Chapter 2
Evolution of Agroforestry as a Modern Science

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Abstract Agroforestry is as old as agriculture itself. Many of the anecdotal agroforestry practices, which are time tested and evolved through traditional indigenous knowledge, are still being followed in different agroecological zones. The traditional knowledge and the underlying ecological principles concerning indigenous agroforestry systems around the world have been successfully used in designing the improved systems. Many of them such as improved fallows, homegardens, and park systems have evolved as modern agroforestry systems. During past four decades, agroforestry has come of age and begun to attract the attention of the international scientific community, primarily as a means for sustaining agricultural productivity in marginal lands and solving the second-generation problems such as secondary salinization due to waterlogging and contamination of water resources due to the use of excess nitrogen fertilizers and pesticides. Research efforts have shown that most of the degraded areas including saline, waterlogged, and perturbation ecologies like mine spoils and coastal degraded mangrove areas can be made productive by adopting suitable agroforestry techniques involving highly remunerative components such as plantation-based farming systems, high-value medicinal and aromatic plants, livestock, fishery, poultry, forest and fruit trees, and vegetables. New concepts such as integrated farming systems and urban and peri-urban agroforestry have emerged. Consequently, the knowledge base of agroforestry is being expanded at a rapid pace as illustrated by the increasing number and quality of scientific publications of various forms on different aspects of agroforestry. It is both a challenge and an opportunity to scientific community working in this interdisciplinary field. In order to prepare themselves better for facing future challenges and seizing the opportunities, scientists need access to synthesized information and develop technologies to assess the environmental benefits we get from different agroforestry services. The global community is still only in the beginning phase to recognize the

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potential benefits of many underexploited systems to address the most intractable land management problems of the twenty-first century, such as food and nutrient security, climate change mitigation and adaptation, biodiversity conservation, and rehabilitation of degraded ecosystems. As we move forward to vigorously exploit these potential benefits, we will witness the involvement of agroforestry and its progress for solving these problems and be able to ensure food and environmental security at global level.

Keywords Agroforestry · History · Concepts · Traditional AF systems · Improved AF systems · Wayforward

1 Introduction

Cultivation of trees and agricultural crops in intimate combination with one another is an ancient practice that farmers have used throughout the world, but agroforestry as a science has a recent origin. Agroforestry now has come of age during the past 35 years. During the earlier stages of this period, traditional practices involving numerous indigenous forms of trees and crops with and without animals were dominant and explained in emerging literature of agroforestry (Nair 1989, 1993; Singh et al. 1998; Dagar et al. 2014b; Dagar and Minhas 2016; Dagar and Tewari 2016a). Understanding the vast but mostly undocumented or partially documented indigenous knowledge concerning the traditional land management practices and land races and incorporating their underlying ecological principles in designing the improved systems and practices have been the key aspects during early stages particularly during 1980s and 1990s. Since then, numerous reports and compilations of improved agroforestry systems focused on specific ecological and geographical regions and individual countries as well as systems based on specific species or groups of species; and site-specific problem-solving systems have been produced from the tropical and temperate regions across the world (Tejwani 1994; Gordon and Newman 1997; Boffa 1999; Garrett et al. 2000; Elevitch 2007; Rigueiro-Rodriguez et al. 2008; Jose 2010; Nair and Garrity 2012a; Dagar et al. 2014b; Dagar and Minhas 2016; Dagar and Tewari 2016a; Peri et al. 2016). Today, agroforestry represents the modern, science-based approach to harness the sustainability attributes and production benefits of such time-tested practices, and its demonstrated role in sustaining crop yields, diversifying farm production, realizing ecosystem services, and ensuring environmental integrity in land use is receiving increasing attention in development programs including climate change around the world (Nair et al. 2016).

Most developments in agroforestry during last four decades of organized research have been based on "improved systems," implying that they represent improvements and modifications of systems existed before. However, Nair et al. (2016) recently have shown the concern that over the years, the emphasis on the study of such indigenous agroforestry systems (AFS) has been sidelined or ignored.

According to them, the neglect of such systems has gone to the extent that sometimes discussions and descriptions of these systems are dismissed disparagingly. This has been referred as paradoxical, because one of the strong tenets of agroforestry and motivation for its promotion has been the importance attached to site-specific local knowledge surrounding the time-tested traditional systems. They have used term "*Cinderella*" to refer such "forgotten" or "downtrodden" AF systems. Actually, the word was popularized by Walt Disney Production's movie by that name expressing with a European folktale (Italian, *Cenerentola*; French, *Cendrillon* or *La Petite Pantoufle de verre*; German, *Aschenputtel*), embodying a myth element of unjust oppression. The word has, by analogy, become known to refer to an individual whose attributes were unrecognized or one who unexpectedly achieved recognition or success after a period of obscurity and neglect. Leakey and Newton (1994) earlier used the term *Cinderella species* to refer to the "really indigenous multipurpose trees, the products of which have traditionally been collected, gathered, and utilized by humans, and are still of enormous importance to many people around the tropics for food and nutritional security and welfare." Such location-specific, time-tested, indigenous systems that have been passed or ignored by "modern" agroforestry research have a lot to contribute to the development of improved agroforestry systems and practices (Nair et al. 2016).

The multitude of systems that have evolved over long periods in variety of ecologies reflect the accrued wisdom and adaptation strategies of millions of farmers particularly smallholders, to meet their basic needs of food, nutrition, fodder, fuel wood, plant-derived medicines, and cash income. In the process, several agroforestry systems/practices have come in existence and many of them are now seen as problem-solving techniques. The prominent examples include multifunctional homegardens, which promote food security and diversity; fast-growing tree-based biodrainage plantations, which ensure lowering down of water table in waterlogged areas along with production of wood, food crops, and sequestration of carbon; woody perennial-based systems furthering employment generation and rural industrialization; domestication of local fruit trees ensuring food security and income generation through value addition; fertilizer trees and integrated tree-grass/crop production systems favoring resource conservation; tree-dominated habitats, which sustain agrobiodiversity; mangrove-based aquaculture sustaining livelihood, conserving biodiversity, protecting shoreline from natural disasters, and mitigating climate change; and urban and peri-urban agroforestry to make cities worth living, handling disposal of sewage water, and reducing air pollution. Thus, agroforestry has potential to meet challenges of the twenty-first century and beyond provided the policies of all governments are favorable for agroforestry developments. To understand transformation of agroforestry research development, we need to understand the agroforestry systems both anecdotal and improved ones along with their economic and socio-ecological principles. Some of these issues have been highlighted in this chapter in brief.

2 The History of Agroforestry

Historically, agroforestry is an age-old land use system since time immemorial as the process of human evolution has been from forests when man (*Homo sapiens*) learnt the art of domesticating plants and animals after leaving hunting and gathering habit. In about 700 BC, the hunting and food gathering system gradually gave way to food producing systems. The role of many common trees such as *khejri* or *samisami* (*Prosopis cineraria*), *aswattha* (*Ficus religiosa*), *palasa* (*Butea monosperma*), and *varana* (*Crataeva roxburghii*) in Indian folklife has been mentioned in ancient literature of *Rig Veda*, *Atharva Veda*, and other Indian scriptures (Mann and Saxena 1980). Horticulture, also as coexistent with agriculture, is found to have been prevalent from early historic period. Archaeological excavations corroborate early tree domestication around the settlements in South Asia. The evidence of this dates to the Mesolithic period (10,000–4000 BC) when fruits of 63 plants including *bael* (*Aegle marmelos*), gooseberry (*Emblica officinalis*), jujube (*Ziziphus mauritiana*), figs (*Ficus glomerata*), *mahua* (*Madhuca indica*), and mango (*Mangifera indica*) were reportedly consumed in one or the other form and were domesticated near the habitats (Randhawas 1980). Incidentally, some stray references occur in different texts of the *Vedic* literature in India and elsewhere (Raychaudhuri and Roy 1993; Pathak and Dagar 2000; Dagar and Tewari 2016b). For example, the cultivation of date palm (*Phoenix dactylifera*), banana (*Musa paradisiaca*), pomegranate (*Punica granatum*), coconut (*Cocos nucifera*), jujube, gooseberry, *bael*, lemon (*Citrus limon*), and many varieties of 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. Puri and Nair (2004) mentioned that rearing of silkworm (*Bombyx* spp) and lac insect (*Laccifer lacca*) was practiced in the Indian subcontinent during the Epic era of *Ramayana* and *Mahabharata* (7000 and 4000 BC, respectively).

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*). As per the second of the 14 *Rock Edicts of Ashoka* (257 BC), planting of medicinal herbs and trees besides shade trees along the roads and fruit plants on the wastelands was the accepted norms in those days – analogous to social forestry project of the present (Kumar et al. 2012). Further, the travelogue of Ibn Battuta (Persian traveler, 1325–1354 AD) provided the earliest literary evidence of intensively cultivated landscapes of Malabar Coast with coconut (*Cocos nucifera*)) along with black pepper (*Piper nigrum*) around the habitats (Randhawas 1980). Warriar (1995), while describing Wayanad as green paradise, mentioned that plough agriculture was prevalent in Wayanad in Western Ghats as early as in the Megalithic Age (between 400 BC and 400 AD), and spices like black pepper, ginger (*Zingiber officinalis*), 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 years old book of agricultural verses in one of the Indian languages *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 in South Asia since ancient times.

Tracing the history of agroforestry, King (1987) stated that in Europe, until the Middle Ages, it was the general custom to clear-fell degraded forest, burn the slash, cultivate food crops for varying periods on the cleared area, and plant or sow trees before, along with, or after sowing agricultural crops. This "farming system" is no longer popular in Europe, but was widely practiced in Finland up to the end of the nineteenth century and was being practiced in a few areas in Germany as late as the 1920s (King 1968). Further, Nair (1993) attempted to give an account of the history of agroforestry, which has also been taken into consideration while formulating this account. Wood pastures (forestry combined with pasture and field crops) are reported to be practiced from Neolithic times (6000 BP) all over Europe. Dehesa and Montado (4500 years old) system, found in Mediterranean zone of Spain and Portugal, is characterized by savannah-like open tree layer, mainly dominated by evergreen oaks (*Quercus* spp.) and to a lesser extent by the deciduous *Q. pyrenaica* and *Q. faginea*. The herbaceous layer is comprised of cultivated cereals (oats, barley, wheat) or more commonly forage grasses grazed by diversified livestock types (sheep, goats, Iberian pigs, and cattle). The practice of fruit tree systems on arable land or grassland called pre'-verger or Streuobst, mixed with grazing animals is widespread and goes back to the Roman Empire. At that time, olive trees (*Olea europaea*) were predominantly intercropped with wheat (*Triticum aestivum*), and in the seventeenth century, orchards in England were also intercropped with wheat (Nerlich et al. 2013). Hauberg of the Siegerland is another specialized practice originated in northwestern Germany in the Middle Age when forest trees (oak and birch *Betula* spp.) provide wood and charcoal and after harvesting of trees cereals are grown for many years followed by a longer fallow with pastoral use until the next generation of forest has grown.

In Southeast Asia, the *Hununoo* of the Philippines practiced a complex and somewhat sophisticated type of shifting cultivation. While clearing the forest for agricultural use, they deliberately spared certain trees which, by the end of the rice-growing season, provided partial canopy of new foliage to prevent the excessive exposure of the soil to the sun. Trees were an indispensable part of this farming system to provide food, medicines, construction wood, and cosmetics (Conklin 1957). By the end of the nineteenth century, however, establishing forests or agricultural plantations had become an important objective for practicing agroforestry. In the beginning, the change of emphasis was not deliberate (Nair 1993). At an outpost of the British Empire in 1806, U Plan Hle, a Karen in the Tonze forests of Tharrawaddy division in Burma (now Myanmar) established a plantation of teak (*Tectona grandis*) and presented it to Sir Dietrich Brandis, the then Governor.

Brandis realized the detrimental effect of shifting cultivation on the management of timber resources and knowing the facts that there were several court cases against the villagers for encroaching the forest reserves, he encouraged the practice of regeneration of teak through *taungya* system based on the well-known German system of Waldfeldbau, which involved the cultivation of agricultural crops in forests. From this beginning, the practice became increasingly widespread and was introduced into South Africa as early as 1887 (Hailey 1957) and to the Chittagong and Bengal areas in colonial India in 1890 (Raghvan 1960). It must be noted that, once introduced, the system was practiced continuously in India. In the second decade of the twentieth century, the system became more and more popular with foresters as a relatively inexpensive method of establishing forests and as Shebbeare (1932) put it, "became a full and rising food." In 1920, it was adopted in Travancore (now Kerala), in 1923 in the United Province (now Uttar Pradesh), and in 1925 in the Central Provinces (Raghvan 1960). Later, it spread throughout Asia, Africa, and Latin America. Essentially, the system consists of growing annual agricultural crops along with the forestry species during the early years of establishment of the forestry plantation and still exists. *Shorea robusta*, *Tectona grandis*, *Dalbergia sissoo*, *Acacia catechu*, *Eucalyptus globulus*, *Populus deltoides*, and *Pinus patula* were some important tree species grown in this system. The land basically belonged to the forestry department and upon their large-scale lease, allowed the subsistence farmers to raise their crops and in turn protect the tree saplings.

In tropical America, many communities have traditional simulated forest conditions in their farms in order to obtain the beneficial ecological effects of forest structure. In Central America, for example, farmers since long imitated the structure and species diversity of tropical forests and have planted about two dozen species on a small piece of land configuring them in different storeys; coconut (*Cocos nucifera*) or papaya (*Carica papaya*) with a lower layer of bananas (*Musa* spp.) or citrus, a shrub layer of coffee (*Coffea arabica/robusta*) or cacao (*Theobroma cacao*), tall and low annuals such as maize (*Zea mays*), and finally a spreading ground cover of plants such as squash (Wilken 1977; King 1987). The Quezungal system in southern part of western Honduras (growing *Cordia alliodora* tree pollarded to 1.5 m along with food crops), the Riberno system in Peruvian Amazon (forest clearing followed by homegardens with multiple species), silvopastoral systems in Brazil (grazing under tree crops such as cashew, coconut, and *Copernicia prunifera* palm), and Amazonian homegardens are traditional practices (Hellin et al. 1999; Miller and Nair 2006; Peri et al. 2016).

The situation was little different in Africa. In southern Nigeria, yams, maize, pumpkins, and beans were typically grown together under a cover of scattered trees (Forde 1937). The Yoruba of western Nigeria, who have long experience of following intensive system of mixing herbaceous, shrub, and tree crops, claim that this system helps in maintaining the soil health (Ojo 1966). The parkland system of West African dryland involving multipurpose trees such as *Faidherbia albida*, *Vitellaria paradoxa*, *Parkia biglobosa*, *Adansonia digitata*, and *Balanites roxburghii* on pasture lands or along with food crops mainly millets and beans is predominant. Within the United States, many indigenous communities and practitioners continue to carry on traditional management practices, but others struggle to do so (Rossier and Lake 2014).

Thus, there are innumerable examples of traditional land use practices used in the past involving combined production of trees and agricultural crops on the same piece of land in many parts of the world (now called agroforestry). Jodha (1995) opined that traditional agroforestry systems manifest the indigenous knowledge and methods to benefit from complimentary uses of annuals and woody perennials on a sustained basis. It also indicates that the farmers have a closer association with trees than any other social land promoters of forests. Several developments in agricultural research and development during 1960s and 1970s were also instrumental in initiating organized efforts in agroforestry. Under the auspicious of the Consultative Group on International Agricultural Research (CGIAR), several International Agricultural Research Centers (IARCs) were established in different parts of the world to undertake research with the objective of enhancing the productivity of major agricultural crops and animals especially in tropics. Many factors and developments in the 1970s contributed to the general acceptance of agroforestry as a system of land management that is applicable to both farm and forest. Among these factors were reassessment of the development policies of the World Bank by its President, Robert McNamara; a reexamination by the Food and Agricultural Organization (FAO) of the United Nations of its policies pertaining to forestry; the establishment by the International Development Research Centre (IDRC) of a project for the identification of tropical forestry research priorities; a reawakening of interest in both intercropping and farming systems; the deteriorating food situation in many areas of developing world; the increasing spread of ecological degradation mainly deforestation; and the energy crisis. In the process, McNamara (1973) felt that the needs of the poorest of the poor were ignored and the hundreds of millions of the poor farmers suffered because of hunger malnutrition menace. It was against this backdrop of concern for the rural poor that the World Bank actively considered the possibility of supporting nationally oriented forest programs. As a result, it formulated a new Forestry Sector Policy paper, which is still being used as the basis for much of its lending in the forestry sub-sector. Indeed, the social forestry program, which expanded considerably and not only contained many of the elements of agroforestry but was designed to assist the ordinary farmer to increase farm production conserving the environment. FAO (1976) reexamined the forestry policies, and the concerns of the poorest, especially the rural poor, were adequately addressed in new policies. It also focused on the benefits that could accrue to both the farmer and the nation if greater attention were paid to the beneficial effects of trees and forests on food and agricultural production, and policy makers were advised to incorporate both agriculture and forestry into their farming system and “eschew the false dichotomy between agriculture and forestry” (King 1979).

As a result of this change in policy, FAO prepared a seminar paper “Forestry for Rural Development” (FAO 1976) and with funding from the Swedish International Development Authority (SIDA) organized series of seminars and workshops on the subject in the tropical countries and formulated and implemented a number of rural forestry projects throughout the developing world. In these projects, as with the

World Bank's social forestry projects, agroforestry plays a pivotal role (Spears 1987). FAO also utilized the eighth World Forestry Congress, which was held in Jakarta, Indonesia, in 1978, to focus the attention of the world's leading foresters on the important topic of agroforestry. The central theme of the Congress was "Forests for People," and a special section was devoted to "Forestry for Rural Communities."

Many of these studies and efforts, although not coordinated, provided important knowledge about the advantages of integrated production systems involving crops, trees, and animals. But, perhaps the most significant single initiative that contributed to the development of present-day agroforestry came from the International Development Research Centre (IDRC) of Canada. In July 1975, the IDRC commissioned John Bene, an indefatigable Canadian to lead the forestry research. Bene's team identified the research priorities and prepared a report in which it was concluded that first priority should be given to combined production systems which would integrate forestry, agriculture, and/or animal husbandry in order to optimize tropical land use (Bene et al. 1977). This report laid foundation stone for establishment of agroforestry as a new front, which is obvious from the contents of the report. It stated that a new front should have been opened in the war against hunger, inadequate shelter, and environmental degradation. This war could be fought with weapons that have been in the arsenal of rural people since time immemorial, and no radical change in their lifestyle was required. This could best be accomplished by the creation of an internationally financed council for research in agroforestry, to administer a comprehensive program leading to better land use in the tropics (Bene et al. 1977). This proposal was well received by international and bilateral agencies; subsequently, the International Council for Research in Agroforestry (ICRAF) was established in 1977. The ancient practice of agroforestry was institutionalized for the first time.

The development of high-yielding varieties of cereals and extension of related technologies through the joint efforts of some of the IARCs and implementation of national programs paved the way for Green Revolution (Borlaug and Dowswell 1988); however, its benefit could not be harvested by poor farmers because many of the technologies that placed a heavy demand on increased use of fertilizers and other costly inputs were beyond the reach of a large number of resource-poor farmers in the developing countries (Nair 1993). Most of the national programs were focused on individual crops such as wheat, rice, maize, and potato and production technologies for monoculture production systems. The resource-poor farmers often cultivated their crops in mixed stands of more than one crop, and sometimes crops and trees. In such circumstances the production technologies developed for individual crops would seldom be applicable. These shortcomings were widely recognized by the scientists and policy makers, and renewed interest was developed in the concepts of intercropping and integrated farming systems. The research efforts indicated that besides many advantages of intercropping on pest and disease problems. Higher yields could be obtained per unit area when multi-cropping systems were compared to sole cropping systems (Papendick et al. 1976). At that stage it was felt that more scientific efforts were needed with respect to understand crop physiology, agronomy, yield stability, biological nitrogen fixation, and plant protection in intercropping research (Nair 1979). Concurrently, the International Institute of Tropical Agriculture (IITA), an IARC in Ibadan, Nigeria, extended its work to include integration of trees and shrubs with crop production (Kang et al. 1981). Other research organizations had also initiated serious work on tree-based croping systems, for example, the integration of animals with plantation tree crops such as rubber and intercropping of coconut (Nair 1983).

This congruence of people, concepts, and institutional change has provided the material and the basis for the development of agroforestry since then. Although many individuals and institutions have made valuable contributions to the understanding and development of the concept of agroforestry since the 1970s, ICRAF (renamed in 1991 as the International Center for Research in Agroforestry) has played the most significant and leading role in collecting information, conducting research, disseminating research results, pioneering new approaches and systems, and, in general, through presentation of hard facts. The Center coined the term “agroforestry”and called for global recognition of the key role trees play on farms.

During the 1980s, ICRAF operated as Information Council focused on Africa. It joined the Consultative Group on International Agricultural Research (CGIAR) in 1991 to conduct strategic research on agroforestry at a global scale, changing its name from Council to Center. After joining the CGIAR, the Center explicitly linked its work to the goals of the CGIAR – reducing poverty, increasing food security, and improving the environment – through overcoming land depletion in smallholder farms of subhumid and semiarid Africa and searching for alternatives to slash-and-burn agriculture at the margins of the humid tropical forests. In implementing this strategy, the Center expanded into South America and Southeast Asia while strengthening its activities in Africa and formally adopted an integrated natural resource management framework for all its work and institutionalized its commitment to impact by creating a development group dedicated to move research results onto farmers’ fields; and in 2002, the Center acquired the brand name the “World Agroforestry Center” (www.icraf.cgiar.org).

