used to grow mango, banana, guava, sweet potato, barley, and flowers. They mostly utilized the food grains, fruits, and vegetables grown on the land of *Ashram*. Maharishi Valmiki had vividly illustrated the arrangement of trees such as Ashok, Neem, Pipal, Bargad in outer ring, jack fruits, mango, banana, and guava in middle ring and flowers namely, Champa, Chameli, Juhi, Bela, etc., in inner ring and *sarover* (water-tank) in the centre in *Ashok vatika*. This clearly indicated that trees, fruit trees and flower plants grown in association in the *vatika* (garden), which could be considered an agroforestry practice. Mahabharat was composed by Maharishi Ved Vyas. The agroforestry practices were improved during this period as compared to Ramayana period. The great teacher Dronacharya not only raised trees, fruit trees, and vegetables, but also raised *Sanwa* and barley in the orchard, which was used for food and worship of God. Rearing of silkworm was a popular profession during that period. It is evident from these two epics that agroforestry practices such as agrisilviculture and agrihorticulture were in operation in their primitive state during epic era.

Agroforestry During Medieval Period

The agriculture was in its primitive state during the medieval period. However, many agroforestry practices existed. Example includes planting trees for shade, shelter, boundary demarcation by planting trees, multipurpose trees, nitrogen-fixing trees, timber trees, fruits, nuts, food, fuel, and fodder yielding trees. Flowers and fruits of mahua, bamboos, sal seeds, and others were being consumed by people. Alcohol was also produced from trees such as palms and mahua. The tribal dances performed around these trees are symbolic of the intimate ethnic bias to protect trees. Trees had considerable socio, ethnic, and religious backing.

Agroforestry During Recent Past

In the recent times especially for the last 3–5 centuries, spectacular improvements were made in tree plantation. The most important agroforestry practice is known from the Kangeyam tract of Tamil Nadu where *Acacia leucophloea* + *Cenchrus setigerus* in silvopasture system was perfected. Similarly in ravines of Yamuna and Chambal, trees, shrubs, and bamboos with grasses were planted for rearing the milk producing Jamunapari breed of goats and sheep. Scattered trees such as Khejri (*Prosopis cineraria*) and Mehndi (*Lawsonia alba*) in association with pearl millet, sorghum, and chilly were grown in the semi-arid area of Tamil Nadu. Tree plantations continued as demarcation and control against wind erosion throughout the country. Plantation of Khejri trees for various uses on farm was a common practice in Rajasthan. In the northeast, large cardamom (*Amomum subalatum*) was introduced in Alder (*Alnus nephalensis*) forests in Sikkim Himalayas by the local farmers more than 200 years ago. Now the Alder-based agroforestry system is covering more than 48,000 ha area in northeastern states (Dhyani 1998). Deliberately growing of trees like *Grewia, Celtis* etc., on field bunds and systematic plantation of shade trees for tea and coffee plantation are other common examples of agroforestry practices in the hilly areas. In the coastal areas, *Casuarina equisetifolia* and other trees were grown in association with crops on farmlands for cash and small timber. Live hedges were common as an agroforestry practice in which Mehndi, *Agave sisalana, Euphorbia* species were commonly raised. In paddy sowing areas, *Pongamia pinnata* and *Sesbania grandiflora* were grown, lopped annually and their leaves applied to fields as green manure. Application of green manure to paddy fields also was common in Madhya Pradesh and Uttar Pradesh. In Western Ghats, *Terminalia* leaves were harvested, spread on land burnt and then paddy and millets were sown. Multistoried homesteads/home gardens were in existence in Kerala, Karnataka, and Tamil Nadu as an important agroforestry practice. This agroforestry practice is still followed in aforesaid states to fulfill the needs of fodder, fodder, fuel wood, fruit, vegetable, medicines, etc (Kumar 2003).

Some of the traditional systems such as shifting cultivation, taungya cultivation, home gardens, trees on boundaries, and block plantations are important and have been discussed in detailed in the regional chapters where these are prevalent.

Agroforestry Research in India

In order to meet the increasing demand of our fast growing population, we require the production of food grain and fuel wood for human consumption and green and dry fodder for livestock to the tune of 250, 350, and 2,085 million ton, respectively besides 75 million m^3 of timber. Under these circumstances, there is no alternative but to follow the integration of trees with agricultural crop, which is known as agroforestry. Agroforestry research is more than 100 years old in India beginning with introduction of shade trees in tea gardens, but organized research was initiated during the second half of the last century in few ICAR Institutes namely Central Arid Zone Research Institute, Jodhpur, Central Soil and Water Conservation Research and Training Institute, Dehradun, Indian Grassland and Fodder Research Institute, Jhansi, as fuel-fodder plantations on degraded lands or establishing the silvopastoral systems.

India has been at the forefront since organized research in agroforestry started worldwide. In 1979 at Imphal, the Ist Seminar on Agroforestry was organized by the Indian Council of Agricultural Research, New Delhi to accumulate and compile the data on the research and development of agroforestry in India. The All India Coordinated Research Project (AICRP) on Agroforestry with 20 centers all over country was launched in 1983 to implement the major recommendations of the aforesaid seminar. Further, National Research Centre for Agroforestry was established in 1988 at Jhansi to accelerate the basic, strategic, and applied research in agroforestry. At the initial phase, agroforestry research also got financial support from different international agencies primarily USAID, UNDP, and others, which helped in strengthening infrastructure and human resource component. At present, there are 37 centers under All India Coordinated Research Project on Agroforestry with project coordinating unit at National Research Center for Agroforestry, Jhansi. These centers represent almost all the agro-climates of the country. In addition to ICAR, Indian Council of Forestry Research and Education (ICFRE) and its Institutes, private institutions and NGOs such as WIMCO, ITC, BAIF, IFFDC, West Coast Paper Mills Ltd., Hindustan Paper Mills Ltd, and National Tree Growers Cooperatives are also engaged in research and promotion of agroforestry in the country.

The major thrust of agroforestry research in the beginning was on the following areas:

- Diagnostic survey and appraisal of existing agroforestry practices.
- Collection and evaluation of promising fuel wood, fodder and timber yielding tree species/ cultivars.
- Studies on management practices of agroforestry systems.
- Development of wastelands, watersheds, and community lands through agroforestry interventions.
- Integration of livestock, fishery, apiculture, lac, etc., as component of agroforestry.

The research and developmental efforts undertaken during the last more than two decades have brought results, which have clearly demonstrated the potential of agroforestry for resource conservation, improvement of environmental quality, rehabilitation of degraded lands, and providing multiple outputs to meet the day–to-day demand of the rural population.

The diagnostic survey and appraisal of existing agroforestry practices in the country revealed that there are a number of agroforestry practices prevalent in different agro-ecological zones (Chauhan and Dhyani 1989, 1994; Singh and Dhyani 1996; Pathak et al. 2000; Sharda et al. 2001). The review of agroforestry system research indicates that agroforestry systems or practices are widely based on nature and arrangement of the components and ecological or socioeconomic criteria. In the documented agroforestry practices, trees serve as wind breaks and shelterbelts, delineate boundaries, and provide shade, ornamentation, and seclusion around homesteads. They supply not only poles, stakes, timber, and fuel, but also cash crops, fodder, fruits and nuts, dyes, gums, resins, fiber, and medicines. Fodder and food trees provide balanced diets during dry seasons, when other foods are scarce. Trees, with their deep rooting systems, consume moisture and nutrients from higher depth in the soil than arable and pastoral crops, and thus there is least competition among the different components. Thus, the value of trees on farmland may considerably exceed that offered by woodlands and plantations (Singh 1987).

