South Asian Agroforestry: Traditions, Transformations, and Prospects

B. Mohan Kumar, Anil Kumar Singh, and S.K. Dhyani

Abstract The South and Southeast Asian region is often described as the cradle of agroforestry in recognition of its long history of the practice of an array of systems under diverse agroecological conditions. The multitude of systems that have evolved in the region over long periods reflect the accrued wisdom and adaptation strategies of millions of smallholder farmers to meet their basic needs of food, fuelwood, fodder, plant-derived medicines, and cash income in the wake of increasing demographic pressure and decreasing land availability. Prominent examples of agroforestry in South Asia include multifunctional homegardens, which promote food security and diversity; woody perennial-based systems furthering employment avenues and rural industrialization; fertilizer trees and integrated tree-grass/crop production systems favoring resource conservation; and tree-dominated habitats, which sustain agrobiodiversity and promote climate change mitigation. The experiences from these dominant land use systems exemplify the role of agroforestry in addressing the land management challenges of the twenty-first century such as climate change, biodiversity decline, food and nutritional insecurity, and land degradation in this highly populated region. The thread running through this chapter is that traditional agroforestry systems that have been practiced over centuries have evolved and adapted to the changing pressures. Such transformations have been a potent means to address some of the present-day global challenges; their efficiency, however, can be enhanced considerably with the input of additional resources and support.

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Introduction

South Asia comprises of the sub-Himalayan countries and the adjoining tracts to the west and the east. High levels of topographic and climatic heterogeneity are intrinsic features of this region. Important South Asian ecologies include the hilly and mountainous areas, Indo-Gangetic plains, arid and semiarid regions, and the coastal humid zones. Afghanistan, Bangladesh, Bhutan, India, the Maldives, Nepal, Pakistan, and Sri Lanka are the principal countries in this region. Most of South Asia and the adjacent territories (popularly known as the Indian subcontinent), which became sovereign nations at different times in history, share close cultural and social values, which are reflected in land use also. Rich natural resource endowments in terms of vegetation, soil, animal, and fish make South Asia a mega-biodiverse region. High demographic pressure (Table 1), however, has led to over-exploitation of natural resources including timber and non-timber forest products (Muraleedharan et al. 2005; Gunawardene et al. 2007). This, together with agricultural intensification, has resulted in rapid biodiversity losses (Kumar 2005; Vencatesan and Daniels 2008) making the Western Ghats and Sri Lanka region as well as the Eastern Himalayas “biodiversity hot spots” of the world (Myers et al. 2000).

Agroforestry systems and practices abound in South Asia, especially in countries such as India, Sri Lanka, and Bangladesh, since time immemorial (Singh 1987). Biophysical heterogeneity and the capacity of such systems to satisfy the needs and aspirations of the local people by providing them with multiple products and services would probably explain this. An attempt is made here to summarize the long history and diversity of South Asian agroforestry systems and practices; their potential to meet the ever-increasing food, fuel, fodder, and timber requirements of the society; and synthesize the available information on ecosystem services (e.g., climate change mitigation and agrobiodiversity conservation potentials) of these systems. This chapter covers broad aspects of agroforestry, from technology, economics, management, and policy in a regional perspective, and focuses on how agroforestry might be sustained and promoted as desirable land use strategies amid competing interests and pressures.

The diverse agroforestry systems practiced over centuries in this region also have undergone transformations in response to changing pressures. Although such transformations reflect the great potential of agroforestry in resolving many of the world’s challenges, the level at which it is applied needs more thrust and encouragement. The focus, therefore, is on how agroforestry might be sustained and promoted as improved land use strategies amid competing interests and pressures. The approach adopted in this analysis is to review the archaeological and literary evidences and draw inferences from past experiences and current propensities. The chapter also aims to

Table 1 Land area and demographic attributes of South Asia

Country	Land area (1,000 ha)	Population 2008 Total (1,000)	Density per km^2	Annual growth rate (%)	Per capita GDP 2008 (US $)
Afghanistan[a]	65,223	29,840	41.7	3.5	466
Bangladesh	13,017	160,000	1,229	1.4	1,335
Bhutan	3,839	687	18	1.6	4,759
India	297,317	1,181,412	397	1.4	2,946
Maldives	30	305	1,017	1.3	5,597
Nepal	14,335	28,810	201	1.8	1,104
Pakistan	77,088	176,952	230	2.2	2,538
Sri Lanka	6,271	20,061	320	0.9	4,564
Total South Asia (excluding Afghanistan)	411,899	1,568,227	381	1.5	2,724
Total world	13,009,550	6,750,525	52	1.2	10,384

[a]Source: UN Statistics Division and FAO (2011) for all others
GDP gross domestic product

examine how the lessons learned from the region could be relevant and applicable to other regions experiencing similar social and environmental pressures.

Historical Aspects of Agroforestry in South Asia: Early Fruit-Tree Domestication

Farmers in many traditional cultures of South Asia have been domesticating fruit trees and other agricultural crops around their dwellings for millennia, primarily to meet their subsistence needs. The best example of this is perhaps the tropical homegardens, which are essentially a complex integration of diverse trees with understorey crops performing several production and service functions (Fig. 1). The prehistoric origin of tree integration in homegardens can be traced to the discarding of seeds or vegetative propagules of edible plants and other useful species collected from the forest by the early man (hunter-gatherers) near the dwellings, where they germinated and grew. Anderson (1952) described this as the “dump heap” method or incidental route to domestication. The sites around habitations provided a congenial environment for the survival of such “regenerants.” The detection and maintenance of such “volunteers” would have been the next phase. Slowly, however, the unintentional dissemination of seeds became more systematic with important species planted to ensure their utilization (Wiersum 2006). The prehistoric people may have also instinctively selected trees with larger fruit size, better quality, or other desirable features from the wild, besides supporting their regeneration. This, in turn, resulted in the cultivated populations becoming genetically distinct from their wild progenitors (Ladizinsky 1998).

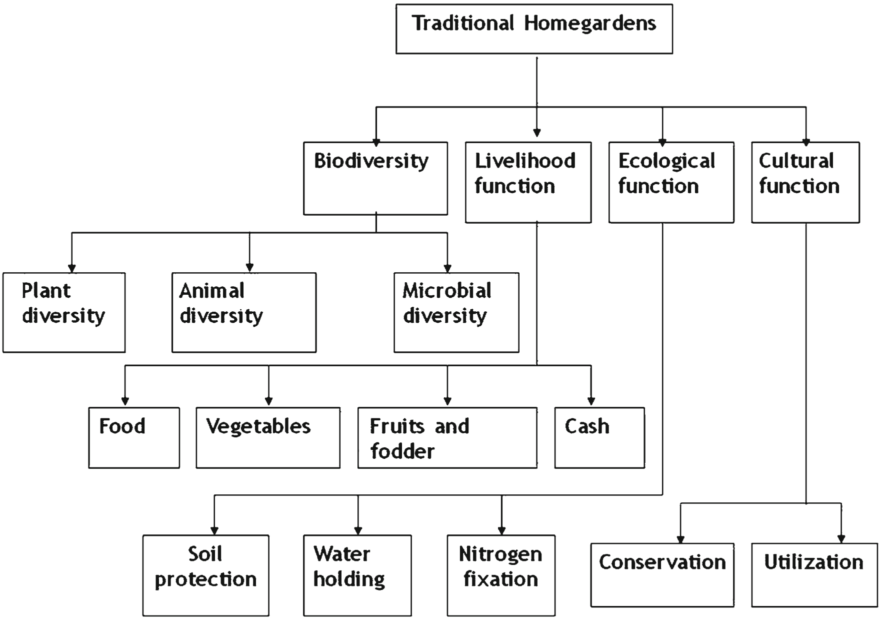

Fig. 1 The homegardens—a case from India (Based on Das and Das (2005), Kumar (2005))

Archaeological excavations corroborate early tree domestication around the settlements in South Asia. The earliest evidence of this dates back to the Mesolithic period (10,000–4,000 before present) when fruits of 63 plants including *Aegle marmelos* (L.) Corr. (bael), *Buchanania lanzan* Spreng. (chirauli-nut), *Phyllanthus emblica* L. (Indian gooseberry), *Mangifera indica* L. (mango), *Ficus* sp. (fig), *Madhuca* sp. (mahua), and *Ziziphus* sp. (ber) were reportedly eaten raw, ripe or roasted, or pickled by the inhabitants of central India (Randhawa 1980). The long history of agroforestry in South Asia (although the term *agroforestry* was not introduced until the late 1970s) is further elucidated in the early literature, as summarized below:

- Agroforestry including homegardening and rearing of silkworm (*Bombyx* spp.) and lac insect (*Laccifer lacca* Kerr) was practiced in the Indian subcontinent during the Epic era when *Ramayana* and *Mahabharat,* the two great epics, were composed (7000 and 4000 BCE, respectively; Puri and Nair 2004).
- Emperor *Ashoka*, a great Indian ruler (273–232 BCE), encouraged a system of arbori-horticulture of plantains (*Musa* spp.), mango, jackfruit (*Artocarpus heterophyllus* Lamk.), and grapes (*Vitis* spp.). As per the second of the 14 *Rock Edicts* of *Ashoka* (257 BCE), planting of medicinal herbs and trees besides shade trees along the roads and fruit plants on the wastelands was an accepted norm in those days—analogous to social forestry and agroforestry programs of the present.
- The travelogue of *Ibn Battuta* (Persian traveler; 1325–1354 CE) provides the earliest literary evidence of agroforestry from peninsular India, and it mentions

that in the densely populated and intensively cultivated landscapes of Malabar coast, coconut (*Cocos nucifera* L.), and black pepper (*Piper nigrum* L.) were prominent around the houses (Randhawa 1980).