As discussed earlier, though having traditional practices of growing trees and crops together and rearing cattle on farm, the organized research in agroforestry was initiated in India also with the establishment of the All India Coordinated Research Project (AICRP) on agroforestry in April 1983 by the Indian Council of Agricultural Research (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 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 splendous 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. In the last three decades, several agroforestry systems have been developed in India which have gone to farmers’ fields and provided livelihood support to resource-poor farmers. Now, the NRCAF has been upgraded as ICAR-Central Agroforestry Research Institute (CAFRI) and is recognized worldwide for its research and development capabilities, agroforestry database and information repository, and natural resource management on watershed basis (http://www.cafri.res.in). The mission of the institute is to improve quality of life of rural people through integration of perennials on agriculture landscape for economic, environmental, and social benefits. Its aim is to develop sustainable agroforestry practices for farms, marginal land, and wastelands in different agroclimatic zones of India; coordinate network research for identifying agroforestry technologies for inter-region; conduct training in agroforestry research for ecosystem analysis; and transfer technology in various agroclimatic zones. The mandate is to integrate woody perennials in the farming systems to improve land productivity through conservation of soils, nutrients, and biodiversity to augment natural resource conservation, restoration of ecological balance, and alleviation of poverty and to mitigate risks of weather vagaries. Now, besides World Center of Agroforestry (ICRAF) and CAFRI, agroforestry as a decipline of science has reached throughout the world and is being taught as subject in several agricultural and forestry institutes such as the Center for Agroforestry at the University of Missouri; Center for Subtropical Agroforestry, University of Florida; and centers of several agricultural and forestry universities/institutes in India.

3 Concepts of Agroforestry

It is clear from above discussion that agroforestry is a new name for a set of ancient practices. The word and concept attained a fair level of acceptability in international land use parlance in a rather short time. In the beginning (during 1970s and early 1980s), undoubtedly, a lot of ambiguity and confusion existed about agroforestry concept. The situation was reviewed in an editorial, appropriately titled "What is Agroforestry?" in the inaugural issue of *Agroforestry Systems* (Vol 1, pp. 7–12, 1982), which contained a selection of "definitions" of agroforestry, proposed by various authors. In summarizing these definitions, Bjorn Lundgren (1982) of ICRAF stated that two characteristics common to all forms of agroforestry and separate them from the other forms of land use, namely:

- The deliberate growing of woody perennials on the same unit of land as agricultural crops and/or animals, either in some form of spatial mixture or sequence.
- There must be a significant interaction (positive and/or negative) between the woody and non-woody components of the system, either ecological and/or economical.

These ideas were later refined through "in-house" discussions at ICRAF, and the following definition of agroforestry was suggested (www.icraf.org):

> "Agroforestry is a collective name for land-use systems and technologies where woody perennials (trees, shrubs, palms, bamboos, etc.) are deliberately used on the same land-management units as agricultural crops and/or animals, in some form of spatial arrangement or temporal sequence"

This definition, though not perfect in all aspects but has been increasingly used in ICRAF and other publications. In agroforestry systems, there are both ecological and economical interactions between the different components (Lundgren and Raintree 1982). Even the simplest agroforestry system is more complex, ecologically (structurally and functionally) and economically than a mono-cropping system.

Today, there is a consensus of opinion that agroforestry is practiced for a variety of objectives. It represents an interface between agriculture and forestry and encompasses mixed land use practices. These practices by and large have been developed based on the special needs and ecological conditions of the farmers in developing countries. Social objectives are very important in their adaptations. Terms like "social forestry," "farm forestry," and "community forestry" are found commonly used in literature. Social forestry is considered to be the practice of using tree plantations for pursuing social objectives, usually for the betterment of the poor through delivery of the benefits (fuel wood, fodder, small timber, shade, financial help, etc.) to the local people. Some local people call it "trees growing by people for the people." Community forestry, a form of social forestry, refers to the tree planting activities undertaken by involving community and plantation is done on community (common property) land for the benefit of entire community. It is based on the local people's direct participation in the process, either by growing trees themselves or by processing the tree products locally. Nowadays many self-help groups earn livelihood by developing government-sponsored programs through value addition to agroforestry products. Farm forestry, a term, commonly used in Asia, indicates tree plantations on farms, usually in association with crops.

The major distinction between agroforestry and the other terms seems to be that in agroforestry emphasis is on land use system where woody perennials are grown in association with crops/grasses and or animals for multiple products and services; the other terms refer to mainly tree plantation, often as woodlots. In literature, all kinds of tree plantations refer to growing and using trees to provide food, fuel wood, fodder, medicine, building materials, thatching, and cash income. Trees of all these systems are used for multiple uses, which is the main concept of agroforestry. Only blurred lines, if any, separate them and they all encompass agroforestry concepts and technologies. As characterized by ICRAF (2008), agroforestry helps in diversifying and sustaining production of the broad spectrum of agricultural commodities for enhanced economic, environmental, and social benefits by integrating trees on farms and in the agricultural landscape. Today, agroforestry represents the modern, science-based approach to harnessing the sustainability attributes and production benefits of such time-tested practices, and its demonstrated role in sustaining crop yields, diversifying farm production, realizing ecosystem services, and ensuring environmental integrity in land use is receiving increasing attention in developing programs around the world (Maffi 2007).

4 Agroforestry Systems/Practices

Agroforestry systems are widely based on nature and arrangement of the components and ecological or socioeconomic criteria. But no single classification scheme can be accepted as universally applicable. Therefore, classification of agroforestry systems will have to be purpose oriented. The complexity of the problem can be reduced if the structural and functional aspects of the systems are taken as the criteria for categorizing the systems and agroecological and socioeconomic aspects as the basis for further continuing. Since there are only three basic sets of components (woody perennials, herbaceous plants, and animals) to be managed, the first step of classification may be based on these components.

During the past four decades, agroforestry has come of age. Numerous indigenous forms of growing trees and crops together, sometimes with animals, were brought under the realm of modern scientific land use scenarios due to the efforts of local, national, and international organizations. Communities around the world have practiced diverse and evolving forms of agroforestry for time immorial (Nair 1989; Birkes et al. 2000; Parrotta and Trosper 2012), and both indigenous and non-indigenous practitioners have taken advantage of indigenous and traditional ecological knowledge for developing improved practices of great value. Many workers (Nair 1993; Dagar et al. 2014b; Rossier and Lake 2014; Dagar and Tewari 2016a; Nair et al. 2016) have mentioned about the utilization of indigenous knowledge among the communities of Asia, Europe, Africa, American Indians, Alaska Natives, Caribbean and Pacific Islanders, and other regions. Because indigenous groups have lived in the same areas for long periods of time, each generation has built on the knowledge of the previous generation through observation and experimentation and implemented in these local practices. In this manner, indigenous groups have evolved intricate ways to manage bio-culturally diverse ecosystems, which are time tested. These ecosystems are managed to provide food, fuel, building materials, agricultural and plant-tending tools, hunting and trapping equipment, baskets, medicines, and ceremonial spaces essential to life and maintaining cultural traditions. Many agroforestry practitioners across the globe have tried to learn from these complex systems and inculcated the useful information while developing the modern systems in many cases (Nair and Garrity 2012a; Dagar et al. 2014b; Dagar and Tewari 2016a).

There is subtle difference between "system" and "practice." A system is a specific local example of a practice. There are an enormously large number of agroforestry systems, but the specific practices that constitute them are few (Nair 1985, 1989; Young 1989). These two terms that used to be distinguished in the early stages of agroforestry development are now used rather synonymously. According to Nair's original classification scheme (Nair 1985), the vast majority of agroforestry practices that have been discussed and researched fall under "conventional" categories, later expanded as five agroforestry systems subgroups (Nair 2012). The three original major groups of systems included agrisilvicultural (crops + trees), silvopastoral (trees + pasture/animals), and agrosilvopastoral (crops + trees + pasture/animals). The five expanded system groups include alley cropping and other forms of tree intercropping, multi-strata systems of homegardens and shaded perennials, silvopasture (grazing and browsing forms), protective systems (such as shelterbelts, windbreaks, and soil conservation systems), and agroforestry tree woodlots for fuel and fodder production and/or land reclamation. In literature, particularly in India, some other terms referring specific associations such as silvipasture, agri-horti, silvi-horti, horti-silvi, and so on have been found used. As stated above, traditional/indigenous systems, which are time tested and have played significant role in developing modern systems, are discussed in brief here explaining how these have helped in evolving modern agroforestry systems.

4.1 Traditional/Indigenous Agroforestry Systems

During the early stages of agroforestry development, description of traditional practices involving trees, crops, pasture, and animals dominated the agroforestry literature. Nair (1989) was among the pioneers to compile these systems mostly from tropical and subtropical regions in the form of a book entitled *Agroforestry Systems in the Tropics* followed by immense literature published in the Journal *Agroforestry Systems*. Most of the present-day systems so-called modern systems are basically not new systems but modified version of indigenous systems. They all have been built upon the native assets of land, water, and other resources, relying on the traditional time-tested knowledge and land races adapted to different edaphic and ecological situations. Each system is unique in terms of its structural, production, environmental, and sociocultural attributes. Recently, Nair et al. (2016) have reported a qualitative SWOT (strengths – weaknesses – opportunities – threats) analysis of the selected indigenous agroforestry systems showing several commonalities among them. While sustainability, multifunctionality, and high sociocultural values are the common strengths, low levels of production and lack of systematic research and technological inputs to improve the systems are the major weaknesses. The opportunities emanating from strengths and weaknesses are also common to most of the systems, and threats to these systems arise mostly from ramifications of government policies (for more details see Nair et al. 2016).

Some of the indigenous and traditional systems/practices, having diverse characteristics, are listed in Table 2.1. Most of these are anecdotal and indigenous; in some cases, enough research has been carried out in the recent past. To understand their basic principles, the characteristic features of some of these practices have been described here in brief.

4.1.1 Shifting Cultivation (Slash-and-Burn System)

Shifting cultivation, one of the most primitive traditional agroforestry practices, is prehistoric and partly a response to agroecological conditions in various regions. It refers to farming system in tropics and subtropics in which land under natural

Table 2.1 Some common traditional agroforestry systems/practices[a]

Main system	Practices	Agroecological adaptations/remarks
Agri-silvicultural (trees with crops)	*Rotated in time (sequential practices)*	
	Shifting cultivation	Trees left after clearing of forests or planted to grow during fallow; mainly in tropical regions
	Taungya	Agricultural crops grown during early age of plantation; in most of hilly regions; widely followed
	Improved fallows	Shrubs (mostly legumes) and crops grown together, shrubs retained as fallows for 2–3 years to improve the soil, and again crops are grown. Herbaceous cover crops are also grown
	Relay intercropping	Shrubs and crops planted together each year; mostly tropical regions
	The Quezungal system	In Central America, *Cordia alliodora* is a common multi-purpose tree, pollarded to 1.5 m, and regenerates naturally; crops such as maize, sorghum, and beans are grown
	The Riberno system	In the Peruvian Amazon, after forest clearance, agricultural crops mainly cassava, yam, plantains, rice and fruits are cultivated along with retained trees
	Spatially mixed (simultaneous practices)	
	Trees on crop land (parkland systems)	Scattered trees on crop lands, e.g., Khejri (*Prosopis cineraria*) on crop fields mainly millet in arid India; *Acacia leucophloea* and many MPTs on crop fields of Tamil Nadu in India
	Plantation crop combinations	Plantation, shade trees with partial shade-tolerant crops, mainly tuber crops or shade trees and commercial crops like coffee or tea; mainly tropical regions
		In the Amazon region, fruit trees, various palms, cacao, Brazil nut (*Bertholletia excelsa*) and agricultural crops (cassava, yams, beans, plantain, etc.) are cultivated. These also become part of their homegardens
	Homegardens (multi-strata systems)	Multi-strata trees like coconut in upper storey, clove, cinnamon in middle storey, tuber crops or pineapple and vegetables as ground crops and vines like black pepper and cucurbits; mostly around homesteads in tropical regions
	Specially zoned (simultaneous practices)	
	Alley cropping	Hedgerow intercropping with woody species which are pruned frequently for fuel, fodder or green manure; mainly on sloping high rainfall areas in almost all regions
	Boundary planting	Trees on field boundaries of agricultural fields or along canals to check seepage; and also as live fences
	Strip planting	Plantations with corridor farming or on acre line to control rise in water table in waterlogged areas; and also to check sand dune movement
	Shelterbelt	Plantations to shelter crops from wind and also as live fences
	Woodlots	Trees for cut-and-carry purposes to be used as fodder, fuel and mulching
	Farming in forests	Cultivation of crops in natural forests; many areas in Europe. For example, in Canada ginseng is commonly cultivated in forests and wild mushrooms are collected as food item

(continued)

Table 2.1 (continued)

Main system	Practices	Agroecological adaptations/remarks
Silvopastoral (tree with pasture and or animals)	*Spatially mixed (simultaneous practices)*	
	Trees on rangeland or pasture (parkland systems)	Scattered or systematically planted MPTs or shrubs mainly of fodder use on pasture lands; mainly in dry regions
	Perennial crops with pasture	Plantation crops like coconut and cashew nut sometimes fruit trees on pasture lands; mainly in tropical regions
		In Brazil, grazing under tree crops such as cashew, coconut and carnauba palm (*Copernicia prunifera*) is common practice
	Specially zoned (simultaneous practices)	
	Boundary plantation	Trees mainly of fodder use on boundary of pasture lands; live fences and streamside protection
	Shelterbelts	MPTs to shelter pastures and animals from wind and snow; mainly in temperate regions
	Woodlots	MPTs used as stock fodder, fodder banks, soil protection, etc. in pastoral systems. In Europe, animals are commonly left for grazing in woodlots
Agro-silvopastoral (trees with crops and pasture/animals)	*Specially mixed (simultaneous practices)*	
	Homegardens with animals	In Tanzania, tall trees like *Cordia abyssinica, Albizia* spp. and *Diospyros mespiliformis* in upper storey; banana and coffee in the 2nd storey; and food crops, fodder, cardamom and medicinal herbs in lower storey
	Global heritage of East Africa (the Chagga, Matengo Ngoro-Pit, and Ngitti systems)	
	Compound farms of West Africa	Food crops like yams, plantain, maize, etc. are grown with fruit trees (e.g., *Treculia africana*, *Dacryodes edulis*, and *Pterocarpus* sp.) and animals
	The parkland system in West Africa	MPTs like *Faidherbia albida, Vitellaria paradoxa*, *Parkia biglobosa*, *Adansonia digitata*, and *Balanites roxburghii* are cultivated along with staple cereals mostly millets and extensive silvopastoralism with free-roaming animals
	Spatially zoned (simultaneous practices)	
	Multipurpose woody hedgerows	Woody hedges for fodder, fuel wood, mulch, soil conservation; in most areas as cut-and- carry system
	Multipurpose woodlots	MPTs are grown widely (mainly on community land) as woodlots for wide range of uses
Others/ Site-specific	Entomo-forestry	Trees and beekeeping; in Africa some insects such as mopane worm are reared on mopane trees as food; some insects are reared as commercial purposes such as lac insect on *Butea monosperma* and silkworm on *Morus alba* in Asia
	Aquaforestry	Trees on boundary of fish/shrimp ponds
	Multi-enterprise farming	Many components such as trees, fruits, animals, poultry, fish, cereals, vegetables, and bees are integrated together for getting sustained income and livelihood
	Reclamation/ rehabilitation/ recreational forestry/biodrainage plantations	Trees, grasses, and crops for reclamation of degraded lands including eroded, salt-affected, and waterlogged areas and to rehabilitate mine-spoil areas; as degraded mangrove areas; as biodrainage plantation to lower down water table in waterlogged areas; etc.

[a]Compiled from various sources. More details and references are available in text

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 is 10–20 years, recently reduced to even 3–5 years. The practice is over 9000 years old, believed to have originated in the Neolithic period around 7000 BC (Maithani 2005), and is still extensively practiced in Northeastern Himalayan Region and other humid and hilly parts of Indian subcontinent.The system is addressed with different names in different parts of the world. In many parts, shifting cultivation and taungya system are considered same.

In the tropics, the system is dominant mainly in sparsely populated and lesser developed area, especially in the humid and subhumid tropics of Africa and Latin America and densely populated in Southeast Asia including northeastern regions of India. Estimates of area under shifting cultivation vary. According to one estimate (FAO 1982), it extends over 360 million ha supporting over 250 million people. Crutzen and Andrea (1990) estimated the system being practiced by 200 million people over 300–500 million ha. Haokip (2003) mentioned that in the world about 500 million people are estimated to practice shifting cultivation in 410 million ha area (forest land) and in Asia alone, about 80 million people spread over nearly 120 million ha are practicing this system. In India, about 60,000 families in 48 districts are cultivating 2.27 million ha area as shifting cultivation (FSI 1997). Though exact figures about total area under shifting cultivation are not available, it is still applied in about 40–50 countries (Mertz 2009) and constitute an important part of the 850 million ha of secondary forest in tropical Africa, America, and Asia (FAO 2005).

The practice is thought to account for about one-third of the deforestation in the Amazon, while cattle ranching is responsible for at least half of the deforestation (Serrato et al. 1996). Rural population in many parts of the eastern Amazon is so dense that fallow periods between cultivation cycles are too short to allow soils to recuperate. Lundgren (1978) reported from 18 locations around the tropics that an average of 8.9 Mg ha^{-1} yr^{-1} litter was added from natural forests, amounting to average nutrients (kg ha^{-1} yr^{-1}) of 134 N, 7 P, 53 K, 111 Ca, and 32 Mg, and the quantity of nutrients lost from such a system was negligible. Clearing and burning the vegetation leads to a disruption of this closed nutrient cycle. The changes in soil due to clearing and burning of vegetation result in sharp increase of available nutrients so that the first crop is very good. Afterward, the soil becomes less and less productive and crop yields decline. The main reasons for the decline in crop yields are soil fertility depletion, increased weed infestation, deterioration of soil physical properties, and increased insect and disease attacks (Sanchez 1976).

Despite remarkable similarity of the system practiced in different parts of the world, marginal differences do exist and are often dependent on the environmental and sociocultural conditions of the locality and the historical features that have influenced the evolution of land use systems over the centuries in different parts of the world. *Jhum* cultivation in Northeastern Himalayan Region is a complex system with wide variation and depends upon ecological variations in the area and cultural diversity among various tribal clans. There are some tribes who have ecological knowledge and have developed the system to be quite sustainable. One of the common features of shifting cultivation in the region is growing of mixed crops after partial or complete removal of vegetation. Common crops such as potato (*Solanum tuberosum*), rice (*Oryza sativa*), maize (*Zea mays*), tapioca (*Manihot esculenta*), colocacia (*Colocasia esculenta*), ginger (*Zingiber officinale*), sweet potato (*Ipomoea batatas*), millets (species of *Panicum*, *Eleusine*, *Pennisetum*), etc. are grown in isolation or mixed crops along with *Pinus kesiya* or other retained trees depending upon the need. Another important attribute of the system is secondary succession of vegetation during fallow period. The Angamis tribe from Nagaland since long has practiced nitrogen-fixing tree Alder (*Alnus nepalensis*)-based sustainable *Jhum* system that has been reported to provide 57 food crops to supplement the staple food crop rice (Singh et al. 2014). The system provides about five dozen food crops to supplement the staple crop rice. Alder improves soil fertility by fixing atmospheric nitrogen into the soil through *Frankia*. The nitrogen fixed varied between 48.3 (60 trees per ha) and 184.8 kg per ha (625 trees per ha). The fallen leaves act as mulch and add humus to the topsoil. Mixed cropping is repeated in the second year. The field is then left fallow for about 4 years. Alder tree is pollarded first time at a height of 2 m when 7–10 years old and subsequent pollarding is performed after 4–6 years.

The Konyak tribes in Nagaland also have sound ecosystem knowledge and have at times about 3000 seedlings of *Macaranga denticulata* per hectare of land. They gradually reduce the density during the fallow period and keep optimum number suiting to their cropping density. These both tribes also keep other multipurpose trees such as *Trema orientalis*, *Sapium baccatum*, *Schima wallichii*, and species of *Grewia* and *Quercus* in the Jhum fields. In the Konyak Jhum field, more than 40 species can be seen. They have sound knowledge of mixing rice and colocasia by which the sloping land is covered under vegetation for a greater part of the year. They also manage fallows (for 7–9 years) cycling twigs and leaves in the soil to increase the soil fertility. In Meghalaya, bun method of cultivation is unique, where twigs and branches of forest trees along with weed biomass (from the surrounding areas) are kept in heaps at regular intervals across slopes. The buns are usually 2–4 m long, 1–2 m wide, and 0.2–0.4 m in height spaced at 1–2 m depending upon soil depth and are covered with a thin layer of soil in order to burn the entire biomass under anaerobic condition converting it gradually into ash. Further, zabo indigenous farming practice in Nagaland is a combination of forest, agriculture, animal husbandary, and pisciculture on highly sloping land. Hill slope is kept under trees, mid slope is used for construction of silting ponds and water harvesting tanks, and land down slope for animals and terraced rice fields. Ponds are desilted every year and material along with forest litter is spread in the fields for manuring. Entire animal dung is cycled in the fields. This way, around 80–100 kg N, 15–25 kg P, and 50–75 kg K per ha, besides organic matter and micronutrients, are added to the soil annually. Farmers rear fish and cultivate rice without adding any inorganic nutrients and get enough fish for the family, and soil loss due to erosion is also below the critical limit.

In Pacific Islands, shifting cultivation is managed through manipulating the different storeys of trees.Various tropical fruit-and-nut trees are maintained as upper storey; shorter trees as second storey; crops, mostly tuber crops, in the lowest storey; and ornamentals along borders (Elevitch 2011). At times, upper storey fruit trees are pruned to allow sunlight for lower storey species and allowed to return to fallow for a period ranging from 4 to 10 years, retaining only fruit trees. A variety of tree products, fruits, food, vegetables, fiber, flowers for decoration, beverages (Kava is used as social beverage), and medicine are obtained from the system.

Shifting cultivation in Vietnam is characterized as production of food crops on land with slopes over 45%. It is still practiced due to the problem of food security in mountainous regions. It is a traditional practice associated with resource poor people and linked with cultural and spiritual life of people. The economy of ethnic minorities still depends basically on shifting cultivation. About two million people of 54 different ethnic groups practice slash- and-burn agriculture in the mountainous area of Vietnam. They describe this form of agriculture as "*nuong ray*" and people are also called by this name. There are three types of practices. In the first, rice (*Oryza sativa*) is the main crop grown which yields 2 Mg ha^{-1}in the third year when the field is abandoned and farmers move to another site. In the second type, seeds of *Melia azedarach* are sown and site is burnt. Usually rice is sown with *Melia* (1000–1500 plants per ha) after burning. After 3 years when cropping is stopped, *Melia* is established along with bamboo as natural crop. In the third type, *Cinnamomum* is planted with rice and cassava (*Dioscorea* spp.) in the first 3 years. Shade trees are also planted. Although under low population pressure earlier, this system was sustainable but now it is the main cause of deforestation, soil erosion, and land degradation. The traditional farmers in low-lying areas of South Vietnam grow *Melaleuca leucadendra* with rice on acid sulfate soils having pH as low as 2.3.