The second major aspect of the research endeavors under agroforestry was collection and evaluation of promising tree species/cultivars of fuel, fodder, and small timber. Quality germplasm of important agroforestry trees has been collected and evaluated in arboretum established by different Centres of the AICRP (Dhyani et al. 2008; Solanki 2006). About 184 promising tree species have been determined based on growth performance trials at these centers. The results indicate that the safest choice of agroforestry species have come from the native vegetation, which has a history of adaptation to local precipitation and other climatic regimes. There are a number of tree-crop combinations, which in turn reflect the differences in the climates and soil fertility of various regions in the country. The examples of major trees in agroforestry practices include: *Grewia optiva*, *Ulmus wallichiana*, *Morus alba*, and *Robina pseudoacacia* in western Himalayan region; *Acacia auriculaeformis, Alnus nepalensis*, Bamboos, *Parasarianthes falcataria* and *Gmelina arborea* for north-eastern Himalayan region; Poplars, Eucalyptus, *Acacia* and *Dalbergia sisoo* in Indo-Gangetic region; *Dalbergia sissoo, Acacia tortilis, A. nilotica, Ailanthus excelsa, Prosopis cineraria, Leucaena leucocephala* and *Azadirachta indica* for arid and semi arid regions; *Acacia nilotica, Prosopis cineraria* and *Zizyphus* in western India; *Tectona grandis*, *Tamarindus indica*, Para rubber (*Hevea brasilensis*) and cashew nuts (*Anacardium occidentale*) in southern region; *Albizia* spp. *Gmelina arborea, Gliricidia, Acacia auriculaeformis, A mangium* for humid and sub-humid regions; and *Artocarpus*, *Pongamia*, *Casuarina equisetifolia, Grevillea robusta* and bamboos in coastal and island regions. The efforts made so far has created voluminous database, which is a great strength for planning agroforestry research strategy. The information collected may be utilized for creating local and regional timber volume tables. The Planning Commission (2001) has also identified six species for major thrust in agroforestry and Joint Forest Management (JFM) programs in the country. The species are *Acacia nilotica*, Bamboos, *Casuarina equisetifolia, Eucalyptus* spp., *Populus deltoides* and *Prosopis cineraria.*

On the basis of identification and evaluation of promising trees and D&D survey of the existing systems, agroforestry interventions were initiated in different agro-climatic regions. Primarily these systems are put in different categories such as agrisilviculture, agri-horticulture, agri-horti-silviculture, hortipastoral, silvopastoral, and specialized systems. Among these systems, agrisilviculture followed by agrihorticlture, are the most prominent being practiced and advocated for the majority of the agro-climatic zones. Home gardens, block plantation, energy plantation, shelterbelts, and shifting cultivation are some of the specialized agroforestry systems developed by the research institutions with the knowledge gained by documenting and analyzing the traditional systems. However, the agroforestry systems developed and recommended by these institutions are location specific, besides in many situations these systems are not looked favorably by the farmers due to wide variations in the choice of species, crop preferences, etc. Also some of the systems developed have not yet completed a full rotation for the tree component, therefore, biomass production and returns are only on the basis of extrapolation. The stakeholders also require full package of practices, choice of crops with trees in temporal sequence and information on insect-pest-disease and effect of aberrant weather conditions, which are now of common occurrence.

Agroforestry initiatives in the country has greatest role in creating awareness among the common man for the protection and preservation of trees, bushes, and grasses. It has been realized that destruction and degradation of forest resources may have detrimental effect on soil, water and hence on human and animal life. In fact, Stern (2006) points out that reducing deforestation and forest degradation would be one of the most cost-effective mitigation approaches. Unfortunately, most forest soils are not suitable for agriculture and quickly became unproductive. The felling of trees for commercial and domestic wood products is mostly unregulated and beyond the forests' ability to replenish itself. Similarly, the grazing of livestock in forested areas is often beyond their carrying capacity. Going by the potential for economic exploitation, it would appear that 90 % of the forests are performing critical functions of protecting fragile watersheds and are not fit for commercial exploitation. As a shift in the National Forest Policy of India harvesting from forests has now practically been banned with social benefits mainly flowing from the protective and environmental functions of the forest apart from meeting the subsistence needs of the communities living close to the forests.

Agroforestry and Ecosystem Services

Owing to increase in population of human and cattle, there is increasing demand of food as well as fodder in the country due to large human and livestock population. Besides, there is little scope to increase food production by increasing the area under cultivation. Hence food production is to be increased from the land already under cultivation or from land not conventionally considered arable. A management system therefore needs to be devised that is capable of producing food from marginal agricultural land and is also capable of maintaining and improving the quality of producing environment. Agroforestry has both productive and protective potential, and it can play an important role in enhancing the productivity of our lands to meet the demand of ever-growing human and livestock population.

In the country, about 7.45 million ha area has been planted with different types of agroforestry plantations (Dhyani et al. 2006). Besides, 25.72 million ha area has been covered under various types of tree plantations viz. agroforestry, social forestry/farm forestry. Future prospects for expansion of agroforestry in different agro ecological regions of India exist in 10 million ha irrigated and 18 million ha rainfed areas (Planning Commission 2001). Further, 15 million ha degraded forest could be developed through joint forest management (JFM). The increase in area under agroforestry and trees outside forests is expected to minimize current deficit in supply of fuel wood (334.5 million tons) and timber (16.0 million cum).

Systemic research in agroforestry has clearly shown that it can contribute significantly to meet the deficits of fuel, fodder, timber, accelerate economic growth, and help in poverty alleviation, women empowerment, and livelihood support in several ways. A major role for agroforestry is now emerging in the domain of ecosystem or environmental services such as biodiversity conservation, watershed protection, carbon sequestration, and mitigating climate change effects besides in livelihood security and employment generation. The major environmental functions of agroforestry can be enumerated as-

- Control of soil degradation and rehabilitation of problem soils
- Control of desertification
- Flood and drought moderation
- Reduction in the pollution of groundwater resulting from high inputs of fertilizers
- Increasing biodiversity in the farming system and watershed scale
- Increasing food security and thereby reduce pressure on land resources
- Checking deforestation and its associated impact on environment
- Reducing pressure on forests through on-farm supply of fuelwood, fodder and other forest products
- Reduction in the build-up of atmospheric carbon dioxide and other greenhouse gases and mitigating adverse effects.

Agroforestry is playing the greatest role in maintaining the resource base and increasing overall productivity of agriculture, thus helping in building climatic resilient agriculture.

Agroforestry for Food and Nutritional Security

The country's food production has increased many folds since independence but recent improvements in food supply have been insufficient to fulfill the nutritional needs of the average person in an ever increasing population of the country. Agroforestry with appropriate tree-crop/legume combination is one option in this regard. The different agroforestry systems provide the desired diversification options to increase the food security of the country and act as a shield against the poor production during drought and other stress conditions. The agroforestry also provides nutritional security because of diverse production systems which include fruit, vegetables, legumes, oilseed crops, medicinal, and aromatic plants in addition to normal food crops grown by the farmers. With the rapid growth of urbanization and economic growth in the country, farming community have witnessed unprecedented opportunities for moving beyond subsistence farming to supplying products needed by urban population. 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. Thus, agroforestry systems offer opportunities to farmers for diversifying their income and to increase farm production. 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. Agroforestry has proven as an important tool for crop diversification. By virtue of diversity of the components of the agroforestry systems like fruits, vegetables, nutritional security to the communities could be ensured. There are ample evidences to show that the overall (biomass) productivity, soil fertility improvement, soil conservation, nutrient cycling, microclimate improvement, carbon sequestration potential of an agroforestry system is generally greater than that of an annual system. In agroforestry, the potentially higher productivity could be due to the capture of more growth resources, e.g., light or water or due to improved soil fertility. The best example is of poplar (*Populus deltoides*)—a popular species in agroforestry system in the Upper Indo-Gangetic region. Poplar was a best choice as it was fast growing, compatible with wheat and other crops and has industrial use. Therefore, poplar-(*Populus* spp.) based agroforestry in northern India made rapid strides. At present, there are 70 million poplar trees in the agricultural fields of the upper Gangetic region producing 10.40 million m^3 of industrial wood. Woodlots of other fast growing trees such as *Eucalyptus* spp., *Leucaena leucocephala*, *Casuarina equisetifolia*, *Acacia mangium*, *A. auriculaeformis, Ailanthus*, teak, and *Melia dubia* are also becoming increasingly popular among the farmers in several parts of the country due to their great market potential. Genetically improved clonal planting stock of eucalypts, poplars and acacias has transformed the productivity and profitability of plantations. Average yields from such clonal plantations are 20–25 times higher compared to the average productivity of forests in India. Almost 50 million plants of improved *Eucalyptus* are being planted every year.