- Plow agriculture was prevalent in Wayanad, one of the high-altitude locations in the Western Ghats, as early as in the Megalithic Age (between 400 BCE and 400 CE), and spices like black pepper, ginger (*Zingiber officinale* Roscoe), and cardamom (*Elettaria cardamomum* (L.) Maton Engl.) were often grown in association with woody perennials—as nurse (shade or support) trees, since the early Middle Ages (500–1400 CE).[1]
- The contents of the over 300-year-old book of agricultural verses in Malayalam, *Krishi Gita* (Kumar 2008), also reflect on the need to maintain better tree cover on the landscape, 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 landscape—presumably for agrobiodiversity conservation and ecological balance.
- Natural history studies during the two previous centuries[2,3] further 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 the like.

Sustainable Land Use and Nature Conservation Ethos in Ancient South Asia

Sustainability was the underlying theme of most traditional production systems. This concept was ingrained in the minds of early inhabitants of South Asia, which is evident from the teachings of *Vedas*. For example, the *Atharva Veda* (2nd millennium BCE) hymn 12.1.35 reads:

> Whatever I dig out from you, O Earth! May that have quick regeneration again; may we not damage thy vital habitat and heart.

During the *Vedic* age, no village would be considered complete without its corresponding woodlands in and around the houses, and every village must have a cluster of five great trees, "panchavati" symbolizing the five primary elements: earth, water, fire, air, and "ether"—the totality of everything. Ancient historical chronicles from the period of King Vijaya of Sri Lanka[4] (ca. 543 BCE) such as "Maha-Wamsa," "Rajaratnacari," and "Rajawali" also exemplify that the village communities lived in harmony with the neighboring forest environment.

Numerous descriptions of trees and groves exemplifying the relationship between the Indian people and trees are also available in the early writings. For example, *Varahamihira's Brihat Samhita* (ca. 700 CE; Bhat 1981) describes the relationships between irrigation tanks and trees. *Varahamihira* provided detailed technical instructions on tank construction and prescribed the species to be planted on the embankments. The trees he mentioned[5] include several of the common fruit- and nut-yielding species that are popular even today. Agriculture by *Parashara* (*Krishi-parasara*: 400 BCE), Laws of Manu or *Manusmriti* (ca. 200 BCE and 200 CE), The Epic of Fire or *Agni Purana* compiled ca. 700–800 CE, A Treatise on Agriculture by *Kashyapa* (*Kashyapiyakrishisukti* ca. 800 CE; Ayachit 2002), and The Science of Plant Life by *Surapala* (*Surapala's Vriksha Ayurveda* ca. 1000 CE; Sadhale 1996) are some of the other relevant texts from that era.

Multitude of Agroforestry Systems and Their Attributes

Diverse agroforestry systems where trees are grown with crops, and/or sometimes with animals, in interacting combinations in space or time dimensions, are practiced in the densely populated regions of South Asia (Table 2). Zomer et al. (2009)[6] estimated that about 21% of the geographical area (approximately 38.91 million ha) of this region has more than 10% tree cover, implying the overabundance of trees in the managed landscapes. According to Tejwani (2008), agroforestry (outside the forest) has more number of trees than the "State" forests. The prominent South Asian agroforestry systems include parkland systems; agrisilviculture involving poplar (*Populus deltoides* Bartr.) and *Eucalyptus* spp.; plantation agriculture involving coffee (*Coffea* spp.), tea (*Camellia sinensis* (L.) O. Kuntze), cacao (*Theobroma cacao* L.), and spices (e.g., black pepper, cardamom) in association with a wide spectrum of trees (planted as well trees in the natural forest), betel vine (*Piper betel* L.)+ areca palm (*Areca catechu* L.); intercropping systems with coconut, para rubber (*Hevea brasiliensis* H.B.K. M.-Arg.), and other trees (Figs. 2, 3, and 4); commercial crop production under the shade of trees in natural forests (e.g., cardamom); and homestead farming systems (Kumar 1999, 2005; Nath et al. 2011). Deliberate growing of trees on field bunds (risers) and in agricultural fields as scattered trees and the practice to utilize the open interspaces in the newly planted orchards and forests for cultivating field crops are also widespread in the subcontinent (Singh 1987).

Multifunctionality is a characteristic feature of agroforestry practices in South Asia, as elsewhere. Most agroforestry systems also have the intrinsic potential to provide food, fuel, fodder, green manure, plant-derived medicines, and timber resources. A new species may be chosen because of its properties, that is, food, wood, medicinal, religious, and ornamental, based on self-instinct or information passed on by neighbors and relatives. The products may be used for domestic consumption and for sale, depending on the scale of production and the economic status of the land manager. The choice of species and planting techniques adopted in such systems also reflect the accrued wisdom and insights of the traditional people who interacted with the environment for long. It is reasonable to assume that the indigenous cultivators used rational ecological approaches to maneuver the plants, which endowed sustainability to the system.

Table 2 Prominent agroforestry systems of South Asia

System	Functions	Remarks
Agrihorticultural system	Timber, fuel, fodder, medicines, non-timber forest products, and food production	Diverse fruit plants integrated with other multipurpose trees; widespread in Bangladesh, India, Nepal, and Sri Lanka
Agrisilviculture	Industrial wood and food production	*Acacia mangium* Willd., *Ailanthus triphysa* (Dennst.) Alston., *Tectona grandis* L.f., and other tree species in association with an array of food crops; *Populus deltoides* Bartr. (poplar) and *Eucalyptus* spp. are important in northern India (Terai region) and Pakistan, where poplar agroforestry increased water productivity and profitability of smallholder farmers (Zomer et al. 2007). High internal rates of return (38–40.5%) with wheat and fodder intercrops for first 7 years in an 8-year poplar cycle (Source: Pratap 2004)
Alley cropping/farming	Food, fuel, fodder, and green manure production, soil fertility enhancement, and environmental conservation	Practiced by the smallholder farmers of South Asia. Quick-growing trees and/or field crops grown in association with commercial tree crops
Aquaforestry	Fish, fruit plants, timber and firewood, nutrient cycling	In the coastal tracts of India, Bangladesh, Sri Lanka, and Maldives
Boundary/hedgerow tree planting/live fences	Fuelwood, fodder, timber, shade, and support trees for trailing black pepper vines, protect crops from roaming wildlife, domestic animals, and human interference	Trees on hedges (0.5 m apart in single rows or paired rows at 1 m apart); require frequent pruning to maintain the desired form (height, width, and shape) to encourage secondary branching to create an impenetrable barrier. Nitrogen-fixing tree genera are important
Commercial crops under the shade of planted trees	Beverage crops, tree spices, medicinal and aromatic plants, besides timber, firewood, and other tree products	Tea (*Camellia sinensis* (L.) O. Kuntze), coffee (*Coffea* spp.), cacao (*Theobroma cacao* L.), spices like clove (*Syzygium aromaticum* (L.) Merr. & Perry), nutmeg (*Myristica fragrans* Houtt.), black pepper (*Piper nigrum* L), betel vine (*Piper betel* L.) etc., require varying levels of shade for optimum growth and production

(continued)

Table 2 (continued)

System	Functions	Remarks
Energy plantations	Lignocellulosic biomass, wood, and biofuel production	Cultivation of biomass crops (e.g., bamboos, wattles, and other short rotation tree crops) and tree-borne oilseed crops (e.g., *Simarouba glauca* DC., *Jatropha curcas* L.) are gaining attention
Entomoforestry	Lac, silk worm, and honey production	Apiculture, lac culture, and sericulture. Sericulture-based agroforestry systems quite remunerative in the hilly areas of northeast India (Dhyani et al. 1996)
Fodder banks	"Cut and carry" fodder production	Designed to provide fodder during the dry season; harvested on a rotational basis providing year-round fodder
Multistoried cropping systems	Fruits, nuts, timber, and fuelwood production	Intercropping food crops with palms (*Cocos nucifera* L., *Areca catechu* L., *Phoenix sylvestris* Roxb., *Borasus flabellifer* L.), jackfruit tree (*Artocarpus heterophyllus* Lamk.), *Acacia nilotica* (L) Del., *Dalbergia sissoo* Roxb., *Paulownia* spp., *Ziziphus jujuba* Mill., *Hevea brasiliensis* H.B.K. M.-Arg., fruit orchards, and growing medicinal and aromatic plants under the shade of trees—popular throughout South Asia
Parkland agroforestry	Food, fuelwood, and timber	*Prosopis cineraria* (L.) Druce systems practiced in India and Pakistan
Shaded commercial crop production systems: coffee (*Coffea* spp.), tea (*Camellia sinensis*), small cardamom (*Elettaria cardamomum* (L.) Maton Engl.), large cardamom (*Amomum subulatum* Roxb.), cacao (*Theobroma cacao*)	Commercial crop production, timber, and fuelwood	Prevalent in the mid and high altitude zones of India, Bhutan, Nepal, and Sri Lanka. Planted shade trees as well as trees in the natural forests are used, e.g., large cardamom grown in association with alder (*Alnus nepalensis* D. Don) in Sikkim Himalayas, small cardamom grown under the shade of trees in the natural forests in the peninsular India (Kumar et al. 1995)