In Brazil (Latin America), the Riberno system in Peruvian Amazon, also known as Swidden fallow system, forest clearance is followed by kinds of homegardens, where no definite planting pattern is followed in multiple configurations. Food crops (yams, plantains, tubers, maize etc.) are cultivated with fruit and other trees such as *Treculia africana*, *Dacryodes edulis*, and *Pterocarpus* sp., and animal products are made for home consumption. Lojka et al. (2016) reported a viable multi-strata agroforestry system as an alternative to slash-and-burn farming in the Peruvian Amazon, where between 1999 and 2005, deforestation rates varied between 632 and 645 km^2 per year. The key component for establishment of multi-strata systems is *Inga edulis*, a tree that besides producing marketable fruits can improve soil fertility and suppress noxious weeds during the first year of establishment. Other promising and fast-growing trees include *Dipteryx micrantha*, *Schizolobium parahyba*, *Parkia* spp., *Tabebuia impetiginosa*, and *Simarouba amara* among timber species and *Annona muricata*, *Spondias dulcis*, and *Poraquei basericea* among fruit trees. Annual crops such as cassava, maize, beans, etc. along with pineapple (*Ananas comosus*) form the system viable (Bortl 2011; Lojka et al. 2016). This system proved to be highly beneficial as compared to traditional system.

4.1.2 Taungya

The *taungya* system in the tropics is like an organized and scientifically managed shifting cultivation, a forerunner to agroforestry. The word is reported to have originated in Burma (now Myanmar) and means hill (*tauang*) cultivation (*ya*) (Blanford 1958). 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 (King 1987; Nair 1993). In German-speaking countries, it is called *haumfeldwirtschaft*, *brandwirtschaft*, or *waldfeldbau*. In francophone countries, it is referred to as *cultures sylvicole et agricole combines*, *culture intercalaires*, *method sylvo agricole*, *systeme sylvo-bananier*, *plantation sur culture*, etc. The Dutch name is *bosakkerbouw*. In Puerto Rico, it is called the *parcelero* system, in Brazil *consorciarcao*, in Libya *tahmil*, in the Philippines *kaingining*, in Indonesia *tumpangsari*, in Malaya *lading*, in Kenya the *shamba* system, in Jamaica *agricultural contractors' system*, in Sri Lanka *chena*, in Tanzania *the licensed cultivator system*, and in India variously described as *dhya*, *jhooming*, *kumri*, *punam*, *taila*, and *tuckle*. In the greatest number of countries in the world, it is called *taungya*. In 1968 (when agroforestry was not defined), King (1968) suggested the genetic term "agrisilviculture" be generally employed to it. It can be considered a step in the process of transformation from shifting cultivation. It is not merely the temporary use of 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 impact studies and changes on 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. In India, *Tectona grandis*, *Dalbergia sissoo*, *Eucalyptus* spp., and *Shorea robusta* are widely grown with various crops, but some site-specific species such as *Populus deltoides* in Indo-Gangetic plains; *Anacardium occidentale*, *Bombax ceiba*, and *Acacia leucophloea* in Andhra Pradesh; *Shorea assamica* and *S. robusta* in Assam; *Schima wallichii* and *Cryptomeria japonica* in West Bengal; *Santalum album* and *Cassia siamea* in Karnataka; and *Pterocarpus dalbergioides* in Andamans are reported frequently grown with local crops.

In a study in southern Nigeria involving *Gmelina arborea* with maize, yam, or cassava, Ojeniyi and Agbede (1980) found that the practice usually resulted in a slight increase in soil N and P, a decrease in organic carbon, and no change in exchangeable base and pH compared with sole stands of *G. arborea* and in a separate study in three ecological zones of southern Nigeria. Ojeniyi et al. (1980) concluded that the practice of inter-planting young forest plantations with food crops would not have any adverse effect on soil fertility. The long-term effect of the practice on soil fertility will, however, largely depend on the management practices adopted at the time of the initial clearing as well as subsequent reestablishment phase. Though there are reports to suggest alternative or improvement to *taungya* (e.g., forest village scheme in Thailand reported by Boonkrid et al. 1984) and the system is still popular in some places as a means for plantation establishment, it continues to be a relatively unimproved land use practice. Chamshama et al. (1992) studying the suitability of Kilimanjaro forest plantation of Tanzania reported that during the early stages of forest plantation establishment, intercropping of young trees with food crops is beneficial in terms of tree survival, food crop production, financial income to the peasant farmers, and reduction of forest plantation establishment costs confirming the sustainability of the system. Oluwadare (2014) after analyzing selecting 100 farmers revealed that agricultural production under *taungya* farming in Nigeria was profitable and productively and technically efficient and ensured the production of choice economic trees that would guarantee continuous production of such trees. The technical efficiency of the taungya farms would improve with improved education and increased technical assistance in the form of extension visits. All these studies confirm the sustainability of the system and severity of livelihood of resource-poor farmers.

4.1.3 Improved Fallows

Improved fallows are also land resting from cultivation and the deliberate planting and managing of fast-growing species of trees, shrubs, and herbaceous cover crops – usually legumes – for rapid replenishment of soil fertility. Improved fallows are rapidly spreading in several regions of the tropics as a sensible way for in situ accumulation of large quantities of N in vegetation and soil, as well as for providing sustainability enhancing services (Sanchez 1999). Research on improved fallows increased after the mid-1980s with the development of what is known as the second soil fertility paradigm, which is based on sustainability considerations. Many lessons have emerged from short-term improved fallows (<5 years' duration). These include the diversity of farm sizes where improved fallows are used, the advantage of sequential versus simultaneous systems, the utilization of dry seasons unfavorable for crop production, the comparative advantages of woody versus herbaceous leguminous fallows, the magnitude of N accumulation, the strategic use of N fertilizers, and the importance of P (Sanchez 1999; Kwesiga et al. 1999, 2005; Franzel et al. 2001). Other key services provided by fallows include fuel wood production, recycling of nutrients besides N, provision of a C supply to soil microorganisms, weed suppression, and improved soil water storage.

Most reviews on alternatives or improvements to shifting cultivation contain recommendations on tree species considered suitable to alternate and/or intercrop with agricultural species, grow fast, and efficiently recycle available nutrients within the system, thus shortening the time required to restore fertility. 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*, *Pithecellobium*, *Prosopis*, *Robinia*, and *Sesbania.* In northwestern India, *Sesbania cannabina/aucleata* grown under irrigation for 65 days between wheat and rice crops could add 7.3 Mg ha^{-1} dry matter and 165 kg N ha^{-1} (Bhardwaj and Dev 1985). Thus, nitrogen-fixing species may play vital role in improving the fallows. Present-day shifting cultivators do not often shift their residences as far apart as did previous generations because of shrinking land area per family due to rise in population. This has forced them, as well as the researchers concerned about their plight to look for land management systems by which they can get something from the land even during the so-called fallow phase. Thus, intercropping under or between fast-growing trees in fallow phase must be one of the approaches while finding alternative to shifting cultivation. It seems logical to accept that managed permanent cultivation systems such as improved *taungya*, homegardens, plantation crop systems, alley cropping in hilly regions, and tree incorporation on farm, and grazing lands are most of the alternatives to solve the problems.

Improved fallows are considered successful because of three sets of factors, viz., their effects on improving household welfare (livelihood), the various environmental services they provide (improve soil properties in terms of organic matter, higher infiltration rate, increased aggregates stabilizing soil, carbon sequestration, etc.), and the development of an institutional mechanism, an adaptive research and dissemination network of government, NGO, and farmer organizations, to sustain adoption of the practice (TECA 2003). The crops and other food items are almost organic or with limited use of fertilizers and insecticides (produced from organic source, e.g., from leaves of *Tephrosia vogelii*) and also reduce pressure from woodlots.The main limiting factor in Africa is clearly the supply of germplasm of improved fallow species. This must be overcome though large-scale seed orchards and nursery development before impact at the scale of millions of farmers can take place.

The decline in soil fertility in smallholder systems is a major factor inhibiting equitable development in much of sub-Saharan Africa. Smalling et al. (1997) estimated that soils in sub-Saharan Africa are being depleted at annual rates of 22 kg ha^{-1} for nitrogen, 2.5 kg ha^{-1} for phosphorus, and 15 kg ha^{-1} for potassium. In many areas, farmers periodically fallow their land, i.e., allow it to lie idle for one or more seasons primarily to restore its fertility. As population increases, fallowing and fallow periods are reduced, continuous cropping becomes more frequent, and crop yields often decline. Cultivation is extended to marginal areas, causing soil degradation. With consistent efforts of the scientists (Buresh and Cooper 1999; Sanchez 1999; Franzel et al. 2001; Amadalo et al. 2003; Kwesiga et al. 2005), many farmers adopted successfully the short fallows and could sustain the crop yields improving the soil properties in deforested areas. They raised one or more woody species in short fallows of 2–5 years along with field crops like maize. The woody species included *Sesbania sesban*, *Tephrosia vogelii*, *Cajanus cajan*, and *Acacia angustifolia* in eastern Zambia, Zimbabwe, and southern Malawi; *Calliandra calothyrsus* in Kenya and Cameroon; *Leucaena leucocephala* in the Philippines and many African countries as alley crop; *Senna siamea* and *Flemingia macrophylla* in Ghana; and *Acacia angustifolia*, *A. mangium*, *Inga edulis*, *Sclerolobium paniculatum*, *Gliricidia sepium*, and *Leucaena leucocephala* in Amazonia, Brazil, Tanzania, Nigeria, and many other countries. Other species are *Tephrosia candida*, *Desmodium uncinatum*, *Crotalaria juncea*, *C. grahamiana*, *C. paulina*, and *C. striata*. In many locations herbaceous cover consisting of *Canavalia ensiformis*, *Calopogonium mucunoides*, *Mucuna pruriens*, *Dolichos lablab*, *Macroptilium atropurpureum*, and *Crotalaria* spp. is frequenly grown to improve the fallow, which also control weed infestation.

Evolutionary trends in tropical systems show that management intensities capable of sustaining productivity are usually introduced only after considerable depletion and degradation of resources (especially of the nonrenewable soil) have taken place. As we know that the role of fallow period in improving soil properties is well known but if this period is reduced, there is sharp deterioration of the soil and productivity status of the system. Kang and Wilson (1987) developed a pathway indicating points at which intervention with planted fallow or other agroforestry methods could be introduced thus preventing further resource degradation. Awareness of the soil-rejuvenating properties of different species in the fallow system, manipulation of species in the short fallow in order to ensure fertility regeneration, retention of useful soil fertility restorer trees, introduction of improved techniques like alley cropping, and concepts of development of the climax multistorey production system based on agroclimatic condition of the region are some of the features which are important. If one adheres to the evolution pattern of shifting cultivation and sustainability, high productivity can be achieved only when conservation and restoration measures are introduced before resources are badly depleted.

It is evident that shifting cultivation has become unsustainable primarily because of reduced *jhum* cycle owing to the increase in population pressure. Sustainable farming strategies and alternatives to ensure the livelihood security of the native people are the need of the day. There is urgent need of settling the land tenureship issue educating the people about the adverse impacts of short *jhum* cycles. 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 crop, fruit, animal husbandry, fishery, and forestry with appropriate conservation measures for natural resources would be most effective in overall development of the shifting cultivation areas. Borthakur (1992), Ramakrishnan (1992), Tripathy and Barik (2003), Tomar et al. (2012), and Singh et al. (2014) have suggested several measures to deal with the problems related to shifting cultivation.

4.1.4 Homegardens

Homegardens depict a transition stage between tropical forest ecosystem and arable cropping that mutually supports the sustainable agriculture and forest ecosystems. Tropical homegardens consist of an assemblage of plants, which may include trees, shrubs, vines, and herbaceous plants growing in or adjacent to a homestead or home compound. These are intended primarily for household consumption, and there is intimate association of woody perennials with annual and perennial crops and, invariably livestock within the compounds of individual houses, with the whole crop-tree-animal unit being managed by family/labour. Homegardens are rich in biodiversity. A farmer in Thailand demonstrated the system as an environmentally sustainable alternative to conventional agriculture where he planted and maintained more than 500 species of plants in 1.9 ha area (FAO 1990). Much has been written about homegardens and numerous terms have been used by various workers. These include mixed-garden horticulture, housegarden, Javanese homegardens, compound farm, kitchen garden, household garden, and homestead agroforestry (Nair 1993).

Javanese homegardens (*Pekarangan talunkebun*) provide an illustrative example of the diversity and complexity of tropical homegardens. Starchy food plants (cassava and *ganyong- Canna edulis*), vegetables, and spices dominate the lower two layers (up to 2 m); banana, papaya, and other fruit trees dominate the next two layers (2–5 m). Fruit trees or other cash crops such as cloves also dominate the five to ten meters' layer. Coconut and other multipurpose trees dominate the top layer (higher than 10 m). Homegardens of Java generate relatively good income and are good source of nutrients. Plantation crops such as coconut, cacao (*Theobroma cacao*), coffee (*Coffea arabica/robusta*), areca nut (*Areca catechu*), and black pepper (vine) (*Piper nigrum*) often are the dominant components of many homegardens of humid tropics. Fruit such as banana (*Musa paradisiaca*), papaya (*Carica papaya*), mango (*Mangifera indica*), guava (*Psidium guajava*), custard apple (*Annona squamosa*), pineapple (*Ananas comosus*), and jackfruit (*Artocarpus* spp.) are the major components of some tropical homegardens.

Nair and Sreedharan (1986) and Kumar and Kunhamu (2011) gave the inventory of crops and trees in homegardens of Kerala. Dagar (1995) and Dagar et al. (2014a) enumerated the yield of fruits and vegetables grown in the homegardens of coastal and island regions. In spite of very small average size of the management units, homegardens are characterized by high species diversity and usually 3–4 vertical canopy strata. A dynamic equilibrium can be expected with respect to organic matter and plant nutrients on the garden floor due to leaf litter and its constant decomposition. The energy and nutrient requirement of local people is fulfilled mainly through the products of these gardens. Another important aspect of these gardens is that the production for home consumption occurs throughout the year. The physical limitations such as remoteness of the area force the inhabitants to produce their basic needs by themselves. Unfortunately, there have been no serious efforts to provide the institutional and policy support for strengthening research on these traditional systems of exception merits.

Homegardens are traditional agroforestry system in Vietnam. In a piece of land around the house (0.5–5 ha), the land is used efficiently and effectively for growing fruits, vegetables, root crops, fish, livestock, fodder, fiber, medicine, small timber, fuel wood, and other products in multilayered structure. Most common homegardens have fruit trees, fishponds, livestock, and forest trees in an integrated system. Medicinal plants are also integrated. In delta homegardens, the main dominance is of fruit trees with three-storey canopy structure. Durian (*Durio zibethinus*), mango, and jackfruit form top storey; mangosteen (*Garcinia mangostana*), guava, lemon, *Achras zapota*, *Annona muricata*, *Citrus sinensis*, *Lansium domesticum*, banana, papaya, *Citrus reticulata*, and *Phyllanthus acidus* form middle storey, while ground storey is consisted of mainly vegetable crops, pineapple, forage grasses, etc. These homegardens have well-developed irrigation and drainage systems. On canal banks, *Cocos nucifera*, *Colocasia esculenta*, and *Alocasia odora* are planted. *Sesbania grandiflora* is planted as fence, green manure, and fuel wood. Some gardens also have flowers particularly *Rosa indica*, *Polianthes tuberosa*, *Dahlia pinnata*, and *Gladiolus gandavensis*. In the mid-hill homegardens on uplands (size 1.5–2.0 ha) depending upon slope and soil depth and knowledge and needs of farmers, tree species are arranged spatially and temporally. On hill tops, *Manglietia glauca*, coconut palm, and bamboos are commonly grown, while on slopes on terraced fields, various trees and crops form different combinations, viz., *Manglietia glauca* + tea (*Thea chinensis*) + *Tephrosia purpurea* + *Tephrosia candida*, *Cinnamomum cassia* + Cassava (*Manihot esculenta*) + *Cassia glauca*, *Aleurites fordi* + tea + pineapple + *Tephrosia purpurea*, and *Artocarpus integrifolia* + tea + pineapple are common. On foot hills, fruit trees such as jackfruit, longon, litchi, apricot, plum, banana, and persimmon are planted around houses; and local vegetables, viz., beans, cucurbits, spices, and medicinal plants, are grown under trees. Apiculture is also practiced besides trees. Lowest ground is used for rice field and fishpond. On terraced fields cassava and maize are intensively grown. These systems are economically viable and environmentally sound, ensuring soil erosion control and sustainable land use.

Okafor and Fernandes (1987) reported compound farms in southeastern Nigeria (West Africa) having trees of various heights forming multi-strata canopy of forest and fruit trees such as *Treculia africana*, *Dacryodes edulis*, and *Pterocarpus* sp. Products from crops such as yams, tubers, and other food crops and animals are consumed at home, and fruits and timbers are sold in the market. In general family labor is used and almost no chemical fertilizers are used. Using traditional knowledge and scientific technologies, there is enough scope of improving the systems. The Chagga in the foothills of Mountain Kilimanjaro, the Matengo Ngoro-Pit system in highlands of Mbinga district, and Ngitill system in western Tanzania are homegarden systems of Tanzania; and compound farms of West Africa growing multipurpose trees, fruits, and food crops (yams, plantain, maize, etc.) along with animals are still popular (Boffa 1999; Nair et al. 2016). In the Chagga system, tall trees such as *Cordia abyssinica*, *Diospyros mespiliformis*, and species of *Albizia* form upper storey; banana and coffee in second storey; and food crops, fodder, cardamom, and medicinal herbs in lower storey. In this system there is high degree of nutrient cycling and permanent cover on soil helps in conserving soil as well as moisture. These systems are valuable gene pool. There is plenty scope of introduction of improved apiculture practices and nitrogen-fixing trees in the system (Kitalyi et al. 2013).

In recent years, much of the forested and bare lands are allocated to farmers where they grow trees along with their crops. Very well designed farming systems and their components have however been adopted by the farmers to improve the land capability. Tropical homegardens are essentially a complex integration of diverse vegetation where trees with understorey crops perform several production and service functions like livelihood (food, spices, fruits, vegetables, cash products), environmental benefits (biodiversity, shade, carbon sequestration, soil protection, nitrogen fixation, etc.), and cultural functions (conservation, utilization, recreation, traditions). Conservation of biodiversity, nutritional security of the family, strengthening of household economy, and improvement of soil health are the main attributes of the homegardens. Singh et al. (2014) have explained in detail some interesting observations on Angami and Konyak homegardens of Nagaland, Ingkhol homegardens of Manipur, and homegardens of War Khasi tribes of Meghalaya and Chktuah of Mizorum, which are economically and environmentally sustainable. There is a need of SWOT analysis of most of the homegardens so that further research for improving these may be planned. Dagar (1995), Kumar and Nair (2006), Pandey et al. (2007), Kumar and Kunhamu (2011), Kumar et al. (2012), Dagar et al. (2014a), and Dagar and Tewari (2016b) have given comprehensive account of homegardens including improved ones.

4.1.5 Plantation-Based Cropping Systems/Commercial Agroforestry

Modern commercial plantation crops like rubber (*Hevea brasiliensis*), coffee (*Coffea arabica/robusta*), and oil palm (*Elaeis guineensis*) represent a well-managed and profitable stable land use activity in the tropics. The scope for integrative practices involving plant associations in these commercial plantations is limited, except during the early phases of plantation when some intercropping is feasible, the commercial production of these crops is aimed at single-commodity objective. Some of the plantation crops like coconut palm have been cultivated since very early time but their economic yield remained low for a long time.

Contrary to popular belief, a substantial proportion of tropical plantation crops are grown by smallholders. For example, most of the cacao production in Ghana and Nigeria comes from smallholdings where it is grown with specific crops like maize (*Zea mays*), cassava (*Manihot esculenta*), banana, cucumber (*Cucumis* spp.), and sweet potato (*Ipomoea batatas*) especially during the first 4 years of planting cacao. In Trinidad, it is grown under forest shade trees. In Kenya, the crop land is characterized by the upper layer being dominated by tall trees such as *Cordia africana*, *Grevillea robusta*, *Commiphora zimmermannii*, and *Trema orientalis* and the middle layer by shrubs (banana and fodder shrubs), while the ground layer is dominated by the annual crops (maize, beans, root crops) and grasses. Cut-and-carry system assures that there is no damage by animals. Inhabitants of the highlands in Kilimanjaro in Tanzania have Kihamba or Chagga homegardens usually having four vegetation layers (Hemp and Hemp 2008). Apart from some cultivated fruit trees (avocado, mango) and some introduced timber trees (*Grevillea robusta*, *Cupressus lusitanic*a), there are more than 80 tree species which are encountered in these plantations. Most widespread are *Albizia schimperiana*, *Rauvolfia caffra*, *Cordia africana*, *Commiphora eminii*, and *Margaritaria discoidea*. Some of these cover banana and coffee fields and also cocoyam (*Colocasia esculenta*). Species such as *Dracaena fragrans* are planted as hedge. Some epiphytes such as fern *Drynaria volkensii* and *Telfairia pedata* (a liana with oil containing seeds) find place on *Albizia schimperiana* var. a*manuensis*. Under banana and coffee, farmers grow vegetables and sometimes fodder grasses for livestock rearing.

In the vast Amazonian humid tropical lowland region of South America (Brazil, Peru, Colombia, Venezuela, Guyana, etc.), many tall timber trees associated with fruit trees and various palms form typical Amazonian plantation-based system in which cacao, Brazil nut (*Bertholletia excelsa*), agricultural crops, cassava, yams, beans, plantain, etc. are commonly cultivated (Miller and Nair 2006). Fruit trees along with other trees are also planted around houses. Indigenous knowledge of interaction of plants and environment as well as social systems helps in domestication of indigenous species.