Agroforestry for Fodder Production

It is evident from discussion in several chapters that trees and shrubs often contribute substantial amount of leaf fodder in all the agro-climatic regions. In arid and semi-arid and hill regions fodder scarcity is more especially during lean period when fodder is collected through lopping/pruning of trees, popularly known as top feed. The leaf fodder yield depends on species, initial age, lopping intensity, and interval as well as agro-climatic conditions. Fodder from trees is mainly available from two parts viz., leaf twigs and pods.

This forage is usually rich in proteins, vitamins, and minerals like calcium. They are however in general low in phosphorus and crude fiber (Singh 1990). Such top feeds species play an important role in human food security through their function as animal feed resource. The importance of top feeds increases with the severity of drought and progression of drought season.

Other uses such as for live fencing are complimentary, as they encourage cultivation of the species and increase the availability of feed. Silvopastoral system is the most appropriate land use system for degraded lands. The top feeds are also considered very important in vegetation stabilization and sustained productivity of rangelands (Dhyani 2003). They also play an important role as windbreaks and by providing shade for the grazing animal. The important ones are *Prosopis cineraria, Albizzia lebbeck. Acacia* spp., *Leucaena leucophloea, Dalbergia sissoo, Ailanthus excelsa, Azadirachta indica, Acacia leucophoela*, etc., for the arid and semi-arid region and *Grewia optiva, Morus alba, Celtis australis, Albizia,* Oaks, species of *Ficus,* etc., for the hilly regions. Tree fodder provides enough nutrients and can serve very well as a green fodder supplement. Besides providing green fodder, such leaves are also conserved in the form of hay and silage to supplement feed during scarcity periods. Bamikole et al. (2003) reported that feed intake, weight gain, digestibility, and nutrient utilization can be enhanced by feeding *Ficus religiosa* in mixture with *Panicum maximum*, and it can be used in diet mixtures up to 75 % of dry matter fed. Dagar et al. (2001) reported that for silvopastoral system on alkali soils *Prosopis juliflora, Acacia nilotica* and *Tamarix articulata* are the most promising trees and *Leptochloa fusca, Chloris gayana* and *Brachiaria mutica* most suitable grasses. *L. fusca* in association with *P. juliflora* produced 46.5 t ha^{-1} green fodders over a period of four years without applying any amendments and fertilizer. More details are discussed in Chap. 9

Agroforestry for Biofuel Production and Energy Security

India ranks 6th in the world in terms of energy demand accounting for 3.5 % of worlds energy demand since the beginning of twenty first century. The energy demand is expected to grow at 4.8 %. A large part of India's population mostly in rural areas, does not have access to the conventional source of energies. Further the Indian scenario of the increasing gap between demand and domestically produced petroleum is a matter of serious concern. In this connection, fuels of biological origin have drawn a great deal of attention during the last two decades. Biofuels are renewable liquid fuels coming from biological raw materials and has proven to be good substitute for oil in the transportation sector as such biofuels are gaining worldwide acceptance as a solution for problems of environmental degradation, energy security, restricting imports, rural employment and agricultural economy. The potential tree borne oilseeds (TBOs) holding promise for biofuel are *Jatropha curcas*, *Pongamia pinnata*, *Simarouba*, *Azadirachta indica*, *Madhuca* spp., etc. These biofuel species can be grown successfully under different agroforestry systems. There is need to identify the genetically superior germplasm of these biofuel species for higher seed yield and oil content (Dhyani et al. 2011). At present, the germplasm of *Jatropha* and *Pongamia* is under multilocation trials to identify the superior germplasm. The promotion of the use of oils could also provide a poverty alleviation option in the rural areas. Farmers can use vacant, waste, and marginally used land for growing such trees and benefit from the annual produce, which will add as 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. But the economics and viability of the Jatropha plantation and biofuel production are still at initial stage and will be governed by international market prices of crude oil as well as government policies.

Agroforestry for Energy Plantation

The main biomass energy sources in rural areas which are being used in the households, include wood (from forest, croplands, and homesteads), cow dung, and crop biomass. Among the sources 70–80 % energy comes through biomass from trees and shrubs. Due to the 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 timber products. Ravindranathan et al. (1997) reported for a Karnataka village that 79 % of all the energy used came mainly from trees and shrubs. *Prosopis juliflora* due to high calorific value of over 5,000 kcal is the major source of fuel for the boilers of the power generation plants in Andhra Pradesh (the other materials are rice husk, cotton stalks, other wood, etc.). About INR 700–1,300 per ton is the price offered for *P. juliflora* wood at factory gate depending on the season and moisture content. An estimated 0.51 million ha area is considered under *P. juliflora*. Even if 25 % of this area is utilized for power generation leaving the rest 75 % for fuel and charcoal, the bioenergy potential works out to 1,000 MW. Similarly, other fast growing and high biomass producing trees/shrubs like *Leucaena, Jatropha*, and *Gliricidia* can be used for running the biomass based power plants. Thus, a total of 5,000 MW power could be produced from the biomass sources from trees under moderate conditions, which meets almost one-third of the ultimate potential of 16,000 MW from biomass. R&D can help in enhancing productivity and assisting the power plants in captive plantation management on degraded lands. Promoting bioenergy through *P. juliflora* also encourages tremendous employment generation to the tune of 6.34 million mandays and 7.03 million woman days for fuel making in Tamil Nadu alone.

The fuel wood potential of indigenous (*Acacia nilotica, Azadirachta indica, Casuarina equisetifolia, Dalbergia sissoo, Prosopis cineraria*, and *Ziziphus mauritiana*) and exotics (*Acacia auriculaeformis, A. tortilis, Eucalyptus camaldulensis* and *E. tereticornis*) trees was studied by Puri et al. (1994). The calorific value ranges from 18.7 to 20.8 MJ $kg^{-1}$for indigenous tree species and 17.3 to19.3 MJ kg^{-1} for exotics. Pathak (2002) opined that species such as *C. 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 for Soil Conservation and Amelioration

Agroforestry plays a key role in keeping the soil resource productive, which is one of the major sustainability issues. Closely spaced trees on slopes reduce soil erosion by water through two main processes: first as a physical barrier of stems, low branches, superficial roots, and leaf litter against running water and secondly as sites where water infiltrates faster because of generally better soil structure under trees than on adjacent land. Agroforestry played a major role in the recent past in rehabilitation of wasteland such as desert and lands that have been degraded by salinization and ravines, gullies and other forms of water and wind erosion hazards. These aspects have been discussed in detail in earlier chapters.