Shelterbelts and windbreaks	Protecting crops and livestock from high-velocity winds, reduce wind erosion, biomass energy, and wood production	Practiced in many parts of South Asia in which fast-growing trees are planted at close intervals (e.g., block planting of *Casuarina equisetifolia* J.R. & G. Forst. and *Acacia mangium* Willd. in the coastal areas)
Shifting cultivation or swidden farming	Subsistence food production	63.57 million ha in Bangladesh, India, and Sri Lanka (ESCAP 1992)
Silvopasture	Timber, fuelwood, and fodder production	Adapted tree + grass combinations contributing to forage production. *Acacia leucophloea* Willd. + *Cenchrus setigerus* Vahl. silvipasture system in the Kangeyam tract of Tamil Nadu; over 400-year-old system. In the ravines of Yamuna and Chambal, trees, shrubs, and bamboos plus grasses; for rearing the milk-producing *Jamunapuri* breed of goats and sheep
Sloping agricultural land technologies (SALT)	Fodder, firewood, soil conservation, environmental protection	Integration of soil conservation and food production strategies on steep slopes; alternate strips of timber and firewood trees with cereals (corn, upland rice, etc.) and legumes (soybean, mung bean, peanut, etc.); provides the farmers returns throughout the year
Taungya	Timber and subsistence food production	Originated in Burma and spread to different parts of the world. Field crops grown in the interspaces of forest crops during the early stages. Trees: *Shorea robusta* Gaertn., *T. grandis*, *Dalbergia sissoo*, *Acacia catechu* (L.f.) Willd., *Eucalyptus globules* (Labil.), poplar *Pinus patula* Schiede & Schltdl. & Cham.
Tropical homegardens	Food, fuelwood, fodder, plant-derived medicines, other non-timber tree products, medicines, and cash income	Cover about 8 million ha in south and southeast Asia (Kumar 2006). Kerala and Kandyan homegardens are prominent in the South Asian context
Woodlots	Timber and firewood production, fodder, lignocellulosic biomass, bio-drainage, CDM projects	Short rotation intensive cultural systems involving fast-growing tree species, e.g., poplar, eucalyptus, mangium, teak, and the like

Fig. 2 Tea+ *Grevillea robusta* (silver oak) system in Munnar, Kerala (Photo: BM Kumar)

Fig. 3 Pineapple (*Ananas comosus*) + rubber (*Hevea brasiliensis*) saplings (Photo: BM Kumar)

Fig. 4 Shaded coffee (*Coffea* spp.) production system in the Western Ghats (Photo: BM Kumar)

Transformations Over Centuries

The traditional land use systems have changed over time—as a function of the interplay of socioeconomic and technological factors. Figure 5 illustrates the paradigm shifts in this respect. In particular, agricultural transformations brought about by market economies in the recent past, especially the incorporation of exotic commercial crops (e.g., *Hevea brasiliensis*), have led to the decimation of many traditional land use systems (Kumar 2005; Guillerme et al. 2011). For example, the homegardens that constituted a predominant land use activity of the subcontinent (e.g., the Kandyan, Kerala, and other homegarden systems: Kumar and Nair 2004, 2006) of late have been showing symptoms of decline (Guillerme et al. 2011). The key drivers of this have been rising population pressure and the policies oriented toward land use intensification to meet the rising food grain requirements (e.g., monospecific production systems). The traditional landscapes and production systems, however, have been receiving some attention more recently. It is now recognized that the traditional farmers have conserved biodiversity of great economic, cultural, and social values (Kumar and Nair 2004).

Environmental concerns such as global warming, land degradation, erosion of biodiversity, loss of wildlife habitats, and increased nonpoint source pollution of ground and surface water have provided an additional impetus for the development and adoption of agroforestry around the world (Fig. 5). Furthermore, as fossil reserves (for producing nitrogenous fertilizers) and the mineral deposits of phosphates and potash are getting progressively depleted, a fertilizer crisis may be emerging. The fossil fuel reserve depletion times for oil, coal, and gas have been calculated as approximately 35, 107, and 37 years, respectively (Shafieea and Topal

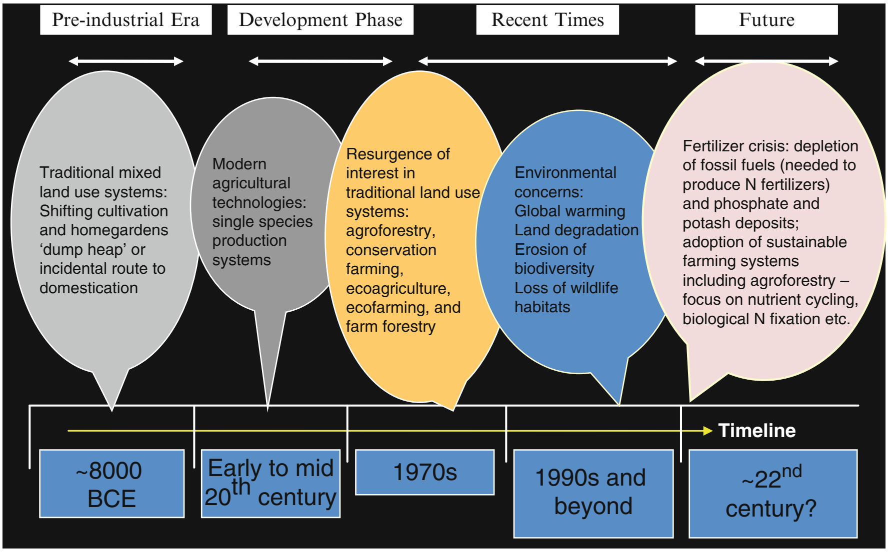

Fig. 5 Evolutionary pathways of South Asian agroforestry. Early to mid-twentieth century up until the 1970s constitutes the "development phase" characterized by the Green Revolution (Modified from Kumar and Takeuchi 2009)

2009); the implications of which are startling. Likewise, it is unlikely that phosphate rock deposits may last beyond another 100 years (Herring and Fantel 1993). With this projected fertilizer crisis, agroforestry focusing on fertilizer trees and other resource conservation and sharing mechanisms is likely to get better attention in the future.

Of late, economic incentives to the land managers also have acted as a major driver of agroforestry in certain parts of South Asia. The poplar (*Populus* spp.)-based agroforestry in northern India, especially in the lowland "Terai" areas at the base of the Himalayas, is a case in point. Following a modest beginning when four poplar clones from Australia were introduced in 1969,[7] poplar cultivation in northern India has made rapid strides. Presently, there are 70 million poplar trees in the agricultural fields of the upper Gangetic region producing 10.40 million m^3 of industrial wood (Rizvi et al. 2011). Consequent to the ban on timber cutting in the state forests of India, and the widening gap between demand and supply, the wood-based industries have no option but to depend on farmers for meeting their raw material demands (Chandra 2003).

Woodlots of other fast-growing trees such as *Eucalyptus* spp., *Leucaena leucocephala* (Lamk.) de Wit., *Casuarina equisetifolia* J.R. & G. Forst., *Acacia mangium* Willd., *A. auriculiformis* A. Cunn. ex Benth., *Ailanthus triphysa* (Dennst.) Alston., and *Melia dubia* Cav. are also becoming increasingly popular among the farmers in several parts of the Indian subcontinent. Overall, agroforestry in South Asia is being both intensified (e.g., intensive tree and crop management practices) and simplified (e.g., fewer economically important species) as a result of current policies (Guillerme et al. 2011) and economic imperatives.

To capitalize on the ecological and production functions outlined earlier, the National Agricultural Policy (2000)[8] of India stressed that "farmers will be encouraged to take up farm/agroforestry for higher income generation by evolving technology, extension, and credit support packages and removing constraints to development of agroforestry." Similar policy initiatives are in place in other countries of the subcontinent too. For example, forest tree planting on farmlands and in homegardens through social forestry was an important component of the National Forest Policy (1995) of Sri Lanka (De Zoysa 2001). This policy recognized that the homegardens and other agroforestry systems and trees on other agricultural lands play a crucial role in supplying timber, bio-energy, and non-wood forest products, while conserving the micro-environment.

Agroforestry Research in South Asia: Early Beginnings

Although agroforestry as a practice was very ancient in South Asia, the science of agroforestry is relatively new. Some research of this nature was conducted earlier but was not recognized as agroforestry (e.g., Nair 1979 and many others). Organized research on agroforestry started in India with the establishment of the All India Coordinated Research Project on Agroforestry in 1983 (ICAR 1981). The research initiatives gained further momentum with the commencement of forestry education programs in the State Agricultural Universities of India during 1985/1986 and the founding of the National Research Centre for Agroforestry (NRCAF) at Jhansi, UP, in 1988. As part of the agroforestry research initiatives, a series of workshops and seminars were held in India; the first in the series was at Imphal in 1979 involving the Indian Council of Agricultural Research (ICAR) and the International Centre for Research in Agroforestry (ICRAF). This was followed by another series of Indo-US Workshop-cum-Training sessions during 1988–1992 on various aspects of agroforestry, in which many key American resource persons participated. Exchange programs were also initiated in the 1980s in which several Indian scientists received advanced training/degrees in agroforestry and related areas from various US, UK, and Canadian universities—with support from the US Agency for International Development, the British Council, and the Canadian International Development Agency. With such programs, India was able to develop a critical mass of agroforestry scientists. Other countries in the region such as Nepal, Sri Lanka, Pakistan, and Bangladesh also followed a similar strategy, and agroforestry came of age in those countries as well. Results of a keyword ("agroforestry" + "country name") search in Scopus,[9] which returned 3,761 hits for India, 734 for Nepal, 609 for Pakistan, 546 for Bangladesh, 451 for Sri Lanka, 71 for Bhutan, 20 for Afghanistan, and 8 for Maldives, exemplify that.

Major Land Use Challenges in South Asia

Food Insecurity

Historically, food production in South Asia increased at the same rate as that of human population during the second half of the past century. However, population growth has outmaneuvered the food production trends in the past decade. According to FAO (2010), South Asia accounts for about 40% of the about 835 million undernourished people in the developing world. To make matters worse, increases in cereal yields are slowing down in all regions of the world, including South Asia, due to reduction in total factor productivity (TFP). Yet another feature of South Asian food production is that it is mostly done by smallholders: about 80% of the holdings are less than 0.6 ha in extent (Gulati 2002), and one or more types of mixed species gardens are present on these smallholdings, and these units function at low levels of productivity. Diminishing soil fertility is yet another concern (De Costa and Sangakkara 2006); although input-intensive agricultural production systems have been promoted on the small farms in the past, such systems have not made much headway because of the high costs of inputs, non-availability of resources, environmental costs, and various other socioeconomic and technological constraints.