Many smallholder rubber plantations in Southeast Asia and Nigeria are based on integrated crops including soybean, maize, banana, groundnut, fruit trees, coconut, and black pepper. In Malaysia poultry raising in rubber stand is a common wealth. In Nicobar Islands (India) poultry and domestication of pigs with coconut is very old practice. Most of the coconut production in India, the Philippines, Sri Lanka, and the Pacific Islands comes from small holdings in which coconut palm is integrated with a large number of annual and perennial crops like clove (*Syzygium aromaticum)*, cinnamon (*Cinnamomum zeylanicum*), coffee, cacao, cassava, yams (*Dioscorea alata*), fodder grasses, and legumes. Grazing under coconut and cashew nut (*Anacardium occidentale*) is also common. In India, Tanzania, Mozambique, and Senegal, smallholders grow cashew nut commonly (in wider spaces) with other crops. Coffee is integrated with other crops like banana and maize in Ethiopian highlands, Colombia, and Kenya. Coconut is one of the most widely grown tree crops in the tropics mostly on islands, peninsulas, and along coasts, covering an area of six million ha (Nair 1993). The major coconut-producing countries are the Philippines, Indonesia, India, Sri Lanka, Malaysia, and the Pacific Islands, and the most of the production is from small holdings.

Important food crops grown with coconut include cereals (rice, finger millet, and maize); pulses (pigeon pea, green and black gram, coupe, soybean, groundnut); root crops (sweet potato, yams, cowpea, elephant foot yam, and taro); spices and condiments (ginger, turmeric, cinnamon, clove, chilies, and black pepper and fruits like pineapple, mango, banana, papaya, and bread fruit); other crops (cotton, sugarcane, sesame, abaca, and vegetables); tree crops (areca nut, cacao, and coffee); improved pasture grass species of *Brachiaria*, *Dichanthium*, *Panicum*, *Setaria*, *Paspalum*, and *Pennisetum*; and improved forage legumes of *Stylosanthes*, *Desmodium*, *Glycine*, *Leucaena*, and *Macroptilium*. Many trees such as species of *Erythrina*, *Ficus*, *Tamarindus*, *Gliricidia*, *Ceiba*, and *Cordia* find the place in these systems. Dagar (1995), Dagar et al. (2014a), and Dagar and Tewari (2016b) gave detailed account of plantation-based agroforestry in coastal and island regions.

Domestication of large cardamom (*Amomum subulatum*) plantations under *Alder* (*Alnus nepalensis)* in Northeastern Himalayan Region 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. The tree management helps cardamom production also. With other fodder trees, lopping during November after maturation of cardamom and not allowing twigs to fall on it does not interfere with the production and makes it an economically viable system. Singh et al. (1982) and Prasad and Singh (1994) have made extensive study on cultivation of large cardamom with *Alnus nepalensis* tree in eastern Himalaya region. Sharma et al. (2000, 2009) reported that the yield of finished cardamom under Alder (454 kg ha^{-1} yr^{-1}) was almost double than produced under natural forest canopy (205 kg ha^{-1} yr^{-1}). This system has the potential to generate net income of INR 80,000–90,000 (US$ 2192) per ha per annum. *Albizia chinensis*, *A. lebbeck*, *A. procera*, *Anogeissus acuminata*, *Bauhinia variegata*, *Ficus* spp., *Gmelina arborea*, *Kydia calycina*, *Mesua ferrea*, *Moringa oleifera*, *Parkia roxburghii*, *Pinus kesia*, *Quercus* spp., *Schima wallichii*, *Bambusa* spp., *Dendrocalamus* spp., *Artocarpus heterophyllus*, *Michelia oblonga*, *Parkia roxburghii*, *Prunus cerasoides*, and *Symingtonia populnea* are other commonly cultivated multipurpose trees in these regions. Mango (*Mangifera indica*), guava (*Psidium guajava*), mandarin (*Citrus* spp.), and banana (*Musa paradisiaca*) are common fruit trees. Turmeric (*Curcuma domestica*), ginger (*Zingiber officinale*), taro (*Colocasia esculenta*), pineapple (*Ananas comosus*), groundnut (*Arachis hypogaea*), soya bean (*Glycine max*), and vegetables are common intercrops grown with fruit trees and multipurpose trees (for more details, see Singh et al. 2014).

4.1.6 Scattered Multipurpose 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. Though the worldwide list of such trees is long, some of them have received more attention compared to others, for example, *Prosopis cineraria* in northwestern India and *Faidherbia albida* in West Africa. In arid regions, this is the most prevalent system particularly on grazing lands. Tewari et al. (2014) gave a comprehensive account for hot desert ecology. The species diversity in these systems is very much related to ecological conditions. With the increase in rainfall, the species diversity and system complexity increases. Thus, we find a proliferation of more diverse multistoreyed homegardens in the humid areas and less diverse, two-tiered canopy of configurations (trees + crop) in drier areas. Pathak and Dagar (2000) compared prevalent agroforestry systems in various ecological zones and found that the number of plant species per unit area, canopy layers, and the animal species dependent upon them show greater richness in tropical ecological zones than in arid or subtropical zones.

In China, during dynasty rule (206 BC–AD 220) raising of forests was recommended along with livestock and crops as per different site conditions. Utilization of competitive habit of fast-growing species for tree production is very old in China. For example, Chinese Scholar tree (*Sophora japonica*) and *Broussonetia papyrifera* raised with sun hemp (*Crotalaria juncea*) and soybean (*Glycine max*) with Chinese chestnut (*Castanea* sp.) are described in sixth-century Chinese books (Xiuling 1995). Ancient agriculture books in China (sixth-century literature) also insisted that tea (*Thea chinensis*) must be sown under mulberry (*Morus alba*) or bamboo because it was afraid of direct light. Similarly, mulberry may be interplanted with several crops. Proso millet (*Panicum miliaceum*) grown under mulberry could promote the growth of both species, but foxtail millet (*Setaria italica*) will have negative effect on mulberry and promoted growth of harmful insects. Sorghum was not desired because it grew to same height as mulberry, resulting in each shading the other from the sun. Other trees such as *Sapium setigerum* could not be utilized for interplanting because of their serious shading characters.

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*, *Syzygium jambos*, *S. cumini*, *Morus alba*, and *Mangifera indica* in Indo-Gangetic plains; *Grewia optiva*, *Quercas* spp., and other tree species in the Himachal Pradesh; *Ficus benghalensis* in Karnataka; *Acacia leucophloea* and *Tamarindus indica* in Tamil Nadu and Andhra Pradesh; *Eucalyptus globulus* in the southern hills of Tamil Nadu; and *Borassus flabellifer* in peninsular coastal regions on fields along with crops is very common (Dhanya et al. 2014; Dagar et al. 2014a; Dagar and Tewari 2016b). These, along with many others, are also common on pasture lands and their leaves are also harvested for animal fodder. Kessler (1992) reported that approximately 20 different tree species are common in the parklands (savannas) in the Sahelian and Sudanian zones of Africa. Nair and Dagar (1991) and Dagar et al. (2014b) 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 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 phosphorus, total potassium, available phosphorus, and potassium and micronutrients (Zn, Mn, Cu, and Fe) and slightly lower pH and electrical conductivity than the soil under field conditions without trees (Aggarwal 1980; Shankarnarayan et al. 1987; Tewari and Singh 2006). Similarly, *Ziziphus nummularia* is preferred and is a favorite bush in Rajasthan. Studies have shown that in hilly areas the yields of wheat and paddy decreased consistently when *Grewia optiva*, *Morus alba*, and *Eucalyptus tereticornis* were grown over a period of 13 years, and growing of crops alone was found more economical (Khybri et al. 1992). But the variety of products obtained was more when trees were grown with crops. More details are given by Kashyap et al. (2014).

However, in the foot hills of Shivaliks, Grewal (1992) reported that growing Bhabar grass (*Eulaliopsis binata*) with *Eucalyptus* and *Acacia catechu* is highly economical. Farmers retain trees of *Acacia nilotica*, *A. catechu*, *Azadirachta indica*, *Butea monosperma*, *Dalbergia sissoo*, *Mangifera indica*, and *Ziziphus mauritiana.* Trees such as *Gmelina arborea* and *Salvadora persica* are preferred in Gujarat with crops. Farmers in subhumid *terai* region of Indo-Gangetic plains prefer *Dalbergia sissoo*, *Psidium guajava*, *Mangifera indica*, *Morus alba*, *Syzyzium cumini*, and *Grewia nudiflora*. In Bihar, *D. sissoo*, *D. latifolia*, *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. Every part of the palm is used by common man. The leaves for thatching, trunk as pillar or timber, fruits are consumed roasted and the radicles of germinating seeds are eaten roasted, and a beverage (alcohol) is extracted from the spadix which is also used to prepare jaggery and vinegar. Other most common trees found on farmers' fields are *Azadirachta indica*, *Moringa oleifera*, *Tamarindus indica*, *Ceiba pentandra*, *Anacardium occidentale*, *Cocos nucifera* palm, and fruits like banana, custard apple, guava, and pomegranate.

In Nepal, growing fodder trees on the terrace risers is very common. This provides fodder to the animals while protecting the farmland from terrace failure (Joshy 1997). The bamboo is also planted for erosion control and people use the bamboo poles as wall to project terraced rice fields. In some places they also use *Alnus nepalensis* and quick-growing species, and forest litter is collected from the high hills and after partially decomposing. It is incorporated in the fields serving as compost.

The Quezungual system from western Honduras in North America is almost similar to indigenous system followed by small landholders. Most of the regenerating trees are retained and pollarded to a height of about 1.5 m. Farmers also retain tall trees such as *Cordia alliodora*, *Diphysa robinioides*, and various fruit trees such as *Byrsonima crassifolia*, *Mangifera indica*, *Persea americana* (advocado), *Carica papaya*, *Anacardium occidentale*, and *Psidium guajava* along with annual crops such as maize (*Zea mays*), sorghum (*Sorghum bicolor*), and beans (*Phaseolus vulgaris*). Some of these fruit trees are planted and an optimum shade is assured (Hellin et al. 1999). In African countries like Kenya, there is fairly good awareness about agroforestry, and people retain trees like *Faidherbia albida*, *Cordia africana*, *Dombeya goatzinii*, *Grevillea robusta*, and *Commiphora zimmermannii.*

Undoubtedly, the multipurpose trees, whether on farms or on pasture lands, are the most important component of all agroforestry systems, but very little efforts have been made to improve these for higher production.

4.1.7 Trees on Farm Boundaries

Trees that are grown in agricultural fields or on field bunds are also often and usually grown on farm boundaries. This is almost common throughout the world. The difference lies only in composition of species and the purpose. Most of the time, these are local species and used as live fences. 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*, *Morus alba*, *Syzygium cumini*, *S. jambos*, and *Azadirachta indica*. Farmers of Sikkim grow bamboo (*Dendrocalamus*) all along irrigation channels. In coastal areas of Andhra Pradesh, *Borassus* is most frequent palm. In coastal and island regions, farmers grow *Gliricidia sepium*, *Jatropha* curcas, *Ficus* sp., *Ceiba pentandra*, *Vitex trifoliata*, *V. negundo*, and *Erythrina indica* as live hedges. At many places succulents like *Agave* and many cactoids are grown as common live fence.

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 auriculiformis* are extensively planted on field bunds and along sandy coastal areas in Orissa. Pathak et al. (2014) and Korwar et al. (2014) have also dealt in detail the plantations on bunds for rainfed areas and Indo-Gangetic plains of India.

4.1.8 Woodlots

In many parts of the world, farmers grow trees in separate block as woodlot along with agricultural fields. This 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 district and *Eucalyptus* and *Populus* for WIMCO industries in India. The woodlots are being raised mostly on large farms due to the increase of labor costs and labor management, lack of irrigation, and risk of crop investments. Woodlots of casuarina, bamboo, poplar (*Populus deltoides*), eucalyptus, red sanders (*Pterocarpus santalinus*), *Dalbergia sissoo*, etc. have become popular in many parts of India. While comparing traditional indigenous trees on the farmland with commercial *Eucalyptus* plantation, Shiva et al. (1985) observed that the traditional trees had a multiplier effect in all the activities of household promoting rural industries and employment while the *Eucalyptus* had limited scope.

In Europe also, woodlots of forest tree species and tree intercropping and forest farming with ginseng (*Panax quinquefolius*) and other cash crops, riparian woody buffers, and collection of non-timber forest products are traditional practices particularly in Canada (Thevathasan et al. 2012).

4.1.9 Shelter Belts

Arid regions witness very high wind velocity throughout the year, and sand can initiate movement of particles even at 12–14 km hr^{-1} wind velocity. Farmers build kinds 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 psuedotomentosa* are planted in 20–25 m apart in rows across the wind direction. Between the lines of these shrubs, grasses, viz., *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. Due to overexploitation for multiple uses, shrubs such as *Phog* (*Calligonum polygonoides*) once predominant on sand dunes have become endangered. *Balsamodendron berryi* is a traditional silvopasture protecting live hedge, particularly in dry regions of Andhra Pradesh. Other common hedge species include *Gliricidia sepium*, *Jatropha curcas*, *J. gossypifolium*, *Lantana camara*, *Agave sisalana*, *Prosopis juliflora*, *Balanites roxburghii*, *Pithecellobium dulce*, *Parkinsonia aculeata*, *Lawsonia inermis*, *Carissa carandas*, *Vitex negundo*, *V. trifoliata*, and many cactoides. *Hippophae rhamnoides*, earlier considered to be brush wood and has emerged as commercial crop because of its fruits, is very common boundary plantation in cold desert area in Leh.

In Europe hedgerows and windbreaks are important traditional systems particularly in the Atlantic region and Central Europe. The primary role of windbreaks is prevention of wind erosion, but also they offer shade for grazing animals, maintain a uniform snow cover, and provide fuel wood. The lumber hedgerows provide live fences to prevent animals from mixing with neighboring herds.

4.1.10 Trees on Rangelands

In Europe wood pastures are reported to be practiced from Neolithic times (6000 BP) and can be found all over Europe. In this system, cattle are allowed to graze in the forest. Some systems, e.g., Dehesa (in Spain) and Montado (in Portugal), are very old grazing-based systems (4500 years old) found in the Mediterranean zone, characterized by the presence of savannah-like open tree layer, mainly dominated by evergreen oaks and grasses. Traditional systems were highly diversified in terms of livestock types (sheep, goats, pigs, cattle, horse). Pollarding and *pannage* practices are also common in Central Europe, where branches from trees are cut to provide leaf fodder for livestock and produce wood for fuel. Pannage is the specific name for pig grazing in beech (*Fagus* spp.) and oak (*Quercus* spp.) woodlands (Nerlich et al. 2013). In many Europian countries, various temperate fruit-and-nut trees such as apple, plum, pear, peaches, walnut, almond, sweet chestnut, and figs are dispersed on meadows and pastures in irregular pattern (Herzog 1998). These stands are common refuge for small mammals, nesting for birds, apiculture, and pleasant landscapes. The Chania system of Greece and other parts of southeastern Europe is a traditional widespread practice since first millennium BC and popular even now. Cereals are intercropped with fruit trees, olives, sweet chestnut, and walnut and are also grown on pastures involving cattle and goats. Leaf and twigs cut from trees and hay from intercropped cereals help livestock survive during winter (Papanastasis et al. 2009). The systems are a part of traditional way of life and rich cultural history.

In dry regions of Indian subcontinent, tree species such as *Salvadora oleoides*, *S. persica*, *Capparis decidua*, *Acacia nilotica*, *A. senegal*, *A. leucophloea*, *Prosopis cineraria*, *Ziziphus nummularia*, *Balanites roxburghii*, *Dichrostachys cinerea*, and now *Prosopis juliflora* are most frequent on community grazing lands. Invasion of *P. juliflora* suppresses other species on grazing lands. In coastal areas, coconut is the most common tree on pasture lands. Cattle raising usually involve grazing on these pastures. In some areas, special fodder plant species particularly legumes, are cultivated. The research results in Sri Lanka have indicated that, as with the case of intercropping, the pasture will not diminish the yield of palm if fertilizers are applied to both (c.f. Nair 1993). An organized form of this natural vegetation as silvopasture assures 10 Mg ha^{-1} yr^{-1} biomass production (as against 1 Mg ha^{-1} yr^{-1} from natural stands) at 10-year rotation in dry zones besides assuring soil conservation, healthy environment, and employment generation (Pathak et al. 1995). While explaining the nature of grassland dynamics and their management, Dagar and Pathak (2005) and Pathak and Dagar (2015) have cited several examples of trees playing crucial role in management of grazing lands. Based on long-term studies, Rai (2012) has reported the role of *Ailanthus excelsa*, *Acacia tortilis*, *Hardwickia binata*, and *Leucaena leucocephala*-based silvopastoral systems for livestock production in detail.

In Austalia, pastures are one of many means of obtaining productive use and rehabilitation of waterlogged saline soils. These pastures include salt-tolerant fodder shrubs (species of *Atriplex*, *Halosarcia*, and *Maireana*), perennial grasses (*Puccinellia ciliata*, *Thinopyrum ponticum*, *Distichlis spicata*, *Paspalum vaginatum*, *Sporobolus virginicus*, *Pennisetum clandestinum*, *Chloris gayana*, etc.) and some annual species. Barrett-Lennard (2003) gave extensive account of pasture lands in Australia. Some of the most useful species for Australian salt-affected soils were introduced from overseas and performed well, and those include *Puccinellia ciliata* and *Thinopyrum ponticum* (tall wheatgrass) from Turkey, *Atriplex undulata* (wavy leaf saltbush from Argentina, and *Atriplex lentiformis* (quail bush) and *Distichlis spicata* from the United States. Somarriba (1992) explained "protein bank" concept as a form of silvopastoral practice in which trees and shrubs (mostly leguminous fodders) are planted in and around the farmland and rangelands. Usually the foliage of these trees is cut-and-carried for feeding animals kept in control conditions or sometimes animals are fed on these on regular intervals. Often these species (e.g., *Prosopis cineraria*, *Acacia nilotica*, *Feronia limonia*, *Ziziphus nummularia*, *Balanites roxburghii*, *Leucaena leucocephala*, etc.) are highly nutritive and sprout easily. There are conclusive evidences to suggest that improved silvopastoral systems with suitable tree species and their management practices such as lopping, fertilizer applications, germplasm improvement, introduction of legumes, etc. has a lot of scope to improve the productivity of existing pasture lands. There is also great potential to utilize sylvopastoral systems in drylands to solve problems like global warming (through increased carbon sequestration) and for biodiversity conservation (Soni et al. 2016). The value-added products from silvopastoral systems, particularly from animal component, have ample scope to improve the livelihood of farmers in dry region. Recently, Peri et al. (2016) have compiled a comprehensive account of silvopastoral systems in southern South America.

4.1.11 Other Systems

Throughout the coastal regions aqua-forestry is quite common, where farmers are cultivating fish and prawn in saline water along rice and also in ponds. They grow coconut and other trees on bunds of ponds. These trees help in producing litter to feed fishery and generating extra income to the farmer. Now fish culture in association of mangroves is also advocated which are rich sources of nutrition to the aquatic life and breeding ground for juvenile fish, prawn, and muscles (Dagar 1995; Dagar et al. 2014a). Backyard poultry is another adventure in many coastal regions. A well-balanced system of animal husbandry including goats, cattle (sometimes rabbit), poultry, ducks, turtles, and fish in the small ponds in homegardens makes 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 oleifera* have been found to serve as fish - feed when offered as pallets and improved the productivity of fishpond. In many parts of India, farmers are raising forest and fruit trees on the dykes of fishponds on their farms and are generating good income.

5 Agroforestry Research Developments During Last Three Decades: Agroforestry Coming of Age as Science

During last three decades, agroforestry research has come of an age. The results of a survey by ICRAF revealed that almost half of all farmed land in the world has more than 10% tree cover, thus, a nearly one billion hectares of agricultural landscapes now have trees on them (Garrity 2012). In some regions, such as Southeast Asia and Central America, tree cover on farms exceeds 30%. Forest transitions are now occurring in a large number of countries in both the tropical and temperate zones. During the 1990s, thanks to agroforestry, about 38% of the countries experienced increase in forest cover, particularly in Europe, North America, and East and South Asia. Many traditional and indigenous systems have been improved through research inputs and techniques have been developed to handle the problematic areas. For example, many improved short fallows, improved pastures, and modern homegardens have been developed inculcating the indigenous knowledge while developing present-day technologies. Farmers are gaining good economic returns from improved homegardens as well as improved fallows and pastures.

As discussed earlier, "improved short fallows" of African countries such as Eastern Zambia, Zimbabwe, South Cameroon, and Ghana; woodlots of Tanzania and many European countries; enrichment of traditional cultivation of Eastern Amazonia; integrated farming systems involving trees, fruits, crops, fishery, livestock, poultary, apiculture, and mashroom culture (all or a few components) on the same unit of land in India; site-specific problem-solving agroforestry systems; and alley cropping systems across the world are the examples of progress made in agroforestry research during the past three decades. Tree planting techniques have been developed for afforestation of highly alkali soils and waterlogged saline soils. Watershed-based agroforestry systems have been developed to check soil erosion and increase crop productivity. Sand dunes have been stabilized in many arid regions using appropriate technologies. Agroforestry is being extended as a tool for solving many environmental and social problems even in the developed countries. Results of some of the recent research (during last three decades) efforts have been summarized below.

5.1 Evaluation of Multipurpose Trees and Development of Improved Agroforestry Systems

In early stages of agroforestry research, one of the major agendas was to collect, identify, and evaluate multipurpose tree species (MPTs) for their suitability in an ecological zone. Major emphasis had been on nitrogen-fixing tree species. A few genera such as *Acacia*, *Calliandra*, *Casuarina*, *Gliricidia*, *Leucaena*, *Prosopis*, and *Sesbania* figured prominently in tropical agroforestry systems. The collection and evaluation of MPTs resulted in establishment of arboretum in many agroforestry centers across the world. For example, a collection of 184 species was made followed by identification of priority tree species of agroforestry research for various agroclimatic conditions by different agroforestry centers working under the All India Coordinated Research Project (AICRP) of Agroforestry in India, and ICRAF also facilitated the distribution of germplasm of improved species in different agroecological regions across the world (www. nrcaf.org; www.icraf.org). Provinance trials of at least two species identified by each AICRP situated in a specified agroclimatic zone were conducted after collecting germplasm from different locations in the country. A significant contribution of the project was on tree selection and improvement of species of different genera such as *Acacia*, *Ailanthus*, *Azadirachta*, *Casuarina*, *Dalbergia*, *Eucalyptus*, *Leucaena*, *Mangium*, *Melia*, *Moringa*, *Pongamia*, *Prosopis*, and *Ziziphus*. Some nongovernmental organizations (NGOs) have also contributed to a greater extant for developing fast-growing clones of *Eucalyptus*, *Casuarina*, *Dalbergia*, and *Melia* which has brought a sea change in adaptability of agroforestry in the country. The implementation projects are in operation, for example, in Haryana clonal *Eucalyptus* has been planted either on acre-line as boundary plantation of agricultural fields or in farm forestry mode, planting trees in wider spaces to adjust about one thousand plants per ha and growing arable crops as intercrops in waterlogged areas to bring down the water table and improve the land for cultivation (Dagar et al. 2016a). This has not only helped farmers to reclaim waterlogged land but has also increased the income of the farmers and sequestered carbon.