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 in the shape of hedge row plantation. 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. The alley cropping with leguminous trees such as Subabul (*Leucaena leucocephala*) has been most widely used on field bunds for producing mulch material for moisture conservation and nutrient recycling. Alley cropping with *Leucaena leucocephala* was effective for erosion control on sloping lands up to 30 %. Reduction in crop yield could be minimized by shifting the management of trees to contour hedge rows. The sediment deposition along the hedge and tree rows increased considerably with consequent reduction in soil loss. Improvement in the organic matter status of the soil can result in an increased activity of the favourable micro-organisms in the root zone. In addition to the nutrient relations, such micro-organisms may also produce growth-promoting substances through desirable interaction and result in better growth of plant species. Inclusion of trees and woody perennials on farm lands can, in the long run, result in marked improvements in the physical conditions of the soil, e.g., its permeability, water-holding capacity, aggregate stability, and soil-temperature regimes. Although these improvements may be slow, their net effect is a better soil medium for plant growth. Experimental evidences give a very clear picture about agroforestry system that increased soil organic carbon and available nutrients than growing sole tree or sole crop. An increase in organic carbon, available N, P, and K content in Khejri based silvopastoral system over no-Khejri soil, advocating retention/plantation of Khejri tree in pasture land to get higher fodder production and to meet requirement of food, fodder, fuel, and small timber is one such example. Similarly, an increase in soil organic carbon status of surface soil under *Acacia nilotica* + *Sacchram munja* and under *Acacia nilotica* + *Eulaliopsis binata* after 5 years was observed. It was found that *Acacia nilotica* + *Eulaliopsis binata* are conservative but more productive and less competitive with trees and suitable for eco-friendly conservation and rehabilitation of degraded lands of Shiwalik foot hills of sub-tropical northern India. Rehabilitation of degraded forests is possible through afforestation by adopting integrated land use planning with soil and water conservation measures on watershed basis. NRCAF observed that in agrisilviculture growing of *Albizia procera* with different pruning regimes, the organic carbon of the soil increased by 13–16 % from their initial values under different pruning regimes, which was five to six times higher than growing of either sole tree or sole crop.

Agroforestry systems have been developed using local resources and conservation-based measures in the North Eastern Hill (NEH) region. Suitable alternate land use systems involving agriculture, horticulture, forestry, and agroforestry have been designed with the support of local natural resources for almost identical hydrological behaviour as under the natural system. The model land use suggests utilizing slopes below 50 % toward lower foothills and valley lands for agricultural crops and pisciculture, middle slopes between 50 and 100 % for horticulture and top slopes over 100 % for forestry/silvopastoral establishment. Under agri-horti-silvopastoral systems, the reduction in runoff was 99 % and in soil loss 98 %. Combining fine-root system of grasses and legumes, such as *Stylosanthes guyanensis*, *Panicum maximum*, *Setaria,* etc., and deep-root system of fodder trees, such as alder (*Alnus nepalensis*) in a silvopastoral system stabilizes terrace risers and provides multiple outputs. In-depth evaluation of soil chemical properties of traditional agroforestry system in northeastern region indicated a spectacular increase in soil pH, organic-C, exchangeable Ca, Mg, K, and build up of avai1able P (Bray's P_2-P) under different agroforestry practices (AFP) within 10–15 years of practice. The exchangeable Al, potential cause of infertility of these lands disappeared completely within 10–15 years of agroforestry practice. Therefore, the agroforestry practices were found to have built in dynamism for the restoration of soil fertility and sustained yield (Singh et al. 1994a, b). Similar results were obtained when multipurpose trees were evaluated in an extremely P-deficient acid Alfisol in Meghalaya (Dhyani et al. 1994).

The use of trees as shelterbelts in areas that experience high wind or sand movement is well-established example of microclimate improvement that resulted in improved yields. Increased agricultural production due to windbreaks and shelterbelts in India has been well demonstrated. Establishment of micro-shelterbelts in arable lands, by planting tall and fast-growing plant species such as castor bean on the windward side, and shorter crop such as vegetables in the leeward side of tall plants helped to increase the yield of lady's finger by 41 % and of cowpea by 21 % over the control. In general, the use of shelterbelts brought about a 50 % reduction in the magnitude of wind erosion. In studies carried out in an agroforestry system, *Acacia tortilis* (7-year old) and guar crop at Jodhpur indicated that relative humidity recorded beneath the tree canopy during the active cropping season of guar was found to be 7 % more than in the open. This will, in turn, help for better growth of the crops.

Agroforestry practices have been developed for arable lands and nonarable degraded lands, boulder laden riverbed land, torrent control, landslide and landslip stabilization, abandoned mine-spoil area rehabilitation, and as an alternative to shifting cultivation. Also, agroforestry systems have proven their efficacy in prevention of droughts, reclamation of waterlogged areas, flood control, rehabilitation of wastelands, ravine reclamation, sea erosion control, control of desertification and mine-spoil rehabilitation, and treatment of saline and alkaline lands. Agricultural use of salt-affected lands and water resources increase due to increasing demands of food and fodder is yet another example where agroforestry played a great role in enhancing the productivity of land and also address the environmental issues. Removal of salts from the soil surface is neither possible nor practical; therefore attempts have been made to minimize adverse effect of salts on crop by developing agro techniques. Central Soil Salinity Research Institute, Karnal (Haryana) has developed appropriate package of agro-techniques for crop production in salt-affected soils. The Institute also developed special planting techniques for sodic and saline soil for better establishment and growth of multipurpose trees. The technique ensures more than 80 % tree survival even after 10 years in highly alkali soil. See the details in Chap. 9.

Bio-Diversity Conservation Through Agroforestry

It is established that India is having rich vegetation with good bio-diversity. According to the Government of India report, biological diversity is estimated to be over 45,000 plant species and 810,000 animal species, representing 7 % of the world flora and 6.5 % of the world fauna, respectively. The UN Convention on Biological Diversity calls for conservation of the biological diversity, sustainable use of its components and fair and equitable sharing of benefits arising out of the utilization of genetic resources. Agroforestry innovations contribute to bio-diversity conservation through integrated conservation-development approach. Forest degradation has caused immense losses to the bio-diversity, which can be conserved through agroforestry by adopting a strategy of conservation through use. The biodiversity shall help in the development or improvement of new varieties or populations. It will further help in enhancing the availability of improved planting material, which is a key to the increase the productivity and production at farm level. Swaminathan (1983) has pointed out that biodiversity is the feed stock for a climate resilient agriculture. Agroforestry with components like trees, agricultural crops, grasses, livestock, etc., provides all kinds of life support system. Trees in agro-ecosystems in Rajasthan and Uttarakhand have been found to support threatened cavity nesting birds and offer forage and habitat to many species of birds. The traditional society of coastal belts and tropics of the country practicing homegardens and sacred groves help in biodiversity conservation. In a majority of the traditional villages, trees have been planted and dedicated to different gods/ goddesses or have stated as abodes of spirit, making them sacred. Frequently, species selected by the local people for social significance might turn out to be of ecological significance. It helps ensure sustainability, stability, and productivity of production systems in spite of the level of complexity of the ecosystem in which it occurs, and in the final analysis, it contributes to social welfare of the population through its involvement to poverty mitigation and sustainable food security.

Carbon Sequestration Potential of Agroforestry

Agroforestry has importance as a carbon sequestration strategy because of carbon storage potential in its multiple plant species and soil as well as its applicability in agricultural lands and in reforestation. The potential seems to be substantial; average carbon storage by agroforestry practices has been estimated as 9, 21, 50, and 63 t C ha^{-1} in semiarid, subhumid, humid, and temperate regions (Schroeder 1994). For smallholder, agroforestry systems in the tropics, potential carbon sequestration rate ranges from 1.5 to 3.5 t C ha^{-1} yr^{-1} (Montagnini and Nair 2004). Agroforestry can also have an indirect benefit on carbon sequestration when it helps to decrease pressure on natural forests, which are the largest sinks of terrestrial carbon. Another indirect avenue of carbon sequestration is through the use of agroforestry technologies for soil conservation, which could enhance carbon storage in trees and soils. Carbon compounds are sequestered or accumulated by plants to build their structure and maintain their physiological process. The energy captured in the molecular bonds of carbon compounds generally present between 2 and 4 % of the radiation absorbed by the tree canopy. Stem wood growth often accounts for less than 20 % of the dry matter produced in a year, the rest being used by foliage most of which is shed during leaf fall which is an important pathway for the flow of organic matter and energy from the canopy to the soil. Only green plant can assimilate carbon on the earth. The analysis of carbon stocks from various parts of the world showed that significant quantities could be removed from the atmosphere over the next 50 years if agroforestry systems are implemented on a global scale. Carbon storage depends on several factors including climatic, edaphic, and socio-economic conditions. Perennial systems like home gardens and agroforestry can store and conserve considerable amounts of carbon in living biomass and also in wood products. For increasing the carbon sequestration, potential of agroforestry systems practices such as conservation of biomass and soil carbon in existing sinks; improved lopping and harvesting practices; improved efficiency of wood processing; fire protection and more effective use of burning in both forest and agricultural systems; increased use of biofuels; increased conversion of wood biomass into durable wood products needs to be exploited to their maximum potential. Agroforestry practices such as agrisilviculture or agrihorticulture systems for food and wood/fruit production; boundary and contour planting for wind and soil protection; silvopasture system for fodder production as well as soil and water conservation; complex agroforestry systems, viz., multistrata tree gardens, home gardens, agrisilvohorticulture and horti-silvopasture systems for food, fruits, and fodder especially in hill and mountain regions and coastal areas and biofuel plantations are suitable for sequestering atmospheric carbon and act as the potential sinks for sequestering surplus carbon from the atmosphere.