Rising Timber and Fuelwood Needs

The gap between supply and demand of major forest products in South Asia has been widening over the past decades, leading to unsustainable extraction of wood from the natural forests and causing forest degradation.[10] The importance of sourcing raw materials for the wood-based industries from non-forest areas through agroforestry, therefore, cannot be overemphasized. The tropical homegardens, poplar-based agroforestry, and other woodlots are of special significance in this respect, as they have the intrinsic potential to provide substantial wood resources. According to some reports (e.g., Kumar and Nair 2004), the tropical homegardens provide 70–84% of the commercial timber requirements of the South Asian societies. However, these multipurpose traditional land use systems are waning in most parts of the subcontinent. In the light of the emerging challenges in meeting the timber requirements, such systems, however, should be revitalized.

Fuelwood consumption has also increased steadily paralleling population growth throughout the developing countries. Fuelwood accounts for ca. 2,300 million m^3 or 60% of the total annual wood production globally (FAO 2003). Although rising income levels and expanding urbanization make it possible for people to have access to more modern forms of energy such as oil, coal, and gas, absolute quantities of fuelwood consumption in South Asia and many other developing countries have been increasing progressively. A recent study from Bangladesh (Akther et al. 2010) indicated that a majority (94%) of households in the downstream zone of the

Old Brahmaputra River experienced fuelwood scarcity. With increasing levels of deforestation and forest degradation, fuelwood not only becomes scarcer but also its collection for household consumption becomes very arduous, a task usually assigned to women and children. In certain cases, gathering fuelwood can consume 1–5 h per day for these women (IEA 2000), implying strong social, gender, and health concerns related to the declining availability of fuelwood.

Land and Forest Degradation

Historically, deforestation and forest degradation have been critical issues threatening ecosystem stability and depleting the natural resource base. Recent FAO (2011) figures suggest that within South Asia, annual deforestation rates are 1.1, 2.2, 0.7, and 0.2% for Sri Lanka, Pakistan, Nepal, and Bangladesh, respectively; India and Bhutan, however, showed modest increases in forest cover over this period. Although no net deforestation has been reported for India, there is still diversion of forests for agriculture (shifting cultivation)—to the tune of about 9 million ha annually, particularly in the northeastern states (MoEF 2006). The National Forest Commission of India reported that about 41% of the country's forest cover has already been degraded and dense forests are losing their crown density and productivity continuously, 70% of forests have no natural regeneration, and 55% are fire-prone (MoEF 2006). On the whole, forest degradation is a still a major form of land degradation in South Asia.

Soil salinization and water logging, which render arable lands unproductive, also continue unabated in most parts of South Asia (van Lynden and Oldeman 1997; Scherr 1999; Eswaran et al. 2001; Lal 2001). Indeed, out of the world's 1,900 million ha of land affected by soil degradation, the largest area (around 747 million ha) is in Asia (Oldeman 1994). In India alone, about 121 million ha land (73, 12.4, 17.45, and 1.07 million ha of arable land under water erosion, wind erosion, chemical degradation, and physical degradation, respectively, and 16.5 million ha open forest area) are under one or the other forms of degradation (ICAR 2010). As in most other developing countries, the South Asian countries also lack capital resources to make the financial investments required to reclaim degraded lands, which further complicates the matter.

Global Warming

During the past two decades or so, concern has also grown among the scientists and public about the possible impacts of climate change on terrestrial ecosystems, especially with respect to plant growth, changes in biodiversity, nutrient recycling, and the overall effect on carbon storage in the biosphere (Rosenzweig and Hillel 1998; Kumar et al. 2005; IPCC 2007). Land use changes have contributed substantially to the rising concentration of CO_2 in the earth's atmosphere. The average annual increase for the past decade (2001–2010) was 2.04 $\mu L\ L^{-1}$ (2.04 ppm), with a predicted doubling of the pre-industrial concentrations by the end of the twenty-first century.[11] The consequences of climate change will be felt across the world and include rise in sea level, drought and flooding, and an irreversible loss of many species of plants and animals. The poor countries in South Asia are likely to be the most vulnerable to the effects of climate change (Pachauri 2012). The impact of global warming on food production in South Asia is particularly distressing as the predicted shifts in monsoonal rainfall patterns (Lal et al. 2001) may render large areas unproductive, leading to significant reductions in cereal yields.[12] So much has been written about these issues, even in this volume, so that whatever is written here will appear to be too skimpy on the one hand, and too elaborate descriptions are unwelcome in this context on the other.

Biodiversity Losses: A Cause of Concern

Erosion of farmland biodiversity is one of the most serious problems in ecosystem management today (Benton 2007). Agricultural intensification in South Asia in the past has decimated many traditional land use systems, which customarily preserved landraces and cultivars, as well as rare and endangered species. A case study in the Indian Central Himalaya indicated that as cropping intensified, the traditional crop varieties declined drastically (Maikhuri et al. 1999). Indeed, of the 3,000 varieties of rice cultivated in India before the green revolution, only 50 have survived (Shiva and Prasad 1993). Likewise, cultivation of high-yielding varieties of cereal crops in the irrigated areas of Central Himalayas exterminated the hitherto prevalent fodder trees (334–418 fodder trees per ha)—a major source of animal fodder especially during the lean seasons (Semwal and Maikhuri 1996). Introduction of exotic fast-growing trees and conversion of traditional agroforestry systems (including homegardens or their parts) to monospecific production systems also led to a declining diversity of herbaceous components such as traditional vegetable crops and ornamental plants, besides tree species (Guillerme et al. 2011). Overall, this decline in landscape diversity signifies reduced on-farm availability of green manure, fodder, and firewood resources and increased dependence on adjacent forests for these resources (Kumar and Takeuchi 2009).

Loss of biodiversity is not limited to managed ecosystems but is a serious problem in natural forests of this region too. Habitat fragmentation leading to loss of native habitat limits the species' potential for dispersal, colonization, and foraging ability. Approximately 15,000 km^2 constituting about 60% of the rainforests in Western Ghats, India, are severely fragmented to parcels of <10–2,000 ha in extent (Collins et al. 1991), contributing to species losses. The International Union for Conservation of Nature[13] reported that a total of 659 Indian species are threatened (246 plants, 96 mammals, 76 birds, 25 reptiles, 65 amphibians, 40 fishes, 2 molluscs, and 109 other invertebrates) because of anthropogenic pressures on the natural habitat. Consistent with this, Puyravaud et al. (2003) reported that among the 352 identified species and varieties of the endemic flora of Western Ghats 14% are threatened.

Agricultural Nonpoint Source Pollution

Agricultural nonpoint source pollution (NPSP) is a significant cause of stream and lake contamination in many regions of the world. Nonpoint source pollution owing to agricultural intensification constitutes a major environmental problem in the Indian subcontinent also. Pawar and Shaikh (1995) reported that ground and surface water samples from a small watershed in the Deccan Trap Hydrologic Province, India, contained anomalously high NO_3 levels (2.2–64 ppm). In another study from the Krishna basin in Belgaum district of Karnataka, India, Purandara et al. (2004)[14] also observed high post-monsoon loads of major anions and cations in the Malaprabha river (kg day^{-1}): Na (1,557–4,276), K (1,145–6,480), Ca (6,594–25,401), Mg (1,786–12,960), Cl (6,493–68,915), SO_4 (11,448–53,784), and HCO_3 (48,603–229,262)—more than 90% of which was derived from nonpoint sources.

Agricultural chemicals such as fertilizers, manures, and pesticides are the principal sources of chemical ions in stream water. Runoff from animal husbandry units, which contain predominantly high levels of organic compounds, is another source of pollutants. Lateral inflows (water that is added to the stream due to effluent seepage from groundwater, overland flow, interflow, or via small springs and seeps) transport such solute mass to the streams and rivers (Singh 1995). Although extensive studies have been carried out in many parts of the world to understand the in-stream reactions and sediment dynamics (Yuretich and Batchelder 1988; Latimer et al. 1988), such studies are rare in the South Asian context, albeit the problem is severe.

Do the Challenges and Opportunities Offer Scope for Adaptation?

Food Security, Diversified Production, and Economic Returns

Traditionally, agroforestry aimed at food production—either directly producing edible products or indirectly (facilitating enhanced and/or sustained production). Recent studies too indicated that certain food crop crops can profitably be combined with woody perennials. For instance, Asiatic yams (*Dioscorea alata* L. and *D. esculenta* (Lour.) Burkill.) and other food crops are well suited as intercrops in the coconut gardens of South Asia (Nair 1979; Pushpakumari and Sasidhar 1992; Ollivier et al.

1994). In the arid regions of northwestern India, food crops grown under *Prosopis cineraria* (L.) Druce trees produced two to three times more yield than crops growing away from trees (Shankarnarayan et al. 1987). Food diversity constitutes yet another dimension of this. Many cereals, tubers, vegetables, and forages are intercropped in such systems. The vertical stratification of canopies characteristic of agroforestry systems provides a gradient in light and relative humidity creating niches for various species groups. Most agroforestry systems are also complementary to other crop production enterprises—as they provide green manure for crop fields and cattle fodder (Table 2)—further augmenting food security and diversity.

The produces from agroforestry are also sources of minerals and nutrients for improving household nutritional security especially for at-risk populations (Kumar and Nair 2004). In experimental studies, the target families significantly increased their year-round production and consumption of vitamin-rich fruits and vegetables compared to the control group without homegardens which led to alleviation of iodine, vitamin A, and iron deficiencies (Molina et al. 1993) and made children of garden owners less prone to xerophthalmia (Shankar et al. 1998). Since little or no chemical inputs are used in such systems, the produce from agroforestry is also of superior quality. In summary, agroforestry is capable of making available diversified foodstuffs, averting malnutrition, and providing organic food materials, for which there is an emerging market even in the developing countries.