Under National Agricultural Technology Project, an "Agroforestry BASE" online database has been developed which is being updated periodically by Central Agroforestry Research Institute (CAFRI), Jhansi, India. Agronomic practices such as planting methods, irrigation methods, composition and fertilization, and spacing and pruning schedules for raising some of the promising MPTs in association with annual crops have been developed and standardized. Crops and cropping sequences which can be grown successfully (without significant reduction in yield through agronomic manipulations and tree canopy management practices) in association with forest and fruit trees have been identified.

Many agroforestry systems are addressed by the major constitute species. For example, *Morus alba* and *Grewia optiva*-based agroforestry systems for western Himalayas, Alder (*Alnus nepalensis*)-based system for northeastern Hill region, *Eucalyptus tereticornis* (mostly clonal) and *Populus deltoides*-based systems for Indo-Gangetic region, Aonla (*Emblica officinalis*) and Khejri (*Prosopis cineraria*)-based systems for semiarid and arid regions, Teak (*Tectona grandis*)-based system for tropical region, and *Gmelina arborea* and *Acacia leucophloea*-based systems for humid and subhumid regions have been developed. The AICRP on agroforestry initiated systematic work on biofuel research with major emphasis on *Jatropha* and *Pongamia*. *Simarouba glauca* has also recently come in limelight.

A network project on bamboo-based agroforestry systems has also been initiated at six centers. Keeping in view the present-day challenges, the project is now focusing on the role of agroforestry in meeting the environmental challenges, value addition for creating livelihood opportunities, and application of modern tools and technologies in agroforestry research. A distinct feature of agroforestry land use system is to utilize woody perennials (including fruit trees and palms) for production as well as conservation. Atul et al. (1994), Tomar et al. (2012), and Kashyap et al. (2014) have reported the production potential of traditional agroforestry system in mid-hills of Himachal Himalayas, Pathak et al. (2014) in Indo-Gangetic plains, Tewari et al. (1998) and Tewari and Singh (2000) in hot arid regions of Rajasthan, Korwar et al. (2014) and Tewari et al. (2014) in rainfed dry areas, and Dagar et al. (2014a) in coastal humid regions. The prevalent systems and their species components have been compiled by many workers (Pathak and Dagar 2000; Dagar et al. 2014b; Dagar and Minhas 2016; Dagar and Tewari 2016a).

5.2 Temperate Agroforestry Systems

In Europe and the United States, agroforestry has been practiced since ancient times, but science-based agroforestry research gained attention only recently. The realization that agroforestry systems are well suited for diversifying farm income while providing environmental services and ecosystem benefits has increased receptivity on the part of some landowners in these regions. Jose et al. (2012) have found that agroforestry systems in the United States offer great promise to produce biomass for biofuel, specialty in organic crops, and pasture-based dairy and beef and also offer proven strategies for carbon sequestration and climate mitigation, soil enrichment, biodiversity conservation, and air and water quality improvement. The USDA Agroforestry Strategy Framework released in 2011, identified agroforestry as an important component of a much-needed national strategy to enhance agricultural landscapes, watersheds, and rural communities. The five categories of agroforestry practices in temperate regions especially in the United States and Europe include riparian and upland buffers (ameliorate nonpoint source pollution, abate soil erosion and nutrient loading, protect watersheds), wind breaks, alley cropping, silvopasture, improved fallows, and forest farming. Marginal floodplain land is considered ideal for biomass production using agroforestry model. Such lands could be placed into an alley cropping or in riparian buffer system that would integrate rows of short rotation, high-yielding woody crops such as willow (*Salix* spp.), and poplar (*Populus* spp.) with alleys of perennial grasses (Jose et al. 2012).

Based on their analysis, Udawatta and Jose (2011) concluded that silvopastoral systems, the most common practice in North America, had the greatest potential to sequester C in the United States. Using a sequestration potential of 6.1 Mg ha^{-1} year^{-1} on 10% marginal land (23.7 million ha) and 54 million ha of forests, they estimated total C sequestration potential for silvopastoral land in the United States as 474 Tg C year^{-1}; and alley cropping (practiced on 10% of 179 million ha cropland) could sequester 60.9 Tg C year^{-1}.

In Canada, the riparian buffer systems are promoted for the Atlantic region; tree-based intercropping and windbreak systems in Quebec, Ontario, and the Prairies; and silvopastoral system in British Columbia. Additionally, windbreaks have a special value in blueberry (*Vaccinium corymbosum*) production system. At the St-Edouard site, N_2O emissions were found to be three times higher in monocropped plots as compared to agroforestry plots (Beaudette et al. 2010) showing the potential of agroforestry in mitigating greenhouse gas emissions. A variety of individual enterprises and community initiatives incorporate forest farming elements into their business models in Canada. Developing cottage industries focused on paper birch (*Betula papyrifera*) and big-leaf maple (*Acer macrophyllum*) tapping, harvesting sap from the tree to make birch or maple syrup, is an ideal example.

Though traditional agroforestry systems in Europe are age-old, the current practices are based on a relatively narrow range of dominant tree species. Most of them are broad-leaved (74%) and are found in Mediterranean environments in silvopastoral systems; actually oaks (*Quercus*) are the predominant tree species. For example, in Spain, *Q. ilex* and *Q. suber*; in Greece, *Q. humilis*, *Q. frainetto*, *Q. coccifera*, and *Q. trojana*; and in Italy, *Q. cerris*, *Q. humilis*, and *Q. suber* are commonly found species. The coniferous species (*Pinus nigra*, *P. sylvestris*, *Juniperus communis*, *J. sabina*, *Abies cephalonica*) are found on high altitudes (Mosquera-Losada et al. 2012). By contrast, reindeer husbandry systems based on forest understorey resources in Finland, Norway, and Sweden extend to 33–40% of total area of these countries (Jernsletten and Klokov 2002). *Pinus sylvestris* occurs in most of the agroforestry systems in these regions. Papanastasis et al. (2009) described 40 prominent on agricultural and pastoral systems in Greece. Most common systems consist prominent tree species such as walnut (*Juglans regia*), almond (*Prunus dulcis*), mulberry (*Morus alba*), populus (*Populus nigra*), olive (*Olea europaea*), carob (*Ceratonia siliqua*), and fig (*Ficus carica*) associated with crops such as maize (*Zea mays*) and other cereals, vegetables, vines, forage crops mainly lucerne (*Medicago sativa*), and tobacco (*Nicotiana tabacum*). Those systems which involve cereals become agrisilvopastoral as animals graze on stubble after grain harvest. Parkland systems are also valued for their landscape, biodiversity, and cultural value. In modern agroforestry, fruit orchards and value-added wood products, and high-value mushroom (truffles) and medicinal and aromatic plants particularly cultivated in forests, are given due wattage.

Agroforestry in northwestern temperate Himalayan regions of India is a composite, diversified, and sustainable land use. Many traditional systems such as homesteads (*kyaroo*), plantation crop combinations, bamboo groves, and fruit-based silvopastoral systems are prevalent. Recently, sea buckthorn (*Hippophae rhamnoides*) system has gained importance because of multiple uses of the bush such as making fruit juices of commercial importance, medicinal value, and environmental benefits such as desert control and its adaptability to degraded habitats in cold regions. Based on research and experiences of farmers, many remunerative systems involving fruit and fodder trees, crops, and forages have been developed for different hill zones. In low hill regions *Kinnow* (*Citrus nobilis* × *C. deliciosa*)- or mango (*Mangifera indica*)-based cropping systems; *Populus deltoides* and *Eucalyptus*-based agri-silvicultural systems with commercial crops like zinger (*Zingiber officinale*) or turmeric (*Curcuma domestica*); multipurpose (mainly fodder) trees on *ghasnies* (pasture lands) on sloping lands with sufficient constituent of legume fodders; and sometimes block plantations are followed. Unlike traditional systems, farmers generate additional income from commercial products. Nowadays, medicinal and aromatic plants under high density peach plantations or poplar plantations on mid-hill zone form quite remunerative system. On high hill temperate zone, apple (*Malus pumila*)-based cropping systems (mainly vegetables, mustard, beans) not only offer diversification in different growing seasons but also help in generating high income without affecting the fruit yield of the orchard. In Kashmir Valley, forest and fruit tree-based pastoral models involving apple, almond (*Prunus amygdalus*), cherry (*P. avium*), and other nut trees; *Ulmus wallichiana* tree in alleys across slope; aromatic and medicinal plants including high-value *Salvia sclarea* (commercial aromatic herb producing linalool and linalyl acetate, main constituent of aromatic oil used in perfumery); temperate forage grasses; and legumes integrated with animals have been developed. Though recently enough research inputs have been added but still many of these systems need to be further improved with suitable technological interventions. In recent times, due to rise in average temperature, the apple belt has shifted toward higher altitudes increasing the total area under the apple. Impact of climate change on various agroforestyry systems including livestock behavior needs to develop new research programs. Recently, Kashyap et al. (2014) and Verma et al. (2016) have given extensive account of different agroforestry systems in northwestern Himalaya region and Tewari et al. (2016) for cold desert in Leh region.

Temperate agroforestry systems generally result in greater nutrient cycling than pure agricultural crops because the leached nutrients from the crop rhizosphere can be captured by the deeper roots of trees once the crops are not able to take them up due to excess of inputs or the lack of crop growth hence shallow roots (Lehmann 2001; Bambo et al. 2009). In turn, these nutrients are made available to crops through litter fall. Moreno et al. (2007) described how nitrogen, phosphorus, and other nutrients were increased near the trees in a Dehesa system. The importance of this better nutrient use and recycling is clear, and nutrients are not lost from the system which helps in checking contamination of watercourses. Nitrogen leaching in waterbodies can cause eutrophication problems in rivers and other water sources; therefore, agroforestry helps in reducing nitrogen leaching and contamination of underground water.

5.3 Systems for Environmental Benefits

The underlying concept of various ecosystem services of all agroforestry systems is the beneficial role of on-farm and off-farm tree production in providing numerous advantages and services besides livelihood products such as food, fodder, timber, fuel wood, fiber, medicine, etc. These services may include rehabilitation and improvement of degraded lands, biodiversity conservation, improvement of landscapes in urban and peri-urban areas, recreation, and general improvement in environment. All the life-supporting ecosystem functions provided by agroforestry systems including nutrient cycling, water quality enhancement, pollution control, and below- and aboveground biodiversity protection can be expected to be operational. Agroforestry systems provide sustainability and stability to agricultural production system. Now, the scientists, administrators, policy makers, and politicians are convinced that agroforestry systems not only provide livelihood sustainability but also can be used to solve the problems of modern world including mitigating climate change. Some of these ecological services are explained in brief here in this chapter.

5.3.1 Agroforestry Potentials for Rehabilitation of Degraded Lands

Indeed, no clear consensus exists as to the extent of degraded land, not only globally, but even within a particular country. Recently, Gibbs and Salmon (2015) have reviewed prominent databases and methodologies used to estimate the area of degraded lands and expressed that the global estimates of total degraded area vary from less than one billion ha to over six billion ha, with equally wide disagreement in their special distribution. The Global Assessment of Soil Degradation (GLASOD) commissioned by the United Nations Environment Program (UNEP) was the first attempt to map human-induced degradation around the world (Oldeman et al. 1990; Oldeman 1994) and is still used today (Nijsen et al. 2012). According to GACGC (1994), the main types of soil degradation are water erosion (56%), wind erosion (28%), chemical degradation (12%), and physical degradation (4%); and causes of soil degradation include overgrazing (35%), deforestation (30%), agricultural activities (27%), overexploitation of vegetation (7%), and industrial activities (1%).

It has been estimated that 580 million ha (Mha) area is degraded due to deforestation, 680 Mha due to overgrazing, 137 Mha due to fuel wood consumption, 550 Mha due to agricultural mismanagement, and 19.5 Mha due to industry and urbanization (FAO 1996). By 2008, more than 20% of all cultivated areas, 30% of natural forests, and 25% of grasslands were undergoing some degree of degradation (Bai et al. 2008). It has been estimated that up to 25% of all land is currently highly degraded, 36% is slightly or moderately degraded but in stable condition, while only 10% is improving (FAO 2011). If the current scenario of land degradation continues over the next 25 years, it may reduce global food production, from what it otherwise would be, by as much as 12% resulting in world food prices as much as 30% higher for some commodities (IFPRI 2012). This is at a time when population growth, rising incomes, and changing consumption patterns are expected to increase the demand for food, energy, and water, by at least 50%, 45%, and 30%, respectively, by 2030 (IFPRI 2012). These expected levels of global demand cannot be met sustainably unless we protect and restore the fertility of our soil and rehabilitate our degraded lands preferably following agroforestry techniques (Dagar 2012, 2015; Dagar and Gupta 2016). Agroforestry approach is viable, sustainable, and environment friendly.

5.3.1.1 Agroforestry on Eroded Lands

Soil erosion has socioeconomic, environmental, and technical dimensions. Those who suffer the most are poor farmers and landless laborers, who are least able to adopt conventional measures for its control. A more beneficial alternative in eroded ecologies both high rainfall and semiarid regions, from an ecosystem perspective, is to create a multifunctional land use system. For example, native trees can be planted together with shade-tolerant agricultural cash crops such as coffee, cocoa, cardamom, zinger or turmeric, or medicinal plants. Plantation crops like coconut are blended suitably with spices such as clove, cardamom, black pepper, and even fruits like pineapple. The sloping lands are planted with alley crops such as *Gliricidia sepium*, *Leucaena leucocephala*, *Cassia siamea*, *Morus alba*, *Pithecellobium dulce*, and *Cajanus cajan* and fodder grasses as intercrops. In Sri Lanka, where 32% of the land is degraded and forest cover is declined rapidly to 21% (in 1997), the government has focused on promoting tree planting and intensification of homegardens aiming to ease pressure on forests; 13% of the country's land is devoted to homegardens. Sri Lankan homegardens are highly biodiverse, multilayered structures, with a canopy of tall trees intercepted with small trees and plantations and shrubs and planted with crops underneath. The national tree planting program "Deyata Sevana" and more recently "Divi Neguma" (livelihood development) aimed to add 1.5 million homegardens to help achieve self-sufficiency in vegetables and reduce vegetable prices; and the target later increased to 2.5 million homegardens and the program included in national climate change and mitigation and adaptation strategies, as well as in the REDD+ reforestation and land restoration program (http://www.gwp.org). Similarly, in Vietnam, farm forestry is included as ambitious reforestation policy including reforestation of five million ha (2 million ha by individual entities such as households and entrepreneurs). Millions of hectares around the world are now covered with agroforestry systems including, for example, 2.8 million ha of rubber forest in Indonesia; 7.8 million ha of cocoa agroforestry worldwide; 9.2 million ha of silvopastoral systems in Central America; and 5.1 million ha (90% of country's agricultural land) of diverse agroforestry systems (IIASTD 2009). Multilayered plantation-based agroforestry systems, improved homegardens, alley cropping on sloping land, tree-based fodder banks, fodder cultivation beneath coconut plantations, integrated farming systems, mangrove-based aquaculture, farming in forests, and nitrogen-fixing and other multipurpose trees on farm boundaries are some interesting agroforestry systems found suitable for coastal and island situations, which will not only restore these ecosystems and sustain livelihood and nutrition security but also will render ecological services such as biodiversity improvement, carbon sequestration, and mitigate climate change (Dagar et al. 2014a). Sajjapongse et al. (2002) developed a sustainable alley cropping model on sloping lands in China by planting daylily (*Hemerocallis* sp.), pears (*Pyrus* spp.), and Chinese prickly ash (*Zanthoxylum* spp.) as hedgerow crops and corn, soybean, and sweet potato as alley crops in interspaces, whereas K application was emphasized in the balanced fertilizer treatments. They obtained 115% higher corn yield as compared to farmers' practice, and soil loss was greatly reduced by alley cropping, ranging from 60 to 80%.

In arid and semiarid regions all along the rivers and their tributaries, the soil is mostly alluvial and prone to soil erosion, and a net of gullies and deep ravines is formed. The phenomenon is more common along Indian rivers where about four million ha fall under ravines. Rehabilitation of ravine lands involves treatment of table and marginal lands (contributing runoff to the gullies) on watershed basis. It requires an integrated approach of using gullies according to land capability classes, soil, and water conservation measures and putting land under permanent vegetation cover involving afforestation or agroforestry, horticulture, pasture, and energy plantations (Chaturvedi et al. 2014). Protection from grazing and afforestation with suitable species are found the most effective measures for checking soil erosion and consequently ravine formation.

Protection from grazing and afforestation with native tree and grass species is the most effective measure for checking soil erosion and consequently ravine formation. Woody species found growing in eroded habitats may find priority in afforestation program. For example, *Acacia nilotica*, *A. eburnea*, *A. leucophloea*, *A. catechu*, *Azadirachta indica*, *Albizia lebbeck*, *Balanites roxburghii*, *Butea monosperma*, *Dalbergia sissoo*, *Dendrocalamus strictus*, *Dichrostachys cinerea*, *Eucalyptus* spp., *Feronia limonia*, *Pongamia pinnata*, *Prosopis juliflora*, and *Ziziphus mauritiana* have been found to adapt easily in the ravines of river Yamuna at Agra and Kshipra at Ujjain. Among grasses *Dichanthium annulatum*, *Cenchrus ciliaris*, *Bothriochloa pertusa*, *Chrysopogon fulvus*, *Themeda triandra*, *Heteropogon contortus*, *Sehima nervosum*, *Tragus biflorus*, *Iseilema laxum*, *Cynodon dactylon*, and *Saccharum munja* flourish well in ravine lands. After protecting from grazing, silvopastoral system involving the above mentioned tree and grass species and introducing legumes such as *Stylosanthes*, *Alysicarpus*, etc. may be developed with great success. High-value medicinal species such as *Aloe vera*, *Ocimum americanum*, *O. sanctum*, *Withania somnifera*, *Adhatoda vasica*, *Barleria prionitis*, *Solanum xanthocarpum*, etc. and biofuels such as *Euphorbia antisyphilitica*, *Jatropha curcas*, and *Pongamia pinnata* (at the bottom of ravines) can easily be blended in these habitats.

Grass species such as Hybrid napier (*Pennisetum* × *purpureum*), *Panicum maximum*, *Chrysopogon fulvus*, *Vetiveria zizanioides*, and *Eulaliopsis binata* have been found suitable in the Shiwaliks and lower hills. Maize and wheat yield were found increased by 23–40% and 10–20%, respectively, when cultivated with grass barriers in addition to 0.6–1.7 Mg ha^{-1} yr^{-1} grass yield (Ghosh 2010). Hedgerows of trees such as *Leucaena* and *Gliricidia* are quite effective in controlling soil erosion when planted across slope. *Eucalyptus tereticornis* and Bhabar grass (*Eulaliopsis binata*) planted in Shiwaliks were found quite remunerative and effective against soil erosion (Sharda and Venkateswarlu 2007). Fruit trees such as citrus (*Citrus* spp.), mango (*Mangifera indica*), apple (*Malus pumila*), walnut (*Juglans regia*), plum (*Prunus domestica*), peach (*P. persica*), and cherry (*P. avium*) are cultivated using soil conservation practices and using mulch. Fruit trees are also grown on terrace risers in combination with vegetables. Integrated watershed management programs are being implemented in India on a massive scale since 1991, which is the most sustainable multipurpose strategy. A review of more than 300 integrated watershed management projects indicated that in majority of them total crop production increased by 50–123 percent (Joshi et al. 2005). Water harvesting technologies resulted in 50–156% increase in irrigated area under different schemes, which increased average cropping intensity by 64% (NAAS 2009). Apart from increasing agricultural productivity, these projects helped the stakeholders in generating employment, and about 47% of degraded lands have been treated for rehabilitation (Sharda et al. 2008). In remaining projects also agroforestry may be incorporated as main component particularly on highly degraded areas.

Dagar and Pathak (2005) and Pathak and Dagar (2015) while reporting the ecology and management of grazing lands in India advocated that in highly eroded habitats the first task must be protection of pasture lands from grazing followed by introduction of local trees (mainly nitrogen-fixing) and perennial grasses and legumes. Fodder banks may be established and as far as possible cut-and-carry practice must be followed or if necessary controlled grazing on regular intervals following the principle of carrying capacity should be followed. Ravenous catchments when planted with *A. nilotica* + *Dichanthium annulatum* and *D. annulatum* alone generated 5.8 and 2.6% of runoff and 1.26 and 0.62 Mg ha^{-1} of soil loss, respectively, compared to 14.7% of runoff and 3 Mg ha^{-1} of soil loss from agricultural catchments. Production of 4.5 Mg ha^{-1} air-dried grass + fire wood from such degraded lands proved the effectiveness of grasses and trees as an alternative land use for protection and productive utilization of degraded ravine lands (Sharda and Venkateswarlu 2007). Further, planting of grasses leads to improvement of soil structure and organic matter in these highly eroded habitats. Silvopastoral systems have been advocated most ideal for ravine lands and highly erodible soils (Prajapati et al. 1989; Dagar 1995, 2012, 2015; Chaturvedi et al. 2014; Dagar and Gupta 2016). Thus, suitable crop-tree-based agroforestry systems on farmers' fields and silvopastoral systems in ravine lands after protecting from grazing not only check soil erosion but also generate employment and income for different stakeholders including landless farmers residing near ravines. For details regarding ecology and rehabilitation of ravine lands, see recent publication by Dagar and Singh (2017).