In India, evidence is now emerging that agroforestry systems are promising land use system to increase and conserve aboveground and soil C stocks to mitigate climate changes (Dhyani et al. 2009b). The average potential of agroforestry has been estimated to be 25 t C ha^{-1} over 96 million ha^{-1} (Sathaye and Ravindranath 1998). In this way, the total potential of agroforestry in India to store C is about 2,400 million tons. Although there is variation in the estimation of area under agroforestry and C stock but there is good indication of agroforestry for gaining popularity for mitigating climate change because desired tree cover can only be achieved including tree in farm field/bunds. The C storage capacity varied from region to region and also depends upon the growth and nature of tree species involved in the system.

Agroforestry for Livelihood Security and Employment Opportunities

Agroforestry systems due to diverse options and products provide opportunities for employment generation in rural areas. Dhyani et al. (2003, 2005) have highlighted the role of agroforestry products and environmental services to meet the subsistence needs of low income households and providing a platform for greater and sustained livelihood of the society. Increased supply of wood in the market has triggered a substantial increase in the number of small-scale industries dealing with wood and wood based products in the near past. Such industries have promoted agroforestry and contributed significantly to increasing area under farm forestry. Recognizing agroforestry as a viable venture, many business corporations, limited companies such as ITC, WIMCO, West Coast Paper Mills Ltd., Hindustan paper Mills Ltd., financial institutes such as IFFCO have entered into the business and initiated agroforestry activities in collaboration with farmers on a large scale. Besides the existing agroforestry practices, there is a tremendous potential for employment generation with improved agroforestry systems to the tune of 943 million person days annually from the 25.4 million ha of agroforestry area. Dhyani and Sharda (2005); Dhyani et al. (2005) have indicated the potential of agroforestry for rural development and employment generation to the tune of 5.763 million human days per year from Indian Himalayas alone.

Sericulture is being practiced in different parts of the country since time immemorial. On the basis of climate, edaphic conditions, host plants, and insect species, four types of sericulture is practiced in India viz. (i) mulberry, (ii) tasar—[a] tropical tasar, [b] oak tasar, (iii) eri, and (iv) muga. Dhyani et al. (1996) successfully developed and demonstrated mulberry and muga sericulture based agroforestry systems for the north-eastern hill region. Sericulture with fruit plants and grass model was highly preferred by farmers, followed by sericulture with field (uplands) crops. Now, tasar sericulture is being promoted in different districts of Bundelkhand region. For this, tasar sericulture insect *Antheria mylata* is being reared on Arjun (*Terminalia arjuna*) which is common tree species of the forest area in this area. Arjun can also be cultivated under dense plantation (2,800 plants per ha at 2 m × 2 m spacing) and intensive management for economic tasar cultivation. The plantation is ready for rearing tasar silkworm within 3–4 years. As per the information of Sericulture Directorate, Uttar Pradesh, one ha dense plantation of Arjun can generate an income of INR 30 to 50 thousand from tasar cultivation. There is scope of tasar sericulture under agroforestry. To promote livelihood opportunities for the farmers, NRCAF introduced lac based agroforestry system for the semi-arid Bundelkhand region on Palas (*Butea monosperma*) and Ber trees which are very common in this region. Success of lac cultivation in *katki* crop (rainy season) was observed in the region. The preliminary results indicate good possibility to promote livelihood through lac cultivation in the region. Similarly, there is scope for augmenting income of farmers by collecting gum and resins from trees. NRCAF identified suitable trees for gum and resin in different agro-climatic regions for development under agroforestry.

However, to achieve the above potential, it will require appropriate research interventions, adequate investment, suitable extension strategies, harvest process technology development of new products and market infrastructure. It will also 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. Above and all, it will require to develop a forward looking National Agroforestry Policy.

Agroforestry Policies

Agroforestry growth and development is influenced by various policies of the economy like credit, trade, taxation, power, transport, etc. These policies impact the sector either directly or indirectly besides the core forest and agriculture policies. The forest policies have a larger bearing on the agroforestry policies in the Indian context. Since forests are in the concurrent list of the constitution, both the union and state governments are empowered to amend the forest laws. Hence, the scope for conflicting policies exists. Historically trees in India have been managed and regulated by customary law. The British exploited the commercial value of Indian forests by establishing rigid control. A systematic forest policy was initiated in 1855. This was followed by the Government Forests Act of 1865 and Indian Forest Act 1878, which classified forests into reserve forests, protected forests, and village forests. The National Forest Policy of 1894 encouraged diversion of forestlands for agriculture, which suited the growing population. Independent India has given two forest policies. The National Forest Policy 1952 gave thrust on having one-third geographical area under forests with a target of 60 % forest cover in hills and 20 % in plains. The National Commission on Agriculture (NCA 1976) had recommended commercialization of forests to meet the needs of defense forces and industry. The involvement of corporate bodies in providing technical knowhow to farmers who took up farm forestry and the momentum given by the social forestry projects were very conducive for tree plantation outside the forest areas. The revised National Forest Policy, 1988 encourages private sector tree plantations on other than forestlands. The Joint Forest Management (JFM) programmes were initiated in the country during 1990 as a sequel to the revised NFP of 1988. The 73rd amendment to the constitution and the recommendations of Bhuria committee, 1996 have given the *Panchayats* wide powers of control over the natural resources including land and forest produce. Subsequently, state governments issued enabling resolutions one by one. As of now, all the state governments in India have issued resolutions in this regard. The MOEF in 1999 initiated National Forestry Action Plan (NFAP) and National Forestry Research Plan (NFRP), which may have some influence on agroforestry development. For promoting agroforestry, some of the states took innovative policy decisions. However, there are many bottlenecks in the marketing of agroforestry produce like inadequate infrastructure, lack of awareness on final use of the produce, exploitation by the middlemen, etc. The tree felling and transit rules as applicable to trees on private lands unique to each of the states have a direct bearing on the progress of agroforestry. There is wide variation in the scope of the felling and transit rules across states. Realizing the magnitude of the problem the MOEF has circulated guidelines to states in December 2004 for relaxing the felling and transit regulations for tree grown on non-forest laws. The guidelines are primarily aimed at achieving the goal of one-third-tree cover in the country. Responding to the guidelines, some states enacted suitable laws but many of them such as Kerala, Odisha, and others retracted instantly to prevent large scale felling. Much more need to be done, say empowering the *Panchayats* to permit the felling and transit of less unrestricted, i.e., category B species.

Agroforestry promotion for realizing the true potential requires efforts from all the concerned like forest and agriculture departments, research and financial institutions, corporate sector, *panchayats*, NGOs, and farmers. The policy thrust must be on creating infrastructure, ensuring quality planting material, plugging the vacuum of extension network, favourable pricing mechanism including support price system, encouraging public–private partnerships in all spheres of agroforestry among others. Recently, an Agroforestry Policy Initiative was jointly organized by the Indian Council of Agricultural Research (ICAR) and The World Agroforestry Centre (ICRAF) at New Delhi on June seventeenth, 2011 to prepare a road map for development of a National Agroforestry Policy. In XIIth Plan it is expected that some concrete proposals for launching a National Mission on Agroforestry and National Agroforestry Policy will be initiated by the MoEF and MoA.