Apart from ensuring food production, such systems augment economic returns to the growers. An economic analysis of 24 agroforestry models by the Planning Commission of India (GITF 2001) highlighted high benefit/cost ratios (1.5–3) and internal rates of return (15–40%) for agroforestry. Consistent with this, Neupane and Thapa (2001) reported that introduction of multipurpose trees such as mulberry (*Morus alba* L.) for sericulture in the mid-hills region of Nepal enhanced profitability. In the Chittagong Hill Tracts of Bangladesh also, practicing agroforestry on the degraded agricultural lands improved economic returns (Rasul and Thapa 2006). Higher cash incomes may provide greater "buying power" with respect to food, especially when agriculture is not practiced, or when crops fail. The potential of agroforestry to provide alternate sources of income and employment to the rural poor which again ensures food security and diversity, therefore, cannot be overemphasized (e.g., Balooni 2003; Puri and Nair 2004; Samra et al. 2005; Dhyani et al. 2009).

Major Sinks of Atmospheric CO_2

Expanding the size of the global terrestrial sink is one strategy for mitigation of CO_2 build-up in the atmosphere. Under the Kyoto Protocol's Article 3.3, A & R (afforestation and reforestation) with agroforestry as a part of it has been recognized as an option for mitigating greenhouse gases. As a result, there is now increasing awareness on agroforesty's potential for carbon (C) sequestration (Nair et al. 2009, 2010; Kumar and Nair 2011). Indeed, the National Climate Change Action Plan of India through the Greening India Mission[15] targets 1.5 million ha of degraded agricultural lands and fallows to be brought under agroforestry. Such climate change mitigation strategies through agroforestry would also ensure greater synergy with the Convention on Biological Diversity in view of the ability to maintain high biodiversity (FAO 2004).

Basically there are three mechanisms which help reduce atmospheric CO_2 levels (Montagnini and Nair 2004; Kumar 2006): *carbon sequestration* (creating new stocks in growing trees and soil), *carbon conservation* (eases anthropogenic pressure on existing stocks of C in forests through conservation and management efforts), and *carbon substitution* (substitution of energy demand materials by renewable natural resources, fuelwood production, increased conversion of biomass into durable wood products for use in place of energy-intensive materials). While all these are relevant for agroforestry, aspects such as carbon sequestration and substitution are focused here, as quantitative data on avoided deforestation on account of agroforestry are not readily available.

Carbon Sequestration

Although variations in C sequestration potential of agroforestry systems abound owing to tree age-, site-, and tree/stand management-related factors (Nair et al. 2009, 2010), there exists a huge but untapped potential of agroforestry as a CO_2 offset mechanism (Kumar and Nair 2011). Indeed, the aboveground C stocks of mixed species tropical homegardens in Kerala (India) and poplar-based systems in north-western India are 17–36 Mg C ha^{-1} (Kumar 2011) and 21–65.62 Mg C ha^{-1} (Rizvi et al. 2011), respectively, comparable to that in the living biomass of Indian forests (41 Mg C ha^{-1}: FAO 2011). Aside from the aboveground C stocks, the "species-rich" land use systems also have a greater chance of maintaining soil organic matter relations than the "species-poor" agricultural systems in the Western Ghats of India (Russell 2002; Kumar 2005). Indeed, more than half of the C assimilated by woody perennials in such systems is transported belowground via root growth and organic matter turnover processes (e.g., fine root dynamics, rhizodeposition, and litter dynamics), augmenting the soil organic carbon (SOC) pool (Nair et al. 2010). Consistent with this, Saha et al. (2009, 2010) reported that for species-rich Kerala homegardens, the soil carbon content (SOC) within the 1 m soil profile was 119.3 Mg ha^{-1}.

Although C is a new commodity that is now traded in financial markets and there is potential for farmers adopting agroforestry to sell C in addition to the other commodities (traditional timber and non-timber), agroforestry C offset projects are a challenging task; high transaction costs being a principal deterrent. As a result, only a small proportion of the A/R CDM (Clean Development Mechanisms) projects are presently based in South Asia: just seven registered A/R CDM projects in India till mid-October.[16] Other countries in the region also have little forest carbon, CDM, and Payment for Ecosystem Services (PES) activity so far. Nonetheless, the potential for more A/R CDM projects throughout the subcontinent cannot be underestimated.

Carbon Substitution (Biomass Utilization as Carbon Neutral Energy)

Although bioenergy can make significant contributions to the world's growing needs for clean energy (Turkenburg et al. 2000), this is still an emerging concept in South Asia. The Government of India (GOI), however, regards biofuels as a feasible option for augmenting future fuel supply (PSA 2006). To promote the utilization of biofuels in the fuel mix, GOI on September 30, 2003 launched a 5% ethanol doping program for petrol in nine states and four union territories of the country. The National Mission on Biodiesel covering an area of 400,000 ha (Planning Commission 2003) is another major initiative to find a renewable alternative for the growing fuel consumption (Kumar 2010). On September 11, 2008, the GOI also issued a National Policy on Biofuels.[17] It calls for 20% blending of bioethanol and biodiesel by 2017 and augmenting indigenous production of non-edible oilseeds and biodiesel from waste/degraded/marginal lands.

A wide spectrum of hydrocarbon-yielding plants such as *Jatropha curcas* L., *Pongamia pinnata* (L.) Pierre., *H. braziliensis, Madhuca indica, Calophyllum inophyllum* L.*, Salvadora persica* L., and *S. oleoides* Decne. are constituents of agroforestry systems in different parts of South Asia. Other oil-yielding species such as *sal* (*Shorea robusta* Gaertn.), *neem* (*Azadirachta indica* Adr. Juss.), *Michelia champaca* L., and *Garcinia indica* L. too have great potential in this regard (Kalita 2008). Annual production of such oilseeds in India is more than 20 million tons (Tg), with *mahua* (*Madhuca* spp.) alone accounting for 181 Gg (1,000 tons).[18] Some of these seeds have high oil contents, for example, *M. champaca* and *G. indica* yielding 45.0 and 45.5% oil, respectively. Fatty-acid composition, iodine value, and cetane number indicate their suitability for use as biodiesel (Hosamani et al. 2009). However, such indigenous tree-based oilseeds (TBOs), despite their high bio-crude potential, have not been adequately exploited in this region (Ghadge and Raheman 2005).

This biofuel route to CO_2 emission reduction, however, is not always risk-free, especially in the populous countries of South Asia where extensive replacement of food crops by energy crops may adversely affect food availability, access, stability, and utilization.[19] Nonetheless, establishment of agroforests/bioenergy plantations appears to be a major, cost-effective method to offset fossil fuel consumption, which should be promoted. According to Lal (2001), biofuels can offset C emission through fossil fuel burning to the extent of 0.3–0.7 Pg C $year^{-1}$. Furthermore, the Indian National Policy on Biofuels emphasizes biofuel production from non-edible oilseeds primarily from degraded lands, which would probably offset any potential land use conflicts in this regard.

Traditional Agroecosystems to Conserve Agrobiodiversity

Integrated, dynamic, landscape mosaics with traditional land use management reflect the potential to harbor an array of species. Although substantial parts of such systems have been lost during the "development phase" (Fig. 5), the remaining agroforestry in South Asia are excellent examples of agrobiodiversity conservation. For example, the mean Simpson and Shannon-Wiener diversity indexes of tropical homegardens of Western Ghats (India) were comparable to those of the adjacent natural forest areas (Kumar et al. 1994; Saha et al. 2010; Kumar 2011). Likewise, the homegardening systems in Bangladesh are thought to be "refuges" for native and rare plants outside the natural and/or protected area systems (Kabir and Webb 2008). Nonetheless, agroforestry may not avert all species losses. With divergent life forms such as trees, agricultural crops, grasses, livestock, etc., it may act as an effective buffer to prevent such losses, especially in the smallholder land use systems (e.g., the homegardens: Kumar et al. 1994) where the "species packing" is generally greater than in the larger ones.

Reclamation of Degraded Sites, Reduced Nutrient Loading of Aquatic Systems, and Soil Fertility Enrichment

Several tree and shrub species have the intrinsic potential to remove pollutants (heavy metals, organic pollutants, etc.) from the environment and/or to render them harmless (phytoremediation). The principal application of this in the South Asian context is in the context of reclamation of salt-affected soils (Davidson 2000). In India, where an estimated 6.74 million ha of lands are affected by salinity/alkalinity (ICAR 2010), salt-tolerant tree species such as *Acacia nilotica* (L.) Del., *Dalbergia sissoo* Roxb., *Prosopis juliflora* (Sw.) DC, and *Terminalia arjuna* have been planted in association with fodder grasses for site improvement with remarkable success (Singh et al. 1992; Garg 1998). P. juliflora, in particular, has improved the physical and chemical properties of highly sodic soils soil by decreasing pH, electrical conductivity, and exchangeable sodium (Na) levels and increasing infiltration capacity, organic C, and nutrient levels (Bhojvaid et al. 1996). Use of trees and shrubs for reclaiming salt-affected/other polluted soils, therefore, offers considerable promise in reversing the process of arable lands going out of production due to soil degradation.

Agroforestry systems which integrate woody perennials with other crops also reduce the magnitude of nutrient loading of streams and lakes (Nair et al. 2010; Nair 2011). In particular, agroforestry designs of grass-shrub-tree buffers (riparian buffer) were found to be superior to grass buffers in reducing sediment losses and NPS of aquatic systems (Rigueiro-Rodríguez et al. 2008; Jose 2009; Palsaniya et al. 2011). Improvements in soil organic matter status following incorporation of tree biomass (litter, fine roots, and green manure) would also improve the infiltration capacity of soils. This is particularly relevant for soils characterized by low infiltration capacity and negligible hydraulic conductivity, where overland flow transfers the excess fertilizers remaining in the top soil layer into the streams.