5.3.1.2 Restoration of Degraded Areas Due to Shifting Cultivation

As stated earlier, shifting cultivation has become unsustainable primarily due to reduced *jhum* cycle owing to increase in population pressure resulting in serious soil erosion, depletion in soil fertility, and low productivity. As explained under improved fallows, technologies have been developed, particularly in African countries to improve the land fertility through introduction of leguminous short-duration shrubs in fallows. In Indian subcontinent, at times annual crops such as potato, rice, maize, and zinger are grown in monoculture or mixed culture along with trees like *Pinus kesiya* and *Alnus nepalensis*. Many workers (Borthakur 1992; Dhyani et al. 1996; Tripathy and Barik 2003; Tomar et al. 2012) suggested alternatives or improvements to shifting cultivation. Nair (1993) included about 44 species of perennial nitrogen-fixing woody species used in Asian farming systems which may help in improving the fallows. These include species of *Acacia*, *Albizia*, *Alnus*, *Cajanus*, *Calliandra*, *Casuarina*, *Erythrina*, *Faidherbia*, *Flemingia*, *Gliricidia*, *Leucaena*, *Parkinsonia*, *Pithecellobium*, *Pongamia*, *Prosopis*, *Robinia*, and *Sesbania*. Saha et al. (2007) reported positive effects of various multipurpose trees on physical properties of soil.

The intercropping between the fast-growing nitrogen-fixing trees during fallow phase is one of the alternative approaches to shifting cultivation. Integrated farming system approach involving fruit and forest trees, arable crops, livestock, fishery, and poultry with appropriate conservation measures for natural resources would be most effective in overall development of these areas. As the hilly region receives high rainfall, the role of trees on the terrains receives much importance and as so is the influence of agroforestry practices on soil and water resources (Singh et al. 2014). The issues which need to be settled include land tenureship, employment opportunities, skill development (e.g., basket making, cane furniture, processing of minor forest produce, honey collection, etc.), and awareness through education.

5.3.1.3 Agroforestry for Arid Ecologies

GLASSOD database indicates that at world level 349.6 million ha of land in arid zone are affected by light to moderate degree of soil degradation and 42.8 million ha by strong to extreme degradation (Dregne and Nan-Ting 1992; Oldeman 1994). Sand dunes are dominant land formation of principal hot arid zone (Africa accounts 46.1% followed by Asia 35.5%, rest 19.4% spread over in Australia and North America). The hot Indian arid zone (Thar Desert) is spread in 31.7 million ha. More than 34% (11 million ha) of the total area of Indian hot arid region is covered by drifting or semi-stabilized sand dunes, sometimes up to 100 m in height, however, their intensity varies from place to place (Tewari et al. 2014). The most important measures for sand dune stabilization are covering the area under trees and providing a surface cover of grasses followed by their protection against biotic interference. Besides fixing the sand dunes, it is important to check the movement of loose sand by applying windbreaks and mulch. Locally available brush woods like *Leptadenia pyrotechnica*, *Calligonum polygonoides* (now rare due to over-exploitation), *Ziziphus nummularia*, and *Aerva tomentosa* and grasses like *Cenchrus ciliaris*, *C. setigerus*, *Lasiurus sindicus*, *Panicum turgidum*, and *Saccharum munja* are being used frequently. The vegetation for sand dune stabilization is highly drought tolerant with deep root system capable of extracting moisture from lower soil depths. Trees such as *Acacia tortilis*, *A. jacquemontii*, *A. leucophloea*, *A. senegal*, *Azadirachta indica*, *Balanites roxburghii*, *Prosopis cineraria*, *P. juliflora*, and *Holoptelea integrifolia* in combination with grasses *Cenchrus ciliaris*, *C. setigerus*, *Dichanthium annulatum*, and *Panicum antidotale* have been found most successful for sand dune stabilization. Silvopastoral system is the most viable, sustainable, and profitable system. It will also assure intangible benefits such as amelioration of soil and climate, control of soil erosion, shelter to annual crops in vicinity, and protection to wild life.

Diversified production systems appear to be very sustainable for hot arid regions. Trees like *Prosopis cineraria*, *Z. nummularia*, *Z. mauritiana*, *Tecomella undulata*, *H. binata*, *Cassia siamea*, *Acacia tortilis*, *A. nilotica*, and many others play an important role in production system. Many of these act as shelterbelt for associated crops and also improve soil health. *P. cineraria* (as is *Faidherbia albida* in Africa) is well-known for its role in improving crop productivity as well as conservation and amelioration of soil. Tewari et al. (2014) observed increase in available nutrients in association with trees proving that trees improve the soil health in arid ecologies.

Arable crops such as Moth (*Vigna mungo*), green gram (*V. radiata*) and cluster bean (*Cyamopsis tetragonoloba*), taramira (*Eruca sativa*), and castor (*Ricinus communis*) could successfully be cultivated when there was some rain at the time of sowing. Species suitable for shelterbelts include *Acacia tortilis*, *A. salicina*, *A. aneura*, *A. ampleceps*, *A. nilotica* ssp. *cupressiformis*, *Tamarix articulata*, *Parkinsonia aculeata*, *Prosopis juliflora*, and *Eucalyptus camaldulensis*. Following suitable techniques and protecting the area by planting close-spaced windbreaks and shelterbelts of suitable trees and using drip irrigation (even of saline water up to EC 10 dS m^{-1}), even fruit trees such as ber (*Ziziphus mauritiana*), karonda (*Carissa carandas*), pomegranate (*Punica granatum*), tamarind (*Tamarindus indica*, frost sensitive), Lasura (*Cordia rothii*, *dichotoma*), custard apple (*Annona squamosa*), and date palm (*Phoenix dactylifera*) can be raised in desert environment.

Many dry regions also have shallow soil, particularly in the eastern and south-eastern parts of Rajasthan and Kutchh area of Gujarat and also in Pakistan. These areas have soil depth of 30–45 cm, and below this depth there lies a calcareous *kankar* pan, which needs to be broken for tree plantations. A few tree species suitable for plantation include *Acacia senegal*, *A. silicina*, *A. jacquemontii*, *P. juliflora*, *Hardwickia binata*, *Capparis decidua*, *Grewia tenax*, *Ziziphus nummularia*, *Holoptelea integrifolia*, and *Dichrostachys nutans*. Some areas in these pockets are extremely rocky and gravelly, and it was found that plantations in these areas are very difficult, and land preparation is a prerequisite. Generally, some staggered counter trenches with a cross section of 60 cm × 40 cm to minimize water erosion are constructed. Pits of 60 cm × 60 cm × 60 cm are dug out planting the seedlings. Good quality of soil from outside is filled in these pits, and seedlings of desired species are planted after adding and mixing farm yard manure (5 kg per pit) in the pits. Among successful species are *A. senegal*, *P. juliflora*, *P. chilensis*, and *Wrightia tinctoria*, while species such as *Grewia tenex*, *Z. nummularia*, and *C. decidua* may be planted with better management. Tewari and Singh (2000, 2006) and Tewari et al. (1998, 2014) have given extensive account for livelihood improvement and climate change adaptations through agroforestry in hot arid environments. Leguminous crop green gram sown under fruit tree *Ziziphus mauritiana* (cv Seb) produced 200 kg ha^{-1} grains and 800 kg ha^{-1} quality fruits (400 trees per ha) even when seasonal rainfall was 200 mm, thus rendering a drought proofing mechanism to the system. On farmers' field in Thar Desert, *Z. mauritiana-Cenchrus ciliaris* grass-based silvopastoral system proved highly remunerative, producing 2.77, 1.87 and 2.64 Mg ha^{-1} yr^{-1} fruit, leaf fodder, and fuel wood, respectively (Tewari et al. 1999, 2014).

About 11 million ha of land is desert (Thal, Thar, Choliston, and Chaki-Kharan) in Pakistan and 31.7 million ha in India, consisting of great tracts of sand dunes, which in places are interspersed with sparsely vegetated clay flats, and groundwater is highly saline EC_{iw} ranging from 4 to 18 dS m^{-1}. These areas could be brought under silvopastoral system utilizing the local vegetation as well as saltbushes consisting of trees (*Prosopis cineraria*, *P. juliflora*, *Acacia nilotica*, *Tamarix articulata*, *T. indica*, *T. stricta*, *Salvadora persica*, *S. oleoides*, *Leucaena leucocephala*), and forages and grasses (*Atriplex* spp., *Maireana* spp., *Leptochloa fusca*, *Echinochloa* *crus-galli*, *Cenchrus ciliaris*, *Arthrocnemum indicum*, *Salsola drummondii*, *Bienertia cycloptera*, *Indigofera oblongifolia*, and *I. cordifolia*) using saline aquifers (Qureshi et al. 1993, Tewari et al. 2014). Further, Abdullah et al. (1993) tested 13 species of *Atriplex* and 8 of *Maireana* for their suitability in Cholistan Desert with saline irrigation (~5 dS m^{-1}) and found that species of *Atriplex* (especially *amnicola*, *bunburyana*, *halimus*, and *lentiformis*) were most promising as compared to species of *Maireana*. Al Muzaini (2003) gave environmental measures including plantation method to control sand movement in Kuwait where it has caused extensive deterioration of the desert ecosystem. Palms including date palm (*Phoenix dactylifera*) and *Eucalyptus* are found suitable for Kuwait environment. Jaradat (2003) advocated cultivation of about 200 species of halophytes (used as grains and oil seeds, fruits, forage crops, fuel, pulp and fiber, and as bioactive derivatives) for sustainable biosaline farming systems in the Middle East. In Zambia, the use of nitrogen-fixing species such as *Sesbania sesban* and *Tephrosia vogelii* could get same crop yield as fully fertilized fields and same species plus *Crotalaria grahamiana* doubled maize yields in western Kenya. Further, across Africa the use of *Faidherbia albida* in various combinations has been well proved to boost maize yields, especially in low-fertility soils (Garrity et al. 2010).

5.3.1.4 Agroforestry of Acid Soils

Acid soils occupy approximately 30% of the world's total land area (Zheng 2010) and it has been estimated that over 50% of the world's potential arable lands are acidic (von Uexkull and Mutert 1995). Aluminum (Al) in these soils is solubilized into ionic forms, especially when the soil pH falls lower than 5. These ionic forms of Al have been shown to be very toxic to plants, initially causing inhibition of root elongation by destroying the cell structure. On the other hand, phosphorus (P), is easily fixed by clay minerals that are rich in acid soils, including various iron oxides and kaolinite, and hence rendering it unavailable for root uptake. Thus, increased solubility and toxicity of Al, Mn, and Fe, deficiency of Ca and Mg, reduced availability of P and Mo, and reduced microbial activity with decreasing pH are the characteristic features and constraints for crop production in these soils. In India, acid soils cover an area of about 90 million ha (Sharma and Sarkar 2005), out of which about 7% are strongly acidic (pH < 4.5), about 28% are moderately acidic (pH 4.5–5.5), and rest 65% are slightly acidic (pH 5.5–6.5).

In northeastern Himalaya regions, Alder (*Alnus nepalensis*)-based agroforestry systems involving arable and high-value crops like cardamom (*Elettaria cardamomum*), large cardamom (*Amomum subulatum*), pineapple (*Ananas sativum*), many fruit trees, and tuber crops like turmeric, ginger, colocacia, and taros make successful and sustainable agroforestry systems, which besides providing good economic yields also ameliorate soil by fixing nitrogen and organic matter.

In humid tropics the soils are generally acidic and low in nutrient availability. Some carry toxic levels of iron and aluminum. Yadav et al. (1983) estimated that coastal saline soils in India are spread over an area of 3.1 million ha. The low-lying coastal lands may contain acid sulfate soils derived from marine and estuarine sediments with high concentration of reduced sulfur components. Upon drainage and aeration, they undergo severe acidification bringing the pH values of the soil at times below 4 in the upper 50 cm layer. Low pH adversely affects the availability of calcium, magnesium, and other nutrients. Drainage results in more oxidation causing further soil degradation. Such lands are managed for rice cultivation and brackish water fish culture. Appropriate agroforestry systems may also prove useful in the management of acid soils as woody perennials can recycle nutrients, maintain soil organic matter, and protect the soil from erosion and runoff. The homegardens, coffee and cacao production systems, plantation-based multi-tiered dense cropping systems, and alley cropping on sloping lands represent typical agroforestry systems. Aquaculture keeping mangroves intact may be ideal, profitable, and sustainable practice in tidal zone. Dagar (1995), Kumar and Nair (2004), and Dagar et al. (2014a) have dealt with in detail some of these systems in tropical regions. On low-lying areas, rice remains important crop. Coconut, *Gliricidia*, *Ceiba pentandra*, and *Morinda citrifolia* are important boundary plantations of rice fields. Farming in forests; homegardens; plantation-based multi-tiered farming systems involving livestock, fishery, and duckry; alley cropping on sloping lands; fodder banks; and aquaculture keeping mangroves intact are some important agroforestry systems for coastal and island regions (Dagar et al. 2014a).

For the past two decades, several attempts were made to incorporate medicinal and aromatic crops in farming systems along with conventional food crops and commercial plantations. This increased land use efficiency and net return of the same piece of land (Maiti and Raju 2004). Among important medicinal and aromatic species suitable for coastal regions include *Abelmoschus moschatus*, *Acorus calamus*, *Adhatoda vasica*, *Aloe barbadensis*, *Alpinia galangal*, *Andrographis paniculata*, *Asparagus racemosus*, *Bacopa monnieri*, *Caesalpinia bonduc*, *C. crista*, *Cassia angustifolia*, *Catharanthus roseus*, *Centella asiatica*, *Clitorea ternatea*, *Coleus forskohlii*, *Curculigo orchioides*, *Curcuma longa*, *C. aromatica*, *Cynometra ramiflora*, *Cymbopogon flexuosus*, *C. martinii*, *Gloriosa superba*, *Kaempferia galangal*, *K. rotunda*, *Morinda citrifolia*, *Piper longum*, *Plumbago zeylanica*, *Pogostemon cablin*, *Solanum surattense*, *Tinospora cordifolia*, and *Zingiber officinale*.

Coastal dunes form a complex sequence of excessively drained ridges separated by poorly drained depressions. Along Orissa coast belts of cashew (*Anacardium occidentale*) plantations following the *Casuarina* line are quite common. Screw pine *Pandanus* is also quite frequent which may be explored commercially for its fruits yielding fragrant oil. *Casuarina equisetifolia* and *Eucalyptus tereticornis* are two very important trees along Andhra coast. Palmirah palm (*Borassus flabellifer*) is most frequent in agricultural fields. Mangroves form the thick belt along protected shores and creeks. These have been denuded in many areas and are in depleted condition throughout the coast. Their importance was realized during *tsunami* in December 2004 and frequent cyclones along Orissa coast. Dagar (1982, 2003, 2008) and Dagar et al. (1991, 1993) gave an illustrative account of distribution, zonation pattern, importance, and management of mangrove forests. Their role in aquaculture, shore protection, and livelihood of coastal population has been well documented. Behind mangrove belt, species such as *Pongamia pinnata*, *Terminalia catappa*, *Calophyllum inophyllum*, *Morinda citrifolia*, *Thespesia populnea*, *Cocos nucifera*, *Pandanus* spp., and *Cynometra ramiflora* can successfully be explored for their commercial importance. Mangrove Nipa palm (*Nypa fruticans*) can successfully be cultivated along creeks for alcohol production.

5.3.1.5 Agroforestry for Salt-affected and Waterlogged Lands

Salinity afflicted landscapes, which now occupy nearly a billion hectares (about 10% of land area) in the world, have their origin either by natural or man-induced causes (Szabolcs 1989), but as per FAO/UNESCO Soil Map of the World (FAO/AGL 2000), the total area of saline soils is 397 million ha (Mha) and of sodic soils 434 Mha. The salinity caused due to anthropogenic factors (secondary salinization) is related to clearing of natural deep-rooted vegetation and large-scale development of irrigated agriculture without adequate drainage. Of the current 230 Mha of irrigated land, 45 Mha is salt-affected and of almost 1500 Mha of dry land agriculture, 32 Mha are salt-affected to varying degrees by human-induced processes. Thus, globally almost 77 Mha of land is salty due to human-induced salinization (Bridges and Oldeman 1999; FAO/AGL 2000).

In alkali soils, a hard *kankar* layer of calcium carbonate is generally found at a depth of about 1.25 to 1.5 m which acts as a barrier for root penetration. The layer, therefore, has to be broken first to allow proper development of roots. However, saline soils do not require such preparation, as they do not have any such barriers. These require special techniques of afforestation so that salt contents in root zone are minimized. Pit-auger-hole technique of tree plantation has been developed and perfected (Singh et al. 1998; Dagar et al. 2001a, b; Singh and Dagar 2005) for planting trees on alkali soils. Tomar et al. (1998) conducted several long-term experiments for developing afforestation technologies on highly saline waterlogged soils. The results suggested that furrow planting improved the survival and growth of tree species as compared to ridge planting method. Besides reducing the water application costs, it improves uniformity in water application and helps in creating a favorable zone of low salinity below the sill of the furrow through downward and lateral fluxes of water making salts move away from the furrow (root zone) especially when low salinity water is used. Creation of such niches favored the establishment of young seedlings of trees. Moreover, such a system seems to be more viable from practical viewpoint of undertaking large-scale plantations of trees. Recently, Dagar (2014) and Dagar and Minhas (2016) have reviewed the agroforestry of salt-affected and waterlogged environments in detail.

On the basis of experiments conducted on highly alkali soil (pH >10), *Prosopis juliflora*, *Acacia nilotica*, *Casuarina equisetifolia*, *Tamarix articulata*, *Eucalyptus tereticornis*, and *Parkinsonia aculeata* demonstrated a higher tolerance. Dagar et al. (2001a, b), Khan (2003), Singh et al. (2008), Dagar et al. (2013), and Dagar (2014) reported positive ameliorative effects of trees raised on highly sodic soil in terms of reduction in pH, increase in organic carbon, and available phosphorus and potassium. Earlier, Singh and Gill (1992) also reported reduction in pH from initial 10.2 to ranging from 7.9 to 8.5 in different species and increase in organic carbon from initial 0.22% to ranging from 0.62 to 0.93% and increase in available P from 28 kg ha^{-1} to 33–11 kg ha^{-1} and available K from 278 kg ha^{-1} to 359–702 kg ha^{-1} in 20-year-old plantations of *Acacia nilotica*, *Albizia lebbeck*, *Eucalyptus tereticornis*, *Prosopis juliflora*, and *Terminalia arjuna*. In that study *P. juliflora* was found most efficient in reclaiming soil in all the aspects.

In this land use system, fruit trees could be raised in wider spaces (row to row 5–6 m, at times even more, and plant to plant 4–5 m), and the arable crops were cultivated in the interspaces on high pH soils. In one trial Egyptian clover (*Trifolium alexandrinum*), wheat, rice, onion, and garlic were grown successfully for 3 years in the interspaces of fruit trees *Carissa carandas*, *Punica granatum*, *Emblica officinalis*, *Psidium guajava*, *Syzygium cumini*, and *Ziziphus mauritiana* (Tomar et al. 2004). Some of the salt-tolerant fruit trees like pomegranate (*Punica granatum*) and bael (*Aegle marmelos*) are unable to tolerate water stagnation during rainy season which should be cultivated on raised bunds (Dagar et al. 2001a). Under agroforestry systems, the bulk density of soil decreased, soil organic carbon and available nitrogen increased, and infiltration rate and water holding capacity increased considerably (Mishra et al. 2004). Medicinal liquorice (*Glycyrrhiza glabra*) has been found very interesting leguminous alkali-tolerant crop, which is not only remunerative but also ameliorates sodic as well as saline waterlogged soils (Dagar et al. 2015).

The grazing lands of salty soils are very poor in forage production under open grazing, but when brought under judicious management, these can be explored successfully for sustainable fodder production. Based on series of long-term experiments, it was found that Kallar grass (*Leptochloa fusca*) could be rated the most tolerant grass to highly sodic soil and waterlogged conditions as compared to other grasses. Among others, Rhodes grass (*Chloris gayana*), Gutton panic (*Panicum maximum*), Para grass (*Brachiaria mutica*), *Panicum antidotale*, *P. laevifolium*, *P. purpureum*, and *Setaria anceps* were successful grasses up to soil pH 9.6. These grasses can be grown successfully with most promising tree species such as *Prosopis juliflora*, *Acacia nilotica*, *Tamarix articulata*, *Casuarina equisetifolia* (susceptible for frost), *Terminalia arjuna*, and *Pongamia pinnata*. On highly sodic soil, mesquite (*Prosopis juliflora*) and Kallar grass silvopastoral practice was adjudged the most promising for fire wood and forage production and also for soil amelioration. An associative nitrogen-fixing bacterium, *Azoarcus*, occurs as an endophyte in the roots of Kallar grass (*L. fusca*) – a pioneer species of alkali soils. Symbiotic nitrogen fixation by *Rhizobium* has been extensively investigated in salt-affected soils (Rao and Ghai 1995; Rao 1998) and their survival is not a problem as they have considerable tolerance to high pH. Kaur et al. (2002) reported bio-amelioration due to silvopastoral system on highly sodic soils (pH > 10) after 7 years of plantations and concluded that grasses along with trees are more effective in bio-amelioration than sole grasses. More than 40 tree species of arid and semiarid areas were evaluated for their salinity tolerance by Tomar et al. (1998), and species like *Acacia farnesiana*, *Parkinsonia aculeata*, and *Prosopis juliflora* were rated the most tolerant to waterlogged salinity and could be grown satisfactorily on soils with salinity levels up to 50 dS m^{-1} in their root transmission zone. Tree species like *Acacia nilotica*, *A. torilis*, *Casuarina glauca*, *C. obesa*, and *C. equisetifolia* could grow on sites with ECe varying from 10 to 25 dS m^{-1}.

The saline black cotton soil zone (saline/sodic vertisols) are generally either contemporary or of secondary origin. After 14 years of plantation with several species, it was found that *P. juliflora*, *Salvadora persica*, and *Azadirachta indica* were most successful species for these soils. Among grasses, *Aeluropus lagopoides*, *Leptochloa fusca*, *Brachiaria mutica*, *Chloris gayana*, *Dichanthium annulatum*, *Bothriochloa pertusa*, *Vetiveria zizanioides*, and species of *Eragrostis*, *Sporobolus*, and *Panicum* were found the most successful and form suitable silvopastoral system.