Success Stories

Poplar Based System

The technology has been developed by AICRP on Agroforestry centre at PAU, Ludhiana. Punjab is an agricultural state and the state has only 5.57 % area under the forest (2.81 lakh ha). The farmers of Punjab have taken to tree planting on their private lands in a big way by raising *Eucalyptus* and poplar plantations on a large tract. The major production of poplar wood in the state is consumed by plywood industries. In Punjab, 75 units (big and small) are manufacturing plywood and plyboard. The plywood industry in Punjab has expanded by almost 50 % from 49 units in 1993 and 90 units in 2008. Owing to short duration and fast growing habits, poplar has become an important agroforestry tree species in Punjab. It offers opportunities for increasing both the income of farmers and the area under tree growth. Farmers have been practicing the integrated cultivation of agricultural crops with fast growing trees to meet their requirements of firewood, fodder, small timber for agricultural and construction purposes. Farmers have earned good returns from the sale of these farm grown trees and thus total area under poplar increased many fold. The central zone has come up as poplar farming belt as 68 % tree growers are practicing poplar based agroforestry system. Large percentage of poplar growing farmers are planting this species in riverine belts of Sutlej and Beas, as the growth of poplars in *'bet'* area is 50–60 % more as compared to table lands. Poplar growers are quite limited in the south-west zone and sub-montane zone due to regular and high irrigation requirements of this tree species which is scanty in these zones. Poplars are grown on agricultural lands either in single rows along field or farm boundaries or even in block plantation at a spacing of 5 × 4 or 7 × 3 m along with annual agricultural crops such as cash crops like sugarcane, turmeric, wheat, pearl millet, oats, maize, mustard, vegetables, and several other fodder crops oats, fodder (berseem), etc., throughout the rotation. Generally farmers do not grow '*kharif*' season crops owing to dense shade of poplars during later years (after 4 years). Poplar + wheat + fodder based agroforestry system is a great success in Punjab. This system is economically viable and much more profitable in comparison to sole cropping system (wheat + rice) commonly followed by majority of farmers. The comparative economics of poplar-based agroforestry model in block and boundary plantation revealed that these were 2.8 and 1.6 times more profitable respectively than rice–wheat rotation. In addition, this system has played an important role in the upliftment of social status of farmers, generated employment and became one of the viable options for crop diversification. The impact of the success resulted in

- Area under tree cover increased in the State
- Productivity per unit area and per unit time increased
- Overall income in terms of money increased per unit area and per unit time over the existing cropping system
- Employment generation at primary, secondary, and tertiary levels
- Social upliftment of small and marginal farmers by adopting boundary plantation.

Sapota/Mango-Teak Based Agroforestry Systems

A multicomponent agroforestry system with sapota (*Achrus zapota*) as base crop, teak (*Tectona grandis*) in the sapota line and agricultural crop in the interspaces was developed by AICRP on Agroforestry, Dharwad Centre for high rainfall areas/areas with irrigation facility of Karnataka. Broad spacing between trees provides an opportunity to intercrop in the initial few years. Under Technology Extension Project on Agroforestry, demonstrations were taken up in 1996 in the village Kyarakoppa, Dharwad, Karnataka. Sapota was planted at a recommended spacing of 10 × 10 m, tree rows being across the slope. Three teak plants were planted at distance of 3–2 to 2–3 m in between two sapota trees. Field crops viz. horse gram, jowar and bajra were grown in the interspaces of sapota + teak alleys. Sapota crop served as an insurance against failure of field crops. Teak trees act as a fixed deposit to the farmers to come in handy during adverse situations. The system generated employment throughout the year. The same technology is adopted by other farmers with a modification viz. Sapota being replaced by Mango. Fruit yields in sapota and mango started from the year 2003 and 2004, respectively. Presently, the sapota tree is yielding 30–40 kg per plant which accounts to be INR 22,000–25,000 per ha and from mango is yielding 30–50 kg per plant which accounts to INR 36,000–60,000 per ha. The income generated from field crop in both the cases is about INR 2,500–3,500 per ha. Growing of field crop was stopped from 2007 due to closure of canopy. The value estimation of teak reveals that each teak pole fetches INR 120. Adoption of Sapota/Mango–Teak based agroforestry model improved microclimatic conditions in the plantation. Under the system, employment generated was to an extent of 180 man days per year. The socio-economic status of the farmers improved and farmers are earning on an average of INR 23,500 $ha^{-1} y^{-1}$ with sapota and INR 48,000 $ha^{-1} y^{-1}$ with mango as against INR 3,000 $ha^{-1} y^{-1}$ during initial period on the same land.

Continuous Contour Trench: A Phule Technique

Shri. Genuji Bhimaji Kurkute a person from middle level farmers family made sincere and continuous effort for the development of Jogaldara hilly area of Jachakwadi of Akola Tahasil in Ahmednagar District of Maharashtra State and succeed to change the whole scenario of Gajanan valley of Jogaldara hill. He purchased 35 acre of mountains hilly land of Sahaydri ranges at Akole and Sangmner Taluka in Ahmednagar District of Maharashtra, locally known as Jogaldara hill. After that he contacted the Scientists of Mahatma Phule Krishi Vidyapeeth, Rahuri, and discussed regarding the development of Jogaldara hill by adopting soil conservation techniques for development of huge hilly, undulated area by tree plantation, intercropping, suitable crops, supplemental irrigation system, etc., through continuous contour trenches (CCT) technique developed by AICRP on Agroforestry centre at MPKV, Rahuri.

Before implementing the development work, he got surveyed all the 35 ha area. After survey of near about 272 feet gradient of hill, he adopted CCT techniques for plantation of different fruit trees. Initially, pomegranate (Var. Mridula and Bhagava) fruit trees were planted on 18 ha hilly area, thereafter, custard apple (Balanagar), mango (Keshar), and gooseberry (Krishna, Kanchan, Narendra, etc.) were planted on 12 ha area The plantation of pomegranate was done on 3 × 3 m spacing and used only organic manure in the plantation. For supplementary irrigation during summer season was very much essential. He constructed one water tank of 180 thousand liters capacity and purchase drip irrigation system in consultation with Jain Irrigation by submitting project proposal to 'National Horticulture Board' for financial assistance in the name of "Gajanan Valley High Tech Project." Thereafter, he has established three bore wells at suitable locations and all these three bore wells were interlinked with each other. The capacity of each of these bore well are 12.5, 7.5, and 5 HP. These three bore wells continuously lifting water, for collection in storage water tank. Shri Kurkute emphasized the benefits of CCT techniques in getting water throughout the year. The main, submain, and laterals of drip irrigation system was attached to the main storage water tank, from where the water is lifted at the peak point of hill through 15 hp electric pump. He got 20 kg average yield of Pomegranate (rate INR 30–35 per kg i.e. INR 600–700 per tree). Accordingly from one hectare area he received near about INR 500–600 thousand. Similarly, from Custard apple he got INR 400–500 thousand per hectare. Shri. Kurkute had obtained INR 4 million Bank loan, within

6/7 year he refunded up to INR three million to bank and till to date only INR 1million is outstanding. According to his experience due to fluctuation in market rate and expenditure on labour the fruit farming with proper utilization of CCT techniques is far better than vegetable farming. Now the Jogaldara hill became a visiting spot to the students from the Agriculture Colleges and Farmers from the neighboring villages/ Districts. Shri Kurkute made a mile stone by adopting technology developed by Mahatma Phule Krishi Vidyapeeth, Rahuri and put forth an example that, how middle level farmers can change the whole scenarios of such mountainous, undulating, hilly region of our country.

There are similar success stories of farmers adopting agroforestry in different agro-climatic regions.