The deeper and more extensive tree roots also take up more nutrients from the subsoil compared to crops with shallower root systems, implying the so-called safety-net effect (Divakara et al. 2001). In experimental studies involving bamboo-based multi-strata systems of Kerala, India, Kumar and Divakara (2001) found that

^{32}P uptake from the subsoil was greater when the bamboo clumps (*Bambusa bambos* (L.) Voss.) and dicot trees (*Tectona grandis* L.f. and *Vateria indica* L.) were close to one another, signifying a substantial potential to "capture" the lower leaching nutrient ions, when trees are grown in close proximity. By extension, nutrient leaching from soils under agroforestry systems where trees are a major component will be substantially lower than those from treeless systems. In addition, the deep-reaching tree roots can pump out excess soil water (bio-drainage),[20] which is of special relevance to salt-affected soils. Annual water use by 3-to-5-year-old *Acacia nilotica* trees was 1,248 mm on the severely saline site and 2,225 mm on the mildly saline sites in Pakistan and the plantation water table fell from 1.7 to 2.9 m below surface (Khanzada et al. 1998). N_2-fixing trees and shrubs have the additional potential to enrich site fertility, which is of special relevance considering the high losses of N from agroecosystems (Kumar et al. 1998) and the impending fertilizer crisis (Fig. 5). Prevention of land degradation by wind erosion is yet another attribute of agroforestry in the arid and semiarid regions (Pathak 2002). Agroforestry thus plays a major role in the rehabilitation of wastelands such as deserts, ravines, and gullies.

Lack of Public Policy Support

Although the traditional agroforestry systems are sustainable production systems that conserve site resources and agrobiodiversity, these are not yet supported by comprehensive public policies (Guillerme et al. 2011). The commodity-centric agricultural policies and the forest policies favoring exotic species in the past have adversely affected the prospects of agroforestry as a land management system in many parts of South Asia. Indeed, "modern" agroforestry technologies (agroforestry practices that have been developed recently with research backing—involving either improvement of traditional practices or introduction of new ones) have not been widely adopted in India (Puri and Nair 2004) despite considerable promotional efforts.[21] Case studies regarding the impact of public policies on tree farming and agroforestry dynamics are also rare (Guillerme et al. 2011). Nonetheless, a plea was made in 2001 to review and amend the outdated or conflicting laws and harmonize them in view of the new challenges of rising wood requirements of the society and increasing pressures on remaining natural forests (Mohanan et al. 2002). The forest policies of Pakistan (1955, 1962, and 1991) also reflect the importance of farm forestry; however, very little was translated into practical measures due to socio-economic and technological constraints (Akbar et al. 2000).

Most public policies also do not take into account the environmental services rendered by agroforestry or even by the farmers. The focus is on the most profitable and marketable crops or trees ("push" toward commercial agriculture, which may not last long in view of an imminent fertilizer crisis; Fig. 5), often neglecting the dimensions of domestic consumption and agrobiodiversity conservation. In the global context of the challenges associated with food security, climate change mitigation, poverty alleviation, and preservation of environment and biodiversity, a reorientation of the public policies in the realm of agroforestry is warranted as most of the small and marginal farmers in most parts of South Asia still rely on agroforestry for their subsistence (e.g., homegardens: Kumar and Nair 2004).

Lessons Learned

With increasing human population pressure and mounting levels of land degradation, arable lands are becoming scarce the world over. This, coupled with the adverse effects of enhanced atmospheric CO_2 levels, would exaggerate the threat to global food security in the twenty-first century. And nowhere else will the detrimental effects be as severe as in the South Asian region, the most densely populated geographical zone on earth. In particular, agricultural lands in South Asia are scarce, and site degradation is most severe in the irrigated lands where intensive cultivation has been practiced. Furthermore, the global warming–induced rise in sea levels may submerge substantial parts of agricultural and other lands in countries such as Maldives, Bangladesh, India, and Sri Lanka (IPCC 2007), which may aggravate the problem of food scarcity, besides causing other problems. As explained, agroforestry emerges as a promising land use option capable of addressing most of these problems. Clearly, there are case studies and "success stories" of agroforestry from South Asia that can probably be replicated elsewhere in the tropics experiencing similar problems.

The first and foremost in this respect is the tropical homegardens (Kumar and Nair 2004, 2006). Although productivity in these traditional agroforestry systems compared to intensive monocultures is modest, diversified production and income generation in perpetuity are its intrinsic features. Homegarden products such as fruits, nuts, rubber, resins, medicines, spices and oils, as well as the materials to make household, hunting, fishing and agricultural implements are cardinal to promote food security. Most of these are also subsistence production systems, yet their role in generating additional cash income cannot be overlooked. In addition, the tropical homegardens may act as refuges for native and rare plants and conserve agrobiodiversity including the preservation of endangered species and cultivars. Considering the multifarious roles performed by such gardens, there is a clear need to revitalize such traditional land use systems, which are on the decline due to socioeconomic and technological factors.

Agroforestry practices including the tree-based smallholder production systems offer great potential to create new jobs in the rural areas, and thus, to a certain extent, reverse the process of transmigration to urban areas. That is, the great diversity of products from agroforests provides opportunities for development of small-scale rural industries and for creating off-farm employment and marketing opportunities. This capacity of agroforestry for rural employment generation through industrialization, however, is complex and has not been adequately emphasized in the past. Nonetheless, considering the potential for raw material production especially for the wood-based industries, many industrial firms are now entering into "buyback" contracts with local communities and small farmers to grow wood on their agricultural lands. The spread of the poplar-based agroforestry in northwestern India and the associated industrial development is a case in point.[22] Furthermore, through farm forestry and "Purchase at Gate" schemes, the Hindustan Newsprint Limited, Vellore, a public sector organization in India,[23] and through similar other schemes (Puri and Nair 2004), wood-based industries in India procure substantial quantities of industrial raw materials from farmers. Quite apart from providing food products and industrial raw materials, agroforestry tree products constitute a source of biofuels for the rural households and can offset industrial/automobile fossil energy consumption (e.g., tree-based oilseeds and lignocellulosic biomass crops: Achten et al. 2008). The prevailing dilemma, however, is that large-scale diversion of croplands for raising biofuel crops may result in conflicts with food security. This, nonetheless, may not be a serious constraint if the biofuel program targets the degraded lands.

To surmount the problem of land degradation also, agroforestry emerges as a promising option. Indeed, agroforestry designs of grass-shrub-tree systems are superior to grass buffers in reducing sediment losses and checking soil erosion on sloping lands. Rehabilitation of saline, alkaline, and water-logged soils through bio-drainage by planting *Eucalyptus* at specified intervals also has been successfully demonstrated.[24] Moreover, by using agroforestry technologies developed at the Central Soil Salinity Research Institute, Karnal, the State Forest Departments, non-governmental organizations (NGOs), National Wasteland Development Board (NWDB), and other developmental agencies in India have rehabilitated more than 1 million ha of salt-affected soils, particularly the village level community lands, areas along road side, canals, and railway tracts (Puri and Nair 2004). The Tree Growers Co-operatives (Gujarat, India) focusing on fast-growing trees and tree-based oilseed crops is another spectacular example of promoting agroforestry on farmlands and wastelands (Misra 2002).

New self-nourishing systems of stand management (e.g., fertilizer trees) that mimic the natural ecosystems where significant quantities of N are added via the biological fixation pathway have potential for adoption in the low fertility sites. Nitrogen-fixing trees and organic matter recycling processes may be a potent mechanism for future crop nourishment. A major role for agroforestry today, however, lies in the domain of environmental services such as climate change mitigation (carbon sequestration), phytoremediation, watershed protection, amelioration of NPS, and biodiversity conservation. Although certain CDM projects involving smallholders have been initiated as outlined before, more efforts are necessary for developing a suitable mechanism to reward the rural poor for environmental services (PES). Besides, it will require appropriate research interventions, investment, and above all a forward-looking agroforestry policy to address these issues.

Although the rate of return to investment in research on tree crops is quite high (88%: Garrity 2004), enterprise development and enhancement of tree-product marketing have been neglected. Furthermore, a question often posed is: If agroforestry is so wonderful, why is it that it is not making much headway? Perhaps the "downside" of agroforestry has not been adequately focused by researchers. Aspects such as competitive interactions (for nutrients, water, and light), impediments relating to governmental procedures in tree harvesting, lack of extension support, allelopathy, displacement of food crops with trees, and other potential land use conflicts may be relevant in most South Asian countries. For large-scale adoption of agroforestry, the following prerequisites are seemingly essential: improving the marketing and processing of agroforestry products involving public-private partnerships; product diversification and value addition; development and promotion of substitutes and/or supplements for costly, imported external inputs (e.g., fodder trees, fertilizer trees); creating an enabling environment and exploring new avenues for dissemination of agroforestry-related technologies; training and capacity building in agroforestry among all major stakeholders including policymakers highlighting the benefits of agroforestry and the constraints impeding its adoption; and partnering with a broad range of actors. Above all, for the potential of agroforestry to be effectively harnessed, there is an urgent need for an appropriate policy and institutional environment that provides farmers with clear incentives to plant and protect trees that contribute to both ecosystem function and rural livelihoods.