Introduction of canal irrigation in arid and semiarid regions without provision of adequate drainage causes rise in groundwater table leading to waterlogging due to seepage and secondary salinization (Tewari et al. 1997). For the reclamation of waterlogged saline soils, the conventional technique is subsurface drainage which is relatively expensive and generates harmful drainage effluents and has environmental problems. A viable alternative of the above technique could be biodrainage (Jeet-Ram et al. 2011; NAAS 2015), which is “pumping of excess soil water by deep-rooted trees using bioenergy.” This technique if not remediation, is at least a protective measure in potential waterlogged areas.The root systems of trees intercept saturated zone or unsaturated capillary fringe above water table to control shallow water table. These plants are known as *phreatophytes.* Fast-growing plants such as cloned *Eucalyptus* could successfully be grown on ridges particularly in areas where salinity is low. The impact of block plantations of *Eucalyptus tereticornis* on reclamation of waterlogged areas was tested and found effective at the Indira Gandhi Nahar Project (IGNP) site in Rajasthan and Dhob-Bhali research plot in Haryana (Heuperman et al. 2002; Jeet-Ram et al. 2007). On these sites it was established that the transect of trees such as species of *Eucalyptus*, *Acacia*, *Populus*, *Prosopis*, *Casuarina*, *Pongamia*, *Terminalia*, *Syzygium*, *Dalbergia*, etc. when planted along canals successfully checked seepage and helped in mitigating waterlogging. During the studies conducted in IGNP area (Heuperman et al. 2002), groundwater under the tree plantation was reported to fall by 15.7 m over a period of 6 years. At 100 m from the edge of the plantation, the level of the groundwater was about 9 m higher than at the edge, with a drawdown of 6.7 m.

Jena et al. (2011) planted *Acacia mangium* and *Casuarina equisetifolium* with intercropping of pineapple, turmeric, and arrowroot which was taken successfully in Khurda district of Orissa coast. The depth to pre-monsoon water table changed from 0.5 m to 1.67 m after 1 year of plantation and to 2.20 in next year and to 3.20 during third year due to biodrainage. Roy Chowdhury et al. (2011) also summarized the role of plantations (*Eucalyptus* and *Casuarina*) in agroforestry mode for reclamation of waterlogged situations in Deltaic Orissa. Jeet-Ram et al. (2011) observed the total drawdown of groundwater table during a period of 3 years to be 0.85 m and more than 2 m when the trees were 5 years old. The average above ground oven dry biomass was 24 Mg ha^{-1} from 240 surviving trees and the average below ground oven dry biomass of roots was 8.9 Mg ha^{-1}. The total carbon sequestration by these plantations was 15.5 Mg ha^{-1}. The wheat grains yield was 3.36 times the yield in the nearby untreated fields. Besides getting rice and wheat crops, the farmers earned additional INR 72000 ha^{-1} from *Eucalyptus* wood at a rotation of 5 years and 4 months resulting in a benefit-cost ratio of 3.5:1 at 12% discount rate of interest. Further, Dagar et al. (2016a) observed that when clonal *Eucalyptus* was planted in different spaces on bunds (adjusting 300, 200, and 100 trees per ha), timber dry wood production was 33.5 Mg ha^{-1} in spacing of 1 m × 1 m (300 trees per ha), 19.1 Mg ha^{-1} in 1 m × 2 m (200 trees per ha), and 13.5 Mg ha^{-1} in 1 m × 3 m (100 trees per ha) and sequestered 15.2, 8.9, and 6.4 Mg C ha^{-1}, respectively. Block plantations of *Eucalyptus* (4 m × 2 m spacing, 1250 trees per ha) generated 154 Mg ha^{-1} timber wood biomass and sequestered 66.5 Mg C ha^{-1}. The physicochemical properties of soil also improved to greater extent, more so in block plantations.

5.3.1.6 Agroforestry on Degraded Soil in Dry Regions Having Saline Aquifers for Irrigation

In most of the dry regions, the underground aquifers are saline. Recent research efforts have shown that these waters can successfully be explored for establishment of trees and developing suitable agroforestry systems (Dagar 2014; Dagar et al. 2014b, 2016b; Dagar and Minhas 2016; Yadav and Dagar 2016). In long-term field experiments conducted (Tomar et al. 2003b) on a highly calcareous soil (*Typic Haplustalf*) in semiarid monsoon-type climate of India, it was found that tree species such as *Tamarix articulata*, *Acacia nilotica*, *A. tortilis*, *Eucalyptus tereticornis*, *Prosopis juliflora*, and *Azadirachta indica* could successfully be established when planted and irrigated in furrows using saline water of EC 10 dS m^{-1}. Litter fall from the most of tree species resulted in an improvement in organic carbon content of the underlying soils. *Acacia nilotica*, *A. tortilis*, *Azadirachta indica*, *Eucalyptus tereticornis*, *Feronia limonia*, *Tamarix articulata*, and *Guazuma ulmifolia* species increased organic carbon content (>5 g kg^{-1}). In another long-term study, Dagar et al. (2016c) established fruit-based agroforestry systems planting karonda (*Carissa carandas*), Indian gooseberry (*Emblica officinalis*), and bael (*Aegle marmelos*) in wider spaces (4 m × 5 m) on sandy loam calcareous soil and irrigated with low (EC_{iw} ~ 4–6 dS m^{-1}, SAR 18) salinity water, alternate irrigation with water of low and high (EC_{iw} 8.5–10.0 dS m^{-1}, SAR 21) salinity, and irrigation with water of high salinity. The interspaces were cultivated with pearl millet (*Pennisetum typhoides* cv HHB 68) and cluster bean (*Cyamopsis tetragonoloba* cv HG 365) during the *kharif* (rainy) season (*Hordeum vulgare* cv BH 375) and salt-tolerant cultivar of mustard (*Brassica juncea* cv CS 54) during winter. This was most successful and remunerative system. There was nominal salinity build up when irrigated with water of high salinity, but when there was a year of normal rainfall during 3–4 years of interval, most of the salinity of root zone leached down and, thus, the system was found sustainable.

Usually salinity limit in irrigation water depends upon soil permeability and salt tolerance of cultivated trees and crops. Over irrigation with saline water at leaching fraction of about 40% results in making ECe almost equal to that of EC_{iw} at sandy strata (Ahmad and Ismail 1993a, b). This makes it possible to use water of 5–20 dS m^{-1} for raising halo-xeric forages and other crops at sandy substratum. Ahmad et al. (1987) and Ahmad and Ismail (1993a, b) observed that certain species of fuel wood (some may also be lopped for forage) and worth grazing grasses and salt bushes show luxuriant growth at sandy strata when irrigated with saline water of oceanic strength. They found that in some trees such as *Azadirachta indica*, *Casuarina equisetifolia*, and *Eucalyptus camaldulensis*, 25% biomass reduction started only at ECiw >15 dS m^{-1}, in *Prosopis juliflora* at >20 dS m^{-1}, while in *Tamarix articulata* only beyond 30 dS m^{-1} at sandy substrata. Among grasses 25% yield reduction in *Sporobolus arabicus*, *Panicum turgidum*, and *Thinopyrum ponticum* was observed only at EC_{iw} 10–15 dS m^{-1}, while in *Leptochloa fusca* it was at ECiw 20 dS m^{-1}.

Aslam et al. (1993) observed that the application of brackish water did not cause any change in soil properties. In contrast, the roots of *Kallar* grass were able to penetrate to depth creating vertical fine channels accelerating the leaching of salts down below 3 m in depth and increasing the hydraulic capacity of the soil. Thus, the cultivation of salt-tolerant plants like *Kallar* grass also initiates a soil improvement process by providing soluble Ca^{+2} to the soil through dissolution of native $CaCO_3$ which lowers the pH. Rashid et al. (1993) demonstrated in Peshawar valley that *Atriplex lentiformis* (159) was the most productive of the 20 saltbushes tested irrigating with brackish water. The other promising accessions were *A. amnicola* (971), *A. lentiformis* (178), *A. halimus*, *A. cineraria* (524), *A. undulata* (471), and *A. amnicola* (573). These saltbushes along with productive salt-tolerant grasses and forage trees may form ideal silvopastoral system on these degraded lands. Quadir et al. (1995) reported the potential of forage biomass production of 32.3 Mg ha^{-1} by *Sesbania aculeata*, 24.6 Mg ha^{-1} by *Leptochloa fusca*, 22.6 Mg ha^{-1} by *Echinochloa colona*, and 5.4 Mg ha^{-1} by *Eleusine coracana* in saline-sodic environment, and these species helped in soil amelioration in terms of reducing soil pH and salinity and increasing nitrogen in the order S. *aculeata* > *L. fusca* > *E. colona* > *E. coracana*. Tomar et al. (2003a) found that forage grasses like *Panicum laevifolium* and *P. maximum* were most suitable species producing annually 14–17 Mg ha^{-1} dry forage showing their potential as silvopastoral grasses if grown in protected conditions.

Among nonconventional crops, castor (*Ricinus communis*), *Aloe vera*, dill (*Anethum graveolens*), and taramira (*Eruca sativa*) could be grown successfully when provided with three irrigations of saline water of EC 10 dS m^{-1} (Dagar et al. 2008). Psyllium (*Plantago ovata*) and lemongrass (*Cymbopogon flexuosus*) could also be cultivated successfully (Tomar et al. 2010; Dagar et al. 2013) with saline irrigation. Psyllium did not show any yield reduction with *Acacia* plantation even at later stages showing its suitability for partial shade tolerance. Other medicinal plants such as *Aloe barbadensis*, *Adhatoda vasica*, *Cassia angustifolia*, *Lepidium sativum*, *Withania somnifera*, *Citrullus colocynthis*, and *Catharanthus roseus* could successfully be grown with saline irrigation as intercrops or in isolation. All these high-value crops can successfully be grown as intercrops with forest or fruit trees at least during initial years of establishment (Dagar et al. 2008; Dagar and Minhas 2016). Ornamental flowers such as *Chrysanthemum*, *Calendula*, and *Matricaria* were cultivated irrigating with water of EC up to 5 dS m^{-1} yielding 13.2, 4.7, and 3.5 Mg ha^{-1}, respectively, fresh flowers in a season (Tomar and Minhas 2002). Many medicinal plants were also cultivated with saline irrigation (Tomar and Minhas 2004b). The aromatic grasses such as vetiver, lemongrass, and palmarosa, when irrigated with saline water (EC 8.5 dS m^{-1}), could produce an average 90.9, 10.4, and 24.3 Mg ha^{-1}dry biomass, respectively (Tomar and Minhas 2004a). Different cultivars of vetiver could produce 72.6 to 78.7 Mg ha^{-1}shoot biomass and 1.12 to 1.71 Mg ha^{-1} root biomass. The roots are used to extract aromatic oil. Oil (property like sperm whale) yielding *Simmondsia chinensis* and petro crop like *Euphorbia antisyphilitica* are other interesting plants having potential to be grown as commercial crops irrigating with saline water up to 8 dS m^{-1} (Dagar et al. 2012).

5.3.1.7 Rehabilitation of Mine Spoils

The mining leads to deterioration of the site to the extent that no biomass can be produced at the mined site. The process of vegetation development begins naturally through colonization by the species found in surrounding areas. Artificial seeding of quick-growing grasses may accelerate development of vegetation, improve soil fertility, moisture retaining capacity, stabilize the slopes, and encourage natural invasion of native tree and shrub saplings. Plantation of mixed tree species may be undertaken after 2–3 years of growing grasses (Singh 2004). Direct seeding of tree species for 3 years with grasses and leguminous forbs has been found to be useful (Juyal et al. 2007). Studies conducted for the limestone mine spoil revealed that 30 kg N ha^{-1} and 20 Mg ha^{-1} farm yard manure or leaf litter helped *Eulaliopsis binata* grass in establishing on such sites. In Amarkantak, successful attempts were made to rehabilitate bauxite mined area by planting *Eucalyptus camaldulensis*, *Grevillea pteridifolia*, *Pinus caribaea*, and *Acacia auriculiformis*. Dhyani et al. (2007) reviewed some case studies of afforestation of mines in India, while Chaturvedi et al. (2014) reported different plant species suitable for revegetation of different mine spoils which included *Eucalyptus camaldulensis*, *Grevillea pteridifolia*, *Pinus* spp., and *Shorea robusta* for bauxite mined area; *Acacia catechu*, *Agave americana*, *Arundo donax*, *Bauhinia retusa*, *Buddleja asiatica*, *Chrysopogon fulvus*, *D. sissoo*, *Erythrina suberosa*, *Eulaliopsis binata*, *Ipomea carnea*, *Leucaena leucocephala*, *Mimosa himalayana*, *Pennisetum purpureum*, *Rumex hastatus*, *Salix tetrasperma*, and *Vitex negundo* for limestone mine spoils; *Acacia auriculiformis*, *A. nilotica*, *Dalbergia sissoo*, *E. camaldulensis*, *E. hybrid*, *Pongamia pinnata*, and bamboo species for coal mines sites; *Acacia catechu*, *D. sissoo*, *L. leucocephala*, *M. himalayana*, *P. purpureum*, *R. hastatus*, *Saccharum spontaneum*, *Salix tetrasperma*, and *V. negundo* for rock phosphate mine site; *Acacia tortilis*, *A. senegal*, *Cenchrus setigerus*, *Cymbopogon* spp., *Cynodon dactylon*, *Dichanthium annulatum*, *Grewia tenax*, *P. juliflora*, *Salvadora oleoides*, *Sporobolus marginatus*, *Tamarix articulata*, *Ziziphus nummularia*, etc. for mica, copper, tungsten, marble, dolomite, limestone, etc. mine spoils; *Albizia lebbeck*, bamboos, *D. sissoo*, *Emblica officinalis*, *Eucalyptus* spp., *Leucaena leucocephala*, and local plants for iron wastes; and species of

Acacia, *Agave*, *Eucalyptus*, and *Leucaena* for lignite mines. Mine rehabilitation is a completely neglected area and needs attention in India. According to the report of the Union Ministry of Mines (Ministry of Statistics and Program Implementation), about 1135 mines covering 11,200 ha area are still under rehabilitation program. A total of 901 mines covering an area of 23,556 ha were planted with 52 million trees out of which 70% survived. This is an encouraging figure, and, hence, based on soil, ecology, and tolerance, a detailed program of rehabilitation of all mine spoils in the country must be planned.

5.3.2 Agroforestry Systems and Biodiversity

Indogenous agroforestry systems are the repositories of biodiversity in many places of the world. In most of the populated countries especially in South and Southeast Asia, tree- dominated homegardens constitute important land use, which provides them to conserve plant and other wildlife population. Tropical homegardens are the richest in biodiversity for a unit area under cultivation. According to some research findings, a total of 525 useful plant species was recorded from 163 homegardens in Tswana *tshimo* homegardens of South Africa (Molebatsi et al. 2010). Over 149 crop species were identified in homegardens of central Sulawes of Indonesia (Kehlenbeck and Maas 2004); 128 plant species from Kerala, India (Kumar 2004); 233 plant species from San Rafael Coxcatlan, Mexico (Blanckaert et al. 2004); 230 in Northeastern Thailand (Black et al. 1996); 150 in Quintan Roo, Mexico (De Clerck and Negreros 2000); 168 in Santa Rosa, Peruvian Amazon (Padoch and de Jong 1987); 250 in Catalonia, Spain (Agelet et al. 2000); 179 in West Java, Indonesia (Soemarwoto 1987); 272 plant species in a hamlet of 41 households (Soemarwoto and Conway 1992; 76 plant species in the homegarden of the offshore island of Bangladesh (Alam and Masum 2005); 84 plant species in the homegardens of Tigray, Ethiopia (Hintsa 2012); and 66 useful species are cultivated in Andaman-Nicobar Islands (Dagar 1995), but relatively small amount of plant species recorded in El Obeid, Central Sudan; 32 different plant species in 81 homegardens (Gebauer 2005). In Bangladesh, more than 20 million households have homegardens covering sabout 12% of the total land area of the country. A survey in more than 400 homegardens revealed 419 plant species found in these gardens, which included six on the IUCN Red List for Bangladesh (Webb and Kabir 2009). Because of their richness in plant species, homegardens are regarded as an ideal production system for in situ conservation of plant species. The greater the diversity means, the greater the chance for adaptation by the local people. However, Abebe et al. (2010) studies illustrate that the species diversity is often not static, but changes in response to socioeconomic dynamics. Consequently, homegardens should not be interpreted as a generic agroforestry system with uniform diversity characteristics, but rather as involving different types with specific features in respect to species diversity.

Different literatures showed that dryland homegarden agroforestry play a major role in the conservation of plant species (Wezel and Bender 2003; Gebauer 2005; Hintsa 2012; Hintsa and Emiru 2016). Moreover, the presence of woody species in homegarden agroforestry may favor the survival of other living organisms and hence contribute to a wider conservation of biological diversity. Homegarden agroforestry is the alternative for biodiversity conservation in environmental limited areas like dry land areas. The variation in species richness in different dryland homegarden agroforestry is related to ecological, cultural, and socioeconomic conditions. For instance, homegardens in the highland humid tropics are expected to be rich in species as compared to the highland semiarid tropics because of rainfall and temperature is very suitable.

Another one of the richest ecosystems in biodiversity are mangrove stands. Besides being rich in floral diversity, these also give shelter to variety of wildlife. Most of the coastal aquatic animals including fish utilize the mangrove water as nursery and breeding grounds. A variety of animals (including benthic organisms) associates with mangroves and make complex but interesting food web. Mangroves not only protect coast but also contribute substantially the nutrients to fishery in the adjacent waters. There are many forms of aquaculture, such as oyster, crab, fish, and shrimp culture enclosed either in pans or cages, which may be undertaken without distruction of mangroves. In many areas shrimp culture is followed behind mangroves in constructed ponds. Species of *Avicennia*, *Ceriops*, *Rhizophora*, *Sonneratia*, *Bruguera*, and *Cynometra* and many associate species are good fodders and may be grown in paired rows in mangrove swamps. In many reclaimed areas, coconut and *Morinda citrifolia* are grown on bunds, and fish is cultivated in channels. Integrated farming system involving aquaculture, poultry, animals, plantation crops, fruit trees, tree spices, black pepper, etc. on uplands and rice-cum-fish on lowlands in most of the coastal areas, which in turn also is rich in biodiversity and highly remunerative (for more details, see Dagar et al. 2014a).

5.3.3 Agroforestry for Carbon Sequestration and Mitigation of Climate Change

The agricultural systems are already affected by unsustainable management and land and resource degradation and further are the most vulnerable to climate change. Managed agroforestry has an important role to play not only in climate change mitigation (following smart agriculture practices) but also in reducing vulnerability to climate-related risks because of a variety of components. Based on the papers presented during Second World Congress of Agroforestry held in Kenya in 2009, Nair and Garrity (2012a) compiled the comprehensive account of agroforestry research and advancement including the role of agroforestry to be played to mitigate climate change. The chapters written by Leakey (2012), Swaminathan (2012), Nair (2012), Minang et al. (2012), Mosquera-Losada et al. (2012), and Nair and Garrity (2012b) are of great significance in this direction. Citing the recognition of the fact by IPCC (Intergovernmental Panel on Climate Change), Swaminathan (2012) and Dagar et al. (2016b) mentioned that agroforestry systems have the highest carbon sequestration potential among managed land use systems, followed by grazing management, forest management, and crop plant management in that order. He further mentioned the agroforestry opportunities in mangrove areas, which have tremendous potential for carbon sequestration, biodiversity conservation, and enhancing aquatic productivity. This ecosystem is attaining attention only now because of the alarm about the rise of sea levels. Mangroves along with other halophytes such as species of *Salicornia*, *Salvadora*, *Suaeda*, *Atriplex*, and *Arthrocnemum* have a great deal of value as repository genes for salinity tolerance. Further, roots and leaf exudates of the mangroves those are rich in nutrients support shrimp and fish production. As mentioned earlier "agro-aqua" farm cultivation with halophytes can be a good strategy for mangrove protection and sequestering huge amount of carbon. These have reputation of increased protection of coastal areas to erosion and storm surges. There is evidence that many types of coastal forests can help dissipate wave energy and force, reducing flooding, and also help to capture debris that would otherwise do more damage, Further, the recommended greenbelt width for protective mangroves varies from 100 m for *tsunami* protection in the Asia South Pacific to 200 m for protection of agricultural lands (Pro Act 2008), suggesting that carbon sequestration potential may be significant.

Agroforestry system has attracted special attention in climate change mitigation and adaptations. However, the site-specific nature of these systems and lack of uniformity in C sequestration estimation methods make it difficult to compare the reported results. Nair (2012) for convenience of comparative analysis grouped the systems in five subgroups – tree intercropping, multi-strata, protective, silvopasture, and tree woodlots – and global areas under each are estimated as 700, 100, 300, 450, and 50 million ha, respectively. Glenn et al. (1992) estimated that 0.6–1.2 gigatonnes (Gt) of C per year could be assimilated annually by halophytes on saline soils; evidence from decomposition experiments suggested that 30–50% of this carbon might enter long-term storage in soil. Thus, halophytes adapted to saline soils could play an important role in soil carbon sequestration. Bhojvaid and Timmer (1998) showed the annual rate of increase of 1.4 Mg C ha^{-1} yr^{-1} over a 30 years' period of plantation of *Prosopis juliflora* on highly sodic soil. In silvopastoral agroforestry systems on sodic soils in northwest India, the total carbon storage was 1.18–18.55 Mg C ha^{-1}, and carbon input in net primary production varied between 0.98 and 6.50 Mg C ha^{-1} year^{-1} (Kaur et al. 2002). The aboveground woody biomass carbon in *Prosopis juliflora* + *Desmostachya bipinnata* silvopastral systems, bole, and branches comprised 82% of the total biomass carbon in 6-year-old systems (Kaur et al. 2002). Total carbon storage was 18.54 to 12.17 Mg C ha^{-1}, and carbon input in net primary production varied between 6.50 and 3.24 Mg C ha^{-1} year^{-1}. In southwestern Australia, the rates of C sequestration in biomass of *Eucalyptus globulus* over a 10-year period ranged from 3.3 to 11.5 Mg C ha^{-1} year^{-1} on a large-scale watershed, the rates of C sequestration being high (Harper et al. 2005, 2007).