Model watershed project on natural resource management through agroforestry interventions at Garhkundar, Teekamgarh, Madhya Pradesh

One watershed management program has been initiated by NRC for Agroforestry, Jhansi in Garhkundar-Dabar, district Tikamgarh in Madhya Pradesh of Bundelkhand region to demonstrate agroforestry technologies in participatory mode. The impact of integrated watershed management interventions, viz. soil and water conservation measures, agroforestry development, crop demonstrations with improved package of practices, plantation, and human resource development on natural resource conservation and livelihood security in Garhkundar–Dabar watershed was assessed for last 5 years. Soil and water conservation measures generated 25,000 m^3 water storage capacity, reduced number of dry wells from 2 to 86 %, increased average available water column depth in wells from 0.88 to 4.36 m and enhanced water availability to round-the-year from 4 to 5 months during the study period. Runoff per unit area and soil loss from treated watershed was 46 and 42.2 % lower than the untreated watershed respectively in 2009. Average productivity and crop intensity of major crops, increased by 26 and 119.5 %, respectively in 2009–2010 as compared to 2005–2006. The fodder availability increased by 208 % and within four years, watershed became a fodder secure area with fodder surplus of 1.992 t y^{-1} $animal^{-1}$ as compared to (−) 0.569 t y^{-1} $animal^{-1}$ in 2005–2006. The increased direct and indirect employment opportunities in watershed reduced migration to 9 % in 2009–2010 from 29 % in 2007–2008 (Palsaniya et al., 2012). This clearly indicates that watershed management through agroforestry interventions is the only way out for sustainable management of natural resources and to support livelihood in the semi-arid and arid region.

Research Gaps and Way Forward

- Inadequate understanding of the causes and processes of biophysical and physio-biochemical issues related to productivity and resource sharing under agroforestry system.
- Lack of knowledge of genetic potential, breeding behavior, and inheritance pattern of economic traits of important woody perennials.
- Paucity of methods to assess the tangible and intangible benefits of agroforestry.
- Limited commercialization of potential technologies.
- Lack of independent agroforestry Policy.

Conclusions

The retrospective and critical perusal of the agroforestry research conducted during the last three decades exhibits its wide spectral potential in sustenance of agriculture as these systems provide food, fodder, fruit, vegetables, fuel wood, timber, medicines, fiber, etc., from the same piece of land at a time which not only fulfill the demand of people but also elevate their socioeconomic status and standard of life.

Table 11.1 Potential agroforestry systems for different agroclimatic zones of the country

Agro-climatic zone	Agroforestry system	States	Tree component	Crop/grass	Net income year^{-1}	Potential area (ha)
Western himalayas	Silvopasture (RF)	Himachal Pradesh	*Grewia optiva*	*Setaria* spp.	18,670	228,487
		Uttar Pradesh	*Morus alba*	*Setaria* spp.	19,732	228,487
	Agrihorticulture	Uttrakhand	*Prunus persica*	Maize, soybean	4,360	265,114
Eastern Himalayas	Agrisilviculture	Arunachal pradesh	*Anthocephalus cadamba*	Paddy	13,880	68,737
		Assam, manipur,				
		Meghalaya, Mizoram,				
		Nagaland, Tripura,				
		West bengal, sikkim				
Lower gangetic plains	Agrisilviculture	West bengal	*Eucalyptus*	Paddy	10,603	66,730
Middle gangetic plains	Agrisilviculture	Bihar,	*Populus deltoides*	Sugarcane-wheat	24,281	161,929
	Agrisilviculture	Uttar Pradesh	*Eucalyptus*	Rice–wheat	16,124	202,411
	Agrisilviculture		*Dalbergia sissoo*	Sesamum	11,600	242,893
Transgangetic plains	Agrihorticulture	Uttar pradesh	*Emblica officinalis*	Black gram/green gram	13,108	372,984
Upper gangetic plains	Agrisilviculture	Haryana, Punjab	*Populus deltoides*	Wheat, bajra fodder	37,125	240,427
Eastern plateau and hills	Agrisilviculture	Delhi, Bihar	*Gmelina arborea*	Paddy, linseed	26,402	185,772
	Silviculture	Jharkhand, MP, Orrisa	Bamboos		6,700	553,460
		West Bengal				
Central plateau and hills	Agrihorticulture (Irrigated)	Madhya pradesh,	*Psidium gujava*	Bengal gram	11,700	177,911
	Agrihorticulture (RF)	Rajasthan, Uttar pradesh	*Emblica officinalis*	Black gram/Green gram	13,108	133,433
	Silvipasture (RF- degraded lands)	Maharashtra	*Albizia amara, L.leucocephala, D.cinerea*	*C. fulvus, S. hamata, S. scabra*	6,095	926,606
	TBOs (RF)		*Jatropha curcas*	–	3,741	308,869
Western and Plateau Hills	Agrihortisilviculture (Irrigated)	Karnataka	*Tectona grandis*	Paddy, maize	80,613	371,378
		Madhya Pradesh	*Achras zapota*			

(continued)

Table 11.1 (continued)

Agro-climatic zone	Agroforestry system	States	Tree component	Crop/grass	Net income year^{-1}	Potential area (ha)
Southern plateau and hills	Agrisilviculture (RF)	Andhra Pradesh	*Eucalyptus*	Cotton	25,605	115,982
	Agrisilviculture (Irrigated)	Karnataka Tamil Nadu	*Eucalyptus*	Chillies	38,695	463,928
	Block plantation (RF)		*Leucaena leucocephala*	–	12,810	231,964
	Block plantation (RF)		*Eucalyptus*	–	32,666	231,964
	Agrihorticulture		*Tamarindus indica*	Chilli	16,126	115,982
	TBOs		*Pongamia pinnata*	–	4,000	60,017
East coast plains and hills	Agrisilviculture (RF)	Andhra Pradesh Tamil Nadu Pondicherry	*Ailanthus excelsa*	Cow pea	13,237	61,103
West coast plains and hills	Agrisilviculture (RF)	Kerala Maharashtra	*Acacia auriculiformis*	Black pepper	114,240	44,629
	Agrihorticulture (RF)	Tamil Nadu	*Artocarpus heterophyllus*	Black pepper	97,440	44,629
	Agrisilviculture (RF)	Goa, Karnataka	*Acacia auriculiformis*	Paddy	21,032	44,629
	Agrisilviculture		*Casurina equisetifolia*	Paddy	24,968	22,315
Gujarat coast plains and hills	Agrisilviculture	Gujarat	*Azadirachta indica*	Cow pea	10,896	98,313
		Dadra& N. Haveli Daman	*Ailanthus excelsa*	Green gram	6,025	98,313
Western dry region	Agrisilviculture	Rajasthan	*Prosopis cineraria*	Pearl millet	30,215	193,768
	TBOs (RF)	Lakshadweep	*Jatropha curcas*	–	3,741	6,058,812
All Islands	Agrihorticulture		*Cocos nucifera*	Paddy	15,433	1

As per perspective plans (based on supply and demand for timber, fuel, and fodder), 338,068 ha of poplars (@ 160 t ha^{-1} productivity at 7 years rotation)
Assuming availability of another 10 % of community wastelands for silvipasture, the additional fodder production (@ 2.5 t ha^{-1} yr^{-1} at 50 % of research yield) would be 14.75 million t from 5.9 million ha in silvipasture (Dhyani et al. 2009a)

Agroforestry is key path to prosperity for millions of farm families, leading to extra income, employment generation, greater food and nutritional security, and meeting other basic human needs in a sustainable manner. As mitigation strategy to climate change as well as rehabilitation of degraded land, the conversion of unproductive grasslands and crop land to agroforestry is a major opportunity as it helps for carbon sequestration and makes land productive and reduces further soil degradation. By virtue of diversity of the components of the agroforestry systems like food grains, vegetables, fruits, nutritional security to the communities could be ensured. Induction of fodder cultivation under agroforestry land use will ensure production of milk, meat, and animal products and also wide range of food crops, pulses, and oil seeds can meet diverse needs of society. The analysis presented here gives a clear identification of the advances made in understanding and appreciation the potential of agroforestry. Owing to increased supply of wood in the market, there has been a significant increase in the number of factories/industries dealing with wood and wood-based ventures. Such industries have promoted agroforestry (through Poplar, *Eucalyptus, Leucaena*, etc.) and contributed significantly in increasing area under agroforestry. On the whole, in addition to promoting indigenous agroforestry models, it appears that a great deal of research needs to be done to identify short rotation, high value species, which suit the farmers' requirement of planting on marginal lands. It would probably be more realistic to select trees that could provide more cash benefit to farmers through their products, and to accept that in the longer term they will also provide environmental benefits arising from a more complex agro- ecosystem (Table 11.1).