End Notes

1. Warriar MRR (1995) Wayanad in the middle ages. In: *Discover Wayanad—The Green Paradise*. Johny KP (ed.). District Tourism Promotion Council, Kalpetta, Wayanad, India, pp. 68–69.
2. Mateer S (1883) *Native Life in Travancore.* W.H. Allen, London, 450p.
3. Logan W (1906) *Malabar Manual* (2 vols). Asian Educational Services, 2nd ed., Madras, India 772p.
4. Maddugoda P (1991) Experience of community forestry in Sri Lanka. Proceedings from second regional workshop on multi-purpose trees. Kandy, Sri Lanka 5–7 April 1991.
5. According to *Varahamihira*, the shoreline (banks) of the tanks should be shaded (planted) with mixed stands of *Terminalia arjuna* (Roxb.) W. & A., *Ficus benghalensis* L., *Mangifera indica*, *Ficus religiosa* L., *Nauclea orientalis* (L.) L., *Syzygium cuminii* (L.) Skeels, *Mitragyna parvifolia* (Roxb.) Korth., *Borassus flabellifer* L., *Saraca asoka* (Roxb.) de. Wilde, *Madhuca indica* J.F. Gmel., *Mimusops elengi* L. and the like.
6. Zomer RJ, Trabucco A, Coe R, and Place F (2009) Trees on Farm: Analysis of Global Extent and Geographical Patterns of Agroforestry. ICRAF Working Paper no. 89. World Agroforestry Centre, Nairobi, Kenya, 63p.
7. Chaturvedi AN (1982) *Poplar Farming in Uttar Pradesh (India).* For. Bull. No. 45, UP Forest Dept. Nainital, Uttar Pradesh, 42p.
8. MoA (2000) National Agricultural Policy, Ministry of Agriculture, Government of India. Available at http://agricoop.nic.in/PolicyIncentives/NationalAgriculturePolicy/nationalagriculturepolicy.htm accessed 15 June 2011.
9. http://www.scopus.com/home.url accessed 25 October 2011.
10. TERI (2009) Is India ready to implement REDD plus? A preliminary assessment. The Energy and Resoruces Institute, New Delhi. Available at www.teriin.org. Accessed 16 June 2011.

11. http://co2now.org/Current-CO2/CO2-Now/annual-co2.html accessed on 18 Oct 2011.
12. UK Climate Programme, http://ukcip.org.uk/ accessed 15 June 2010.
13. IUCN (2008) *IUCN Red List of Threatened Species*. www.iucnredlist.org. Accessed on 21 May 2009.
14. Purandara BK, Varadarajan N and Kumar CP (2004) Application of chemical mass balance to water quality data of Malaprabha River. J Spatial Hydrol 4(2): 1–23. Available at http://www.spatialhydrology.com/journal/subscription/paper/mass_balance/Massbalance.pdf, accessed 18 October 2011.
15. MoEF (2010) National Mission for a Green India, Available at: http://moef.nic.in/downloads/public-information/green-india-mission.pdf (accessed 20 January 2011).
16. Small Scale Cooperative Afforestation CDM Pilot Project Activity on Private Lands Affected by Shifting Sand Dunes in Sirsa, Haryana; Reforestation of severely degraded landmass in Khammam District of Andhra Pradesh, under ITC Social Forestry Project; The Bagepalli CDM Reforestation Programme Chickballapur district of Karnataka; Reforestation of degraded land by Mangalam Timber Products Limited (Orissa, Andhra Pradesh, and Chattisgarh); The International Small Group and Tree Planting Program (TIST), Tamil Nadu, India; Improving Rural Livelihoods through Carbon Sequestration by Adopting Environment Friendly Technology based Agroforestry Practices (Orissa and Andhra Pradesh); Himachal Pradesh Reforestation Project – Improving Livelihoods and Watersheds (http://cdm.unfccc.int/Projects/ accessed 18 October 11).
17. http://mnes.nic.in/policy/biofuel-policy.pdf accessed on 17 March 2010.
18. Kaul S, Kumar A, Bhatnagar AK, Goyal HB, and Gupta AK (2003) Biodiesel: a clean and sustainable fuel for future. Scientific strategies for production of non-edible vegetable oils for use as biofuels. All-India Seminar on National Policy on Non-Edible Oils As Biofuels. SUTRA, IISc Bangalore, unpublished.
19. FAO (2008) Bioenergy, food security and sustainability–towards an international framework. High-Level Conference on World Food Security: The Challenges of Climate Change and Bioenergy. Rome, 3–5 June 2008, available at http://www.fao.org/fileadmin/user_upload/foodclimate/HLCdocs/HLC08-inf-3-E.pdf (accessed 7 May 2009).
20. http://www.indg.in/agriculture/crop_production_techniques/biodrainage.pdf accessed 5 August 11.
21. http://www.incg.org.in/Agriculture/Policies/NationalAgriculture Policy.htm
22. Zomer RJ, Bossio DA, Trabucco A,Yuanjie L, Gupta DC, and Singh VP (2007) Trees and water: Smallholder agroforestry on irrigated lands in Northern India. IWMI Research Report 122. International Water Management Institute, Colombo, Sri Lanka, 47p.
23. http://www.hnlonline.com/php/showContent.php?lid=60&pid=53&cid=51&spid=53 accessed 2 Aug 11.
24. Hira GS, Gupta PK, Shakya SK, and Thind HS (1999) A new technology for planting *Eucalyptus* in waterlogged sodic soils. PAU, Ludhiana.

References

Achten WMJ, Verchot L, Franken YJ, Mathijs E, Singh VP, Aerts R, Muys B (2008) Jatropha biodiesel production and use. Biomass Bioenerg 32:1063–1084
Akbar G, Baig MB, Asif M (2000) Social aspects in launching projects in developing countries. Sci Vis 5:52–58
Akther S, Miah D, Koike M (2010) Household adaptations to fuelwood shortage in the old Brahmaputra downstream zone in Bangladesh and implications for homestead forest management. Int J Biodivers Sci Ecosyst Serv Manag 6(3):139–145
Anderson E (1952) Plants, man, and life. Little, Brown, Boston, 245 p
Ayachit SM (trans) (2002) *Kashyapiya Krishisukti* (A treatise on agriculture by Kashyapa). Agri-History Bulletin No. 4. Asian Agri-History Foundation, Secunderabad, 158 p
Balooni K (2003) Economics of wasteland afforestation in India, a review. New For 26:101–136
Benton TG (2007) Managing farming's footprint on biodiversity. Science 315:341–342
Bhat MR (trans) (1981) *Varahamihira's Brhat Samhita*. Parts I and II. Motilal Banarasidas, Delhi, 1106 p
Bhojvaid PP, Timmer VR, Singh G (1996) Reclaiming sodic soils for wheat production by *Prosopis juliflora* afforestation in India. Agrofor Syst 34:139–150
Chandra JP (2003) Role of forest based industries/plantation companies in development of agroforestry. In: Pathak PS, Newaj R (eds) Agroforestry: potentials and opportunities. Agrobios and Indian Society of Agroforestry, Jodhpur, pp 305–309
Collins NM, Sayer JA, Whitmore TC (1991) The conservation atlas of tropical forests: Asia and the Pacific. IUCN, Gland
Das T, Das AK (2005) Inventorying plant biodiversity in homegardens: a case study in Barak Valley, Assam, North East India. Curr Sci 89:155–163
Davidson AP (2000) Soil salinity, a major constraint to irrigated agriculture in the Punjab region of Pakistan: contributing factors and strategies for amelioration. Am J Altern Agric 15:154–159
De Costa WAJM, Sangakkara UR (2006) Agronomic regeneration of soil fertility in tropical Asian smallholder uplands for sustainable food production. J Agric Sci 144:111–133
De Zoysa M (2001) A review of forest policy trends in Sri Lanka. Policy Trend Rep 2001:57–68
Dhyani SK, Chauhan DS, Kumar D, Kushwaha RV, Lepcha ST (1996) Sericulture based agroforestry systems for hilly areas of north-east India. Agrofor Syst 34:1–12
Dhyani SK, Kareemulla K, Ajit HAK (2009) Agroforestry potential and scope for development across agro-climatic zones in India. Indian J For 32:181–190
Divakara BN, Kumar BM, Balachandran PV, Kamalam NV (2001) Bamboo hedgerow systems in Kerala, India: root distribution and competition with trees for phosphorus. Agrofor Syst 51:189–200
ESCAP (1992) State of the Environment in Asia and the Pacific 1990. United Nations Economic and Social Commission for Asia and the Pacific, U.N. Economic and Social Commission for Asia and the Pacific, Bangkok, Thailand, 352 p
Eswaran H, Lal R, Reich PF (2001) Land degradation: an overview. In: Bridges EM, Hannam ID, Oldeman LR, de Vries FWT Pening, Scherr SJ, Sompatpanit S (eds) Response to land degradation. Oxford & IBH Pub. Co. Ltd., New Delhi, pp 20–35
FAO (2003) State of the world's forests: FAO report. Food and Agriculture Organization, Rome
FAO (2004) Assessing carbon stocks and modelling win–win scenarios of carbon sequestration through land-use changes. Food and Agriculture Organization of the UN, Rome, 156 p
FAO (2010) The state of food insecurity in the world addressing food insecurity in protracted crises. Food and Agriculture Organization of the United Nations, Rome, 58 p
FAO (2011) State of the world's forests. Food and Agriculture Organization of the United Nations, Rome, 2010, 164 p
Garg VK (1998) Interaction of tree crops with a sodic soil environment: potential for rehabilitation of degraded environments. Land Degrad Dev 9:81–93

Garrity DP (2004) Agroforesty and the achievement of the millennium development goals. Agrofor Syst 61:5–17

Ghadge SV, Raheman H (2005) Biodiesel production from mahua (*Madhuca indica*) oil having high free fatty acids. Biomass Bioenerg 28:601–605

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

Guillerme S, Kumar BM, Menon A, Hinnewinkel C, Maire E, Santhoshkumar AV (2011) Impacts of public policies and farmers' preferences on agroforestry practices in Kerala, India. Environ Manag 48:351–364

Gulati A (2002) The future of agriculture in Sub-Saharan Africa and South Asia. In: Sustainable food security for all by 2020. Proceedings of an international conference. IFPRI, Washington, DC, pp 109–111

Gunawardene NR, Daniels AED, Gunatilleke IAUN, Gunatilleke CVS, Karunakaran PV, Geetha Nayak K, Prasad S, Puyravaud P, Ramesh BR, Subramanian KA, Vasanthy G (2007) A brief overview of the Western Ghats–Sri Lanka biodiversity hotspot. Curr Sci 93:1567–1572