Carbon sequestration was estimated both in plant biomass and soil in two pasture systems (*Cenchrus ciliaris* and *Cenchrus setigerus*), two tree systems (*Acacia tortilis* and *Azadirachta indica*), and four silvopastoral systems (combination of one tree and on grass) on moderately alkaline soils (pH 8.36 to 8.41) in Kachchh, Gujarat, northwestern India (Mangalassery et al. 2014). This study showed that maximum carbon was sequestered by silvipastoral system of *Acacia* + *C. ciliaris* (6.82 Mg C ha^{-1}) followed by A*cacia* + *C. setigerus* (6.15 Mg C ha^{-1}) compared to 6.02 Mg C ha^{-1} sequestered by sole plantation of *Acacia tortilis.* The silvipastoral system of *Azadirachta indica* + *C. ciliaris* and *A. indica* + *C. setigerus* registered a total carbon stock of 4.91 and 4.87 Mg C ha^{-1}, respectively, against sole plantation of *A. indica* (3.64 Mg C ha^{-1}). The silvopastoral system sequestered 36.3%–60.0% more total soil organic carbon stock compared to the tree system and 27.1–70.8% more in comparison to the grass alone. Thus, silvopastoral system sequestered more carbon (Mangalassery et al. 2014).

Neumann et al. (2011) have provided estimates of carbon sequestration and biomass production rates from agroforestry in lower rainfall zones (300–650 mm) of Southern Murray-Darling Basin Region on the basis of data of agroforestry on 121 sites (32 species); the average age of the plantings in this study was 16.5 years, with plantation ages ranging from 5.7 to 99 years since establishment. Potential productivity was found to be highly variable and influenced by species choices, planting designs, land management practices, and climatic conditions. Preliminary assessments suggested that the average aboveground carbon sequestration rates across the region were 9.5 Mg of carbon dioxide equivalents ha^{-1} yr^{-1} (CO_2-e Mg ha^{-1} yr^{-1}) for all measured plantations (Neumann et al. 2011). For tree-form eucalyptus, the rate was similar, i.e., 10.6 CO_2-e Mg ha^{-1} yr^{-1}, while formallee-form eucalyptus, it was 6.3 CO_2-e M ha^{-1} yr^{-1} and for non-eucalyptus trees it was 6.9 CO_2-e M ha^{-1} yr^{-1}. In these lower rainfall areas, growth and sequestration rates are naturally slower and mallees could be the best option (Neumann et al. 2011).

Nair (2012) stated that tillage, crop residue management, and plant diversity are reported as the major management operations that influence the role of land use systems in climate change mitigation. Based on SWOT analysis, he concluded that existing multi-strata and tree intercropping systems will continue to provide substantial climate change mitigation benefits; large-scale initiatives in grazing land management, working trees in drylands, and establishment of vegetative riparian buffer and tree woodlots are promising agroforestry pathways for climate change mitigation and adaptations.

5.3.4 Sociocultural and Recreational Value

The indigenous and traditional systems have been appreciated for ecological principles and sustainability; but very little attention has been paid toward the recreational and cultural values of the systems. Wherever these systems are practiced, these are an important component of local cultural heritage. The indigenous bamboo + pine system and the rice + fish culture of the Apatani tribe of Arunachal Pradesh in India have earned the rare distinction as a UNESCO World Heritage Site for its extremely high productivity and the unique way of preserving the ecology (Tangjang and Nair 2016). The Saharia tribes from central India traditionally collect leaves of *Butea monosperma* for making platter cups (dona patta) and collect gum of commerce from the same tree without damaging the ecology. This is cultural tradition of earning livelihood from the natural stands of these trees. Similarly, broom making from wild palm (*Phoenix sylvestris*) is commonly prevalent in Bargundas belonging to Khajuravanshi community from Khandwa region of Madhya Pradesh in India (Ram-Newaj et al. 2016). They also use fruits as edible and ooze a fluid used as Toddy or Neera, jiggery from fruit juice leaves for making brooms, baskets, fans, floor mats, etc. Thus, there are many unrecorded cultural tales associated with traditional agroforestry systems which need documentation.

5.4 Alley Cropping

Alley cropping though is considered a modern system but it is not new concept. During 1930s the Dutch system colonial government introduced contour terracing using *Leucaena leucocephala* hedgerows planted 3 m apart for erosion control and soil fertility improvement on the island of Timor in eastern Indonesia (Metzner 1982). The introduction initially was not accepted locally because in short time the plant colonized widely due to lack of management. However, during the 1970s through the combined efforts of the local extension service, the Leucaena contour terracing system together with management was successfully introduced in the island of Flores in Indonesia (Parera 1989; Kang et al. 1990). The system, locally known as *Lamtoronisasi*, was adopted widely. A similar system known as sloping agricultural land technology (SALT) is also used in the Philippines (Laquihon and Watson 1986). Further, during 1970s, the International Institute of Tropical Agriculture (IITA) in Nigeria conducted investigations to assess the potential of intercropping woody species with food crops as a land use system to manage fragile uplands for continuous crop production in the humid and subhumid zones and to improve the traditional bush-fallow slash-and-burn cultivation system. This led to development of and research on the alley cropping system (Kang et al. 1981, 1990).

In recent times, substantial research has been put into alley cropping (hedgerow intercropping) system in which usually arable crops are grown in alleys formed by hedgerows of trees or shrubs. The system is more effective and useful for sloping lands in high rainfall areas where problem of soil erosion is acute. The hedgerows 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 hedgerows are allowed to grow when there are no crops and normally pruned during the season, and the pruned material is either used as mulch or as source of green manuring or sometimes also as fodder. Tree species such as *Leucaena leucocephala*, *Gliricidia sepium*, *Cassia seamea*, and *Sesbania sesban* have already been tested for their efficiency. Short duration rainy crops such as pearl millet and sorghum were found to be compatible with *Leucaena* and *Gliricidia*. In high rainfall areas, *Gliricidia* has been found very successful on sloping lands, and forage grasses such as *Pennisetum purpureum*, *P. polystachion*, *Seteria anceps*, and legume *Stylosanthes guianensis* grown as fodder crops found effective which in turn also helped in checking soil erosion. Other crops such as turmeric, ginger, colocasia, yams, etc. were also grown as cover crops. Hedgerows are generally used for production of fodder, fuel wood, mulch production, nutrient yield (nitrogen fixation), weed control, and protection of soil from erosion. Since the pioneer studies by Kang et al. (1990) for mostly African countries, the system has been worked out globaly for standardization of space, nutrient interaction, and tree-crop interactions. Rao et al. (1991), Korwar (1992, 1999), and Osman et al. (1998) have reported interesting results from India.

5.5 Parklands Agroforestry Systems

Parklands constitute the predominant agroforestry systems in semiarid West Africa. In the Sahelian zone, crops grown under discontinued cover of scattered trees are dominant in many landscapes and constitute so-called parklands. These are playing an important role through trees and shrubs in providing soil cover that reduces erosion and buffers the impacts of climate change. They provide green fodder for livestock feeds, and fruits and leaves for human consumption and income generation. Some parklands are mono-specific (e.g., *Fadherbia albida* and *Borassus aethiopum* based), but others have dominant tree species mixed with a range of tree and shrub species (Boyala et al. 2014). In some instances, the original species such as *Prosopis africana*, *Vitellaria paradoxa*, *F. albida*, and *Parkia biglobosa* are retained, while in some other cases, cash plantations such as oil palm (*Elaeis guineensis*) are introduced while in others (e.g., *Adansonia digitata*) even fruits and leaves are collected systematically, and these are improved as compared to traditional ones. So is true with *Acacia senegal* and *A. laeta* parklands of Sudan, where gum is collected from these trees and *F. albida* is intercropped successfully with maize. Rural communities in Burkina Faso, Mali, Niger, and Senegal value more than 115 indigenous tree species for the livelihood benefits of their products and services (Faye et al. 2011). The parklands are the most common and improved agroforestry in these countries and combine with crops, grasses, trees, and livestock. Farmers maintain several indigenous tree species in parklands for food (e.g., *Adansonia digitata*, *Parkia biglobosa*, *Vitellaria paradoxa*, *Ziziphus mauritiana*); dry season fodder (e.g., *Balanites roxburghii*, *F. albida*, *Pterocarpus erinaceus*); wood for fuel, construction, household, and farm implements (e.g., *B. roxburghii*, *Combretum glutinosum*, *Guiera senegalensis*, *Prosopis africana*); medicines; and environmental services such as shade, soil fertility improvement, and soil/water conservation (Leakey et al. 2012). The sale of these products contributes 25–75% of annual household revenue in Mali (Faye et al. 2010), with some having international market.

5.6 Domestication of Wild Fruit Trees

Selecting superior trees from the wild; improving their desirable characteristics such as early bearing, taste, quality, and nutrition value; and popularizing them among farmers have to go a long way in ensuring food and nutritional security of the local people. Some small-scale farmers in Western and Southern Africa are diversifying high-value enterprises that involve production, processing, and commercialization of fruits from indigenous fruit trees and their products (Maathai 2012). The Miombo woodlands are rich in edible indigenous fruit trees and species such as *Sclerocarya birrea*, *Strychnos cocculoides*, *Uapaca kirkiana*, *Vangueria infausta*, *Parinari curatellifolia*, *Ziziphus mauritiana*, and *Adansonia digitata*, many of which are traded in the region. Farmers have indigenous knowledge about the importance of many of these trees and, hence, their participation is valuable for any domestication program. Farmers have been trained in techniques of germplasm collection based on wanted traits, nursery management, propagation, tree cultivation, and postharvest processing. As seeds of most of the species have short viability, their collection and germination have to be rapid.

Market research has indicated that traders want a consistent and regular supply of uniform fruits of good quality, which cannot be accomplished from wild collection and, therefore, domestication is the best way to achieve uniformity and superior quality and regular supply. As a part of a participatory tree domestication program, rural communities in many Western and Southern African countries, particularly women farmer are establishing provenance/progeny tests of several fruit tree species in their parklands. They have also been trained in postharvest handling and value addition such as preparing juice, jelly, and other products from fruits.

5.7 Commercial Agroforestry Plantations

Most of the commercial tree plantations are monocultures, e.g., oil palm and rubber plantations. But many commercial commodities are obtained with support of tree-crop intercropping. For example, tea and coffee are cultivated under partial shade and so is true for tropical spices (black pepper, clove, cardamom, cinnamon) which are cultivated in multi-tiered cropping systems. In Indo-Gangetic plains, trees like poplar *(Populus deltoides*) and *Eucalyptus* are grown on farmers' fields on bunds or as part of farming system in wider spaces, and crops are cultivated in the interspaces. Now, many improved clones have been developed in some fast-growing trees such as *Casuarina*, *Populus*, *Eucalyptus*, *Dalbergia*, *Melia*, etc. for uniform and faster growth. Parthiban (2016) and Singh (2016) have found industrial agroforestry as a successful value chain model, which has been implemented in southern states of India, though it has production and processing constraints, but with more technological and policy interventions, it may lead to advantage to the farming community in times to come.

5.8 *Urban and Peri-Urban Plantations/Agroforestry*

These days the contributions of urban and peri-urban agroforestry, particularly ornamental trees and palms, ornamental hedges, and flower-yielding plants are immense to the quality of urban life and general environment. Most of the public parks and landscapes are developed having lush green grasses, flowers, and trees. Many people also cultivate cut flowers and vegetables along with a few fruit trees in their courtyards. Urban agroforestry is a quite old system and developed along with the development of cities; but in recent times through new approaches, urban forestry and urban agriculture join forces in supporting livelihoods. A review of the current status of urban forestry research and development, policy-making, implementation, and education across the globe shows that advances have indeed been made (van Veenhuizen 2006). Urban forestry has been developed in response to the call for innovative, comprehensive concepts that promote the multiple benefits of urban greenspace. Trees can help improve livelihoods, temper harsh urban climates, conserve biodiversity, and contribute to better human health by reducing air pollution. During recent years, integrative and strategic concepts and fields of activity have been developed and implemented across the globe to promote and develop tree-based resources catering to multiple urban demands. In the industrialized countries, cities have often turned to green areas for providing attractive environments for businesses to settle in and people to live in (Konijnendijk 2003). The generally positive impact of nearby well-managed forests, green areas, and trees on real estate prices and business development has been documented during recent years, for instance, through hedonic pricing studies (Wolf 2004; Tyrväinen et al. 2005).

Many of the world's largest cities rely on fully or partially protected forests in nearby or more remote catchment areas for much of their drinking water. Additional protective measures are often needed to ensure high-quality drinking water from these watersheds (Dudley and Stolton 2003). Trees also act as shelterbelts in cold as well as arid regions to stop the sand movements; and also intercept particles and gaseous pollutants and thus help reduce air pollution. Establishing woodlots in villages close to the urban centers relieves the pressure on natural forests for fuel wood, poles, and fodder as in many developing countries population in cities still depends on fuel wood. Urban and peri-urban forests can enhance urban agricultural production, primarily in agroforestry systems (FAO 2003; Akinbamijo 2004; Yadav and Dagar 2016; Yadav et al. 2016).

In many developing countries, disposal of sewage water is a problem. Out of estimated 356 km^3 per year of total wastewater generated across all the continents (Sato et al. 2013), only 50% is treated to primary level. In developing countries of the Middle East and North Africa, Latin America, and Asia, only 8%, 18%, and 32%, respectively, of total wastewater generated is treated. Overall, about 20 million ha of agricultural land is irrigated with treated and untreated wastewater throughout the world. Such practice has resulted in the potential health risks due to pathogens, salts, nutrients, and toxic elements in food chain. Many studies have been conducted and reported in Egypt (Braatz and Kandiah 1998; Omran et al. 1998), Australia (CSIRO 1995; Duncan et al. 1998; Lone et al. 2008), India (Das and Kaul 1992; Minhas et al. 2015; Yadav and Dagar 2016; Yadav et al. 2016), and many other countries on utilization of sewage water for raising trees, which comparative to food crops absorb and lock up more amount of the toxic elements in wood. Trees like *Acacia nilotica*, *A. salicina*, *Casuarina glauca*, *C. equisetifolia*, *Eucalyptus camaldulensis*, *E. globulus*, *E. grandis*, *E. tereticornis*, *Pinus eldarica*, *P. resinosa*, and many other species grow faster with sewage water irrigation comparative to normal water because of availability of more nutrients in sewage water. Many of these such as *Eucalyptus* evaporate huge amount of water reducing the problem of disposal. The use of tree plantations continues to be investigated globally for sustainable disposal or reuse of wastewater, improving livelihood security of million of smallholders in peri-urban areas (Quadir et al. 2010), impact on soil fertility (Yadav et al. 2003; Kumar and Reddy 2010; Tabari et al. 2011), phytoremediation (Tangahu et al. 2011; Lal et al. 2016), soil reclamation (Lone et al. 2008), creation of wetlands for improving biodiversity (Quadir et al. 2010), environmental services (Dagar 2014; Gupta and Dagar 2016a,b), and potential as carbon sequestration and climate change adaptation measures (Minhas et al. 2015; Yadav and Dagar 2016). It has been advocated that the sewage water can successfully be utilized for sustainable and high economic gains in agroforestry mode if we grow high-value crops such as cut flowers like marigold (*Tagetes erecta*), *Chrysanthemum indicum*, and *Gladiolus grandiflorus* and aromatic oil-yielding crops such as lemongrass (*Cymbopogon flexuosus*), palmarosa (*C. martinii*), German chamomile (*Matricaria chamomilla*), vetiver (*Vetiveria zizanioides*), etc. whose products in use (aromatic oil) do not come in food chain, along with trees like *Eucalyptus tereticornis* and *Populus deltoides*. Many trees and crops absorb heavy metals and act as phytoremediation agents (Ebbs et al. 1997; Tangahu et al. 2011; Lal et al. 2013).

Due to lack of awareness about the concept, lack of information exchange, and lack of strategic and coordinated action for implementation of afforestation programs and policies, the full potential of the urban agroforestry concept remains to be realized. FAO has been among the first organizations taking up the challenge of promoting the concept – under the name urban and peri-urban forestry – as a framework for action, with emphasis on the developing countries and countries with economies in transition and urban forestry's contributions to food security and poverty alleviation. The Forestry Outlook Study for West and Central Asia (FOWECA) is one among a series of regional forestry sector outlook studies initiated by FAO in collaboration with member countries to examine the trends in the development of forests and forestry (FAO 2004).

The primary objective of FOWECA is toprovide a long-term perspective of the development of the forestry sector in the West and Central Asia region in the context of economic, social, institutional, and technological changes. Using 2020 as a reference year, FOWECA aims at analyzing the trends and driving forces that will shape the sector during the next two decades and at identifying policies, programs, and investment options that can enhance the sector's contribution to sustainable development. More research inputs are required in this field, particularly about developing green belts, shelterbelts, landscapes, in-house greenry, roadside plantations, and woodlots particularly utilizing sewage water. Attention may also be paid in roof cultivation and water harvesting technologies and commercial and integrated agroforestry in peri-urban areas.

6 The Way Forward

As of today, agroforestry is considered as a problem-solving science, which is based upon solid ecological principles, and in addition to that it has inbuilt social and economical linkages. While sustainability, multifunctionality, and high sociocultural values are common strength, in general, low levels of production, lack of advance research, and technological inputs to improve the systems are the major weaknesses. There are emmense opportunities to take this science forward provided government policies are favorable. With global awareness about the role of agroforestry in mitigating climate change, the future of global agriculture lies with agroforestry.

The forest cover across the world is dwindling; it will be the trees outside forest, which will enhance tree cover more so as farm forestry. In a way forward toward climate justice, agroforestry becomes a potent instrument of resilience building for vulnerable, resource-poor communities; its potential for adaptation to climate change needs to be mainstreamed and highlighted in all measures related to farmers' welfare. All kinds of degraded lands (including those are suffering from secondary salinization) are to be brought under agroforestry systems in a mission mode. Farmers, particularly, those who are resource poor would have to be facilitated and given inter alia incentives for practicing agroforestry in the context of environmental services through proper pricing, credit, insurance, marketing, etc.

The tree species already identified for promoting agroforestry need to be denotified immediately as per their agroecological zone suitability. Special efforts are needed now to produce high-quality planting material of elite varieties so identified by the research institutions, associated with much needed certification and accreditation systems. National sustainable development strategies should integrate agroforestry more fully into key areas such as poverty elevation, rural livelihood security, skill development, natural resources management, agricultural productivity enhancement, and restoration of degraded landscapes, so as to contribute more effectively toward India's intended nationally determined contribution to the UNFCCC. Public and private sector investments in agroforestry projects and programs related to research, extension, enterprise, and education be encouraged and incentivized; and innovative financial mechanisms, including climate finance for agroforestry be developed.

In regional context, agroforestry needs to be recognized as a distinct subsector under agriculture. The nodal ministry and/or agency for dealing matters relating to agroforestry needs to be clearly demarcated/nominated at the national and subnational (local) levels. Development of country-specific national policies on agroforestry and enabling mechanisms for their implementations need to be given high priority. Indian experience, ICRAF's experience, APAARI's facilitating role, and assistance from international agencies could be useful to further this initiative. A regional/international consortium-cum-network on agroforestry with a facilitation role of ICRAF, in partnership with APAARI, needs to be initiated quickly to ensure policy advocacy, public awareness, knowledge and research germplasm sharing, and capacity development and to accelerate much needed collective regional actions. The development of sound regional database, information system, and eco-region-based decision support system should receive high priority for the proposed network. Sharing of success stories of countries in the region also needs to be encouraged through open access to relevant information. An independent scientific study be undertaken to identify and assess the determinants for the scaling up of agroforestry products including market mechanism, import and export policies, and support prices, etc. Efficacy of communication and mass awareness strategies may be considered to promote agroforestry among all stakeholders. Investments, being critical for agroforestry research, teaching, training, and extension, should be at least doubled to promote agroforestry in the national and regional interests.

Medium to long-term collaborator studies to quantify contribution of agroforestry to ecosystem services, carbon sequestration, and climate change mitigation and adaptation need to be institutionalized by IARCs and the regional institutions. Awareness for public-private partnership through creation of enabling environment such as process patenting, branding, and incentives to both producers and industry needs to be created to promote further agroforestry in the region. Development of agroforestry value chains would be critical for scaling up promising innovations and to create win-win situations in the agroforestry subsector. Business planning and development involving all stakeholders in the value chain (farmer to consumer) needs to be institutionalized in a mission mode approach. Development of elite multiple-stress-tolerant germplasm and making it available for stakeholders on affordable price, establishment of acredated nurseries in large number, value addition to agroforestry products, domestication of high-value agroforestry crops, and evolving stable and sustainable marketing mechanism need attention as policy initiatives.

7 Conclusions

Agroforestry research now has provided powerful technological and policy innovations that are rapidly spreading in Africa, Asia, Latin America, and more recently in several developed countries. Now, agroforestry systems are not only for sustainable production but are also problem-solving mechanism. For example, for rehabilitation of degraded lands, mitigating climate change through carbon sequestration, employment generation, and food and nutrient security agroforestry systems are playing a vital role. Agroforestry plays important role in rehabilitation and biological reclamation of problem soils such as degraded dry lands prone to water and wind erosion including sand dunes; acid sulphate soils of humid regions characterized by low pH, toxicity of aluminum, and iron and deficiency of nutrients; salt-affected sodic and saline soils; and waterlogged saline soils. Profitable agriculture is possible if appropriate agroforestry technologies and know how are used judiciously. For checking wind erosion, windbreaks and shelterbelts involving appropriate species which require less water, possess deep root system, can be established easily with less water, and grow fast will be useful tools. The trees and shrubs will play major role in improving efficiency of nutrient cycling in the system.

Biological barriers such as alley cropping and plugging in ravines, involving appropriate species play important role in checking water erosion in sloping and ravine lands. The highly alkali soils (pH > 10) may be rehabilitated with identified tree. The saline soils may be successfully brought under vegetation cover following suitable planting techniques. For arid soils, proper agroforestry systems may be established successfully using saline water for irrigation. The tree species not only produced economic yields in terms of wood biomass but also improved soil conditions, i.e., in terms of organic matter and physical properties. Fruit-based agroforestry system involving trees and low water requiring crops such as cluster bean, pearl millet, mustard, and barley as intercrops is most suitable for calcareous soils irrigating with saline water. Nonconventional crops such as castor, *Aloe vera*, dill, taramira (*Eruca sativa*), Isabgol, senna, and lemongrass could be cultivated successfully. Biodrainage involving fast-growing trees like *Eucalyptus* and *Populus* is an eco-friendly agroforestry technique to combat waterlogging, increase farmers' income, and sequester carbon. Agroforestry helps in improving both below and aboveground biodiversity and provides opportunities to meet the livelihood security of poor and landless masses and mitigate climate change and several other ecological services. For a successful action plan, we need agroforestry and farmer friendly policies both at national and regional level. If implemented seriously, there is no reason that the problem of poverty and malnutrition is not solved at global level along with mitigating climate change and having environmental benefits.

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