References

Bamikole MA, Babayemi OJ, Arigbede OM, Ikhatua UJ (2003) Nutritive value of *Ficus religiosa* in west African dwarf goats. Anim Feed Sci Technol 105(1):71–79

Chauhan DS, Dhyani SK (1989) Traditional agroforestry practices in N. E. Himalayan region. Indian J Dryland Agric Res Dev. 4(2): 73–81

Chauhan DS, Dhyani SK (1994). Agroforestry-an approach to sustainable development of degraded lands in NEH region of India. In: Punjab S et al (eds) agroforestry systems for degraded lands, vol I. Oxford & IBH Publishing Co. Pvt. Ltd., New Delhi, pp 154–158

Planning Commission (2001) Report of the task force on greening India for livelihood security and sustainable development. Planning Commission, GoI, New Delhi, p 254

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

Dhyani SK (1998) Tribal alders-an agroforestry system in the northeastern hills of India. Agrofor Today (ICRAF) 10(4):14–15

Dhyani SK (2003) Role of watershed management in improving forage production. In: Jakhmola RC, Jain RK (eds) Sustainable animal production. Pointer Publishers, Jaipur, pp 173–207

Dhyani SK, Sharda VN (2005) Agroforestry systems as rural development options for the Indian Himalayas. J Tree Sci 24(1):1–19

Dhyani SK, Singh BP, Chauhan DS, Prasad RN (1994) Evaluation of MPTs for agroforestry system to ameliorate infertility of degraded acid alfisols on sloppy lands. In: Punjab S, Pathak PS, Roy MM (eds.) Agroforestry systems for degraded lands, vol I. Oxford & IBH Publishing Co.Pvt. Ltd., New Delhi, pp 241–247

Dhyani SK, Chauhan DS, Kumar D, Kushwaha RV, Lepcha ST (1996) Sericulture based agroforestry systems for hilly areas of north-east India. Agrofor Syst 34:1–12

Dhyani SK, Sharda VN, Sharma AR (2003) Agroforestry for water resources conservation; issues, challenges and strategies. In: Pathak PS, Ram Newaj (eds) Agrofor potentials opportunities. Agribios (India) and ISA, pp 9–30

Dhyani SK, Sharda VN, Samra JS (2005) Agroforestry for sustainable management of soil, water and environmental quality; looking back to think ahead. Range Manag Agrofor 26(1):71–83

Dhyani SK, Kareemulla K, Handa AK (2006) Agroforestry potential and returns across agroclimatic zones. NRCAF, Jhansi

Dhyani SK, Handa AK, Uma (2008) Twenty five years of agroforestry networking (1983–2008). NRCAF, Jhansi, p. 102

Dhyani SK, Kareemulla K, Ajit, Handa AK (2009a). Agroforestry potential and scope for development across agro-climatic zones in India. Indian J. Forest 32:181–190

Dhyani SK, Ram N, Sharma AR (2009b). Agroforestry: its relation with agronomy, challenges and opportunities. Indian J. Agron 54(3):70–87

Dhyani SK, Kumar RV, Ahlawat SP (2011) *Jatropha curcas* L.: A potential biodiesel crop and its current R&D status. Indian J Agric Sci 81(4):295–308

Kareemulla K, Dhyani SK, Rizvi RH, Yadav RS, Ram M (2007) Agroforestry for rural development: a cooperative experience. NRCAF, Jhansi 91

Kareemulla K, Rhizvi RH, Yadav RS, Munna R, Dhyani SK (2009) Agroforestry for rural development-cooperatives as viable institutions. Agriculture situation in India. pp 61–67

Kumar BM (2003) Homegardens as a livelihood security system in the humid tropics with special reference to Kerala. In: Pathak PS, Ram N (eds) Agroforestry: potentials and opportunities, Agrobios, Jodhpur, pp 121–142

Montagnini F, Nair PKR (2004) Carbon sequestration: an under exploited environmental benefit of agroforestry systems. Agrofor Syst 61:281–295

Palsaniya DR, Singh R, Tewari RK, Yadav RS, Dhyani SK (2012) Integrated watershed management for natural resource conservation and livelihood security in semi arid tropics of India. Indian J. Agric. Sciw 82(3):241–247

Pathak PS (2002) Common pool degraded lands: technological and institutional options. In: Marothia DK (ed) Common Pool Resources. Concept Publishing Company, New Delhi, pp 402–433

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

Pathak PS, Pateria NM, Solanki KR (2000) Agroforestry systems in India: a diagnosis and design approach. NRC for Agroforestry. ICAR. pp 166

Puri S, Singh S, Bhushan B (1994) Evaluation of fuel wood quality of indigenous and exotic tree species of India's semiarid region. Agrofor Syst 26:123–130

Ravindranathan NH, Chanakya HN, Kerr JM (1997) An ecosystem approach for analysis of biomass of energy In: Ker JM, Marothia DK, Singh K, Ramaswamy C. and Bentley WR (eds.) Natural resource economics theory and application in India. Oxford & IBH, New Delhi. pp 156–163

Sathaye JA, Ravindranath NH (1998) Climate change mitigation in the energy and forestry sectors of developing countries. Annu Rev Energy Env 23:387–437

Schroeder P (1994) Carbon storage benefits of agroforestry. Agrofor Syst 27:89–97

Sharda VN, Dhyani SK, Sharma AR (2001). Role of agroforestry in disaster management. Submitted to Chairman, HPC (DM Plan), DOA&C, GoI, New Delhi

Singh GB (1987) Agroforestry in the Indian subcontinent: past, present and future. In: Steppler HA, Nair PKR (eds) Agroforestry–a decade of development. International council for research in agroforestry nairobi, Kenya, pp 117–138

Singh P (1990) Agrisilviculture systems in India. In: Devendra C (ed) Shrubs and tree fodder for farm animals. IDRC, Ottawa (Canada), pp 186–195

Singh BP, Dhyani SK (1996) An appraisal of indigenous land use systems in Meghalaya for developing sustainable rainfed hill agriculture, In: Kohli RK, Arya KS (eds) Proceedings. IUFRO-DNAES International meet on resource inventory techniques to support agroforestry and environment activities, (eds) DNAES, Chandigarh, Oct. 1–3, 1996, pp 61–72

Singh BP, Dhyani SK, Chauhan DS, Prasad RN (1994a) Effect of multipurpose tree species on chemical properties of an acid Alfisols in Meghalaya. Indian J Agric Sci 65(5):345–349

Singh BP, Dhyani SK, Prasad RN (1994b) Traditional agroforestry system and their soil productivity on degraded alfisols/ultisols in hilly terrain. In: Panjab Singh, Pathak PS, Roy MM (eds) Agrofor Sys Degraded Lands. Oxford & IBH Publishing Co. Pvt. Ltd., New Delhi, Vol. I, p. 205–214

Solanki KR (2006) Agroforestry- opportunities and challenges. In: Chauhan SK, Gill SS, Khajuria HN, Chauhan R (eds) Production technology and management of agroforestry models. Agrotech Publ, Academy, pp 14–15

Stern N (2006) Stern review on the economics of climate change. HM Treasury, London

Swaminathan MS (1983).Genetic conservation: microbes to man. Presidential address to the 15th International Congress on Genetics. In: Genetics: new frontiers, Vol. 1. Oxford & IBH Publishing Co., New Delhi, India

Tejwani KG (1994) Agroforestry in India. Oxford and IBH, New Delhi 233 pp