Herring JR, Fantel RJ (1993) Phosphate rock demand into the next century: impact on world food supply. Nat Resour Res 2:226–246

Hira GS, Gupta PK, Shakya SK, Thind HS (1999) A new technology for planting *Eucalyptus* in waterlogged sodic soils. PAU, Ludhiana

Hosamani KM, Hiremath VB, Keri RS (2009) Renewable energy sources from *Michelia champaca* and *Garcinia indica* seed oils: a rich source of oil. Biomass Bioenerg 33:267–270

ICAR (1981) Proceedings of the agroforestry seminar, Imphal, 1979. Indian Council of Agricultural Research, New Delhi, 268 p

ICAR (2010) Degraded and wastelands of India: status and spatial distribution. Indian Council of Agricultural Research, New Delhi, 158 p

IEA (2000) World energy outlook 2000. International Energy Agency, Paris

IPCC (2007) Climate change 2007: mitigation of climate change. In: Metz B, Davidson OR, Bosch PR, Dave R, and Meyer LA (eds) Contribution of working group III to the fourth assessment report of the intergovernmental panel on climate change, Cambridge University Press, Cambridge/New York, 851 p

Jose S (2009) Agroforestry for ecosystem services and environmental benefits: an overview. Agrofor Syst 76:1–10

Kabir ME, Webb EL (2008) Can homegardens conserve biodiversity in Bangladesh? Biotropica 40(1):95–103

Kalita D (2008) Hydrocarbon plant—new source of energy for future. Renew Sustain Energ Rev 12:455–471

Khanzada AN, Morris JD, Ansari R, Slavich PG, Collopy JJ (1998) Groundwater uptake and sustainability of Acacia and Prosopis plantations in Southern Pakistan. Agric Water Manag 36:121–139

Kumar BM (1999) Agroforestry in the Indian tropics. Indian J Agrofor 1(1):47–62

Kumar BM (2005) Land use in Kerala: changing scenarios and shifting paradigms. J Trop Agric 43(1–2):1–12

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

Kumar BM (trans) (2008) Krishi Gita (Agricultural verses) [A treatise on indigenous farming practices with special reference to *Malayalam desam* (Kerala)]. Asian Agri-History Foundation, Secunderabad, 111 p

Kumar BM (2010) Self sustaining models in India: biofuels, eco-cities, eco-villages, and urban agriculture for a low carbon future. In: Osaki M, Braimoh A, Nakagami K (eds) Designing our future from local and regional perspectives—bioproduction, ecosystems, and humanity. United Nations University, Tokyo, pp 207–218

Kumar BM (2011) Species richness and aboveground carbon stocks in the homegardens of central Kerala, India. Agric Ecosyst Environ 140:430–440

Kumar BM, Divakara BN (2001) Proximity, clump size and root distribution pattern in bamboo: a case study of *Bambusa arundinacea* (Retz.) Willd., Poaceae, in the Ultisols of Kerala, India. J Bamboo Rattan 1:43–58
Kumar BM, Nair PKR (2004) The enigma of tropical homegardens. Agrofor Syst 61:135–152
Kumar BM, Nair PKR (eds) (2006) Tropical homegardens: a time-tested example of sustainable agroforestry. Springer, Dordrecht, 380 p
Kumar BM, Nair PKR (eds) (2011) Carbon sequestration potential of agroforestry systems: opportunities and challenges, vol 8, Advances in agroforestry. Springer, Dordrecht, 307 p
Kumar BM, Takeuchi K (2009) Agroforestry in the Western Ghats of peninsular India and the Satoyama landscapes of Japan: a comparison of two sustainable land use systems. Sustain Sci 4:215–232
Kumar BM, George SJ, Chinnamani S (1994) Diversity, structure and standing stock of wood in the homegardens of Kerala in peninsular India. Agrofor Syst 25:243–262
Kumar BM, Sajikumar V, Mathew T (1995) Floristic attributes of small cardamom (*Elettaria cardamomum* (L) Maton) areas in the Western Ghats of peninsular India. Agrofor Syst 31:275–289
Kumar BM, Kumar SS, Fisher RF (1998) Intercropping teak with Leucaena increases tree growth and modifies soil characteristics. Agrofor Syst 42:81–89
Kumar BM, Haibara K, Toda H (2005) Does plant litter become more recalcitrant under elevated atmospheric CO_2 levels? Global Environ Res 9:83–91
Ladizinsky G (1998) Plant evolution under domestication. Kluwer, Dordrecht, pp 4–9
Lal R (2001) Managing world soils for food security and environmental quality. Adv Agron 74:155–192
Lal M, Nozawa T, Emori S, Harasawa H, Takahashi K, Kimoto M, Abe-Ouchi A, Nakajima T, Takemura T, Numaguti A (2001) Future climate change: implications for Indian summer monsoon and its variability. Curr Sci 81:1196–1207
Latimer JS, Carey CG, Hoffman EJ, Quinn JG (1988) Water quality in the Pawtuxet river: metal monitoring and geochemistry. Water Resour Bull 24:791–800
Maikhuri RK, Rao KS, Saxena KG, Semwal RL (1999) Traditional crops-diversity based nutrition and prospects for sustainable development in the Central Himalaya. Himalaya Paryavaran (J Environ Prot Soc) 6:36–44
Misra VK (2002) Greening the wasteland: experiences from the Tree Growers Co-operatives Project. In: Marothia DK (ed) Institutionalizing common pool resources. Concept Publishing Company, New Delhi, pp 334–354
MoEF (2006) Report of the National Forest Commission. Ministry of Environment and Forests, Government of India, New Delhi, 421 p
Mohanan C, Chacko KC, Seethalakshmi KK, Sankar S, Renuka C, Muralidharan EM, Sharma JK (eds) (2002) Proceedings of the national workshop on policy and legal issues in cultivation and utilization of bamboo, rattan and forest trees in private and community lands. Kerala Forest Research Institute, Peechi, 221 p
Molina MR, Noguera A, Dary O, Chew F, Valverde C (1993) Principal micronutrient deficiencies in Central America. Food Nutr Agric 7:26–33
Montagnini F, Nair PKR (2004) Carbon sequestration: an underexploited environmental benefit of agroforestry systems. Agrofor Syst 61:281–295
Muraleedharan PK, Sasidharan N, Kumar BM, Sreenivasan MA, Seethalakshmi KK (2005) Non-wood forest products in the Western Ghats of Kerala, India: floristic attributes, extraction, regeneration and prospects for sustainable use. J Trop For Sci 17:243–257
Myers N, Mittermeier RA, da Fonseca GAB, Kent J (2000) Biodiversity hotspots for conservation priorities. Nature 403:853–857
Nair PKR (1979) Intensive multiple cropping with coconuts in India: principles, programmes and prospects. Verlag Paul Parey, Berlin/Hamburg, 149 p
Nair PKR (2011) Agroforestry systems and environmental quality: introduction. J Environ Qual 40:784–790
Nair PKR, Kumar BM, Nair VD (2009) Agroforestry as a strategy for carbon sequestration. J Plant Nutr Soil Sci 172:10–23

Nair PKR, Nair VD, Kumar BM, Showalter J (2010) Carbon sequestration in agroforestry systems. Adv Agron 108:237–307

Nath TK, Inoue M, Pradhan FE, Kabir MA (2011) Indigenous practices and socio-economics of *Areca catechu* L. and *Piper betel* L. based innovative agroforestry in northern rural Bangladesh. For Trees Livelihoods 20:175–190

Neupane RP, Thapa GB (2001) Impact of agroforestry intervention on soil fertility and farm income under the subsistence farming system of the middle hills, Nepal. Agric Ecosyst Environ 84:157–167

Oldeman LR (1994) The global extent of land degradation. In: Greenland DJ, Szabolcs I (eds) Land resilience and sustainable land use. CABI, Wallingford, pp 99–118

Ollivier J, Daniel C, Braconnier S (1994) Food crop intercropping with young coconut palms examples in Vanuatu. Oleagineux 49:91–108

Pachauri RK (2012) Climate change and agroforestry. In: Nair PKR, Garrity DP (eds) Agroforestry: the future of global land use. Springer, Dordrecht, pp xx–xx

Palsaniya DR, Singh R, Yadav RS, Tewari RK, Dhyani SK (2011) Now it is water all the way in Garhkundar-Dabar watershed of drought-prone semi-arid Bundelkhand, India. Curr Sci 100:1287–1288

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

Pawar NJ, Shaikh IJ (1995) Nitrate pollution of ground waters from shallow basaltic aquifers, Deccan Trap Hydrologic Province, India. Environ Geol 25:197–204

Planning Commission (2003) Report of the committee on development of biofuel. Planning Commission, Government of India, New Delhi, 164 p.

Pratap T (2004) Sustainable farming systems in upland areas. Report of the APO study meeting on sustainable farming systems in upland areas held in New Delhi, India, 15–19 Jan 2001. Asian Productivity Organization, Tokyo, pp 3–13

Principal Scientific Adviser (PSA) (2006) Report of the working group on R&D for the energy sector for the formulation of the eleventh five-year plan (2007–2012). Principal Scientific Adviser to the Government of India, New Delhi, 226 p

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

Pushpakumari R, Sasidhar VK (1992) Fertilizer management of yams and aroids in coconut based cropping system. J Root Crops 18:99–102

Puyravaud J-P, Davidar P, Pascal J-P, Ramesh BR (2003) Analysis of threatened endemic trees of the Western Ghats of India sheds new light on the red data book of Indian plants. Biodivers Conserv 12:2091–2106

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

Rasul G, Thapa GB (2006) Financial and economic suitability of agroforestry as an alternative to shifting cultivation: the case of the Chittagong Hill Tracts, Bangladesh. Agric Syst 91:29–50

Rigueiro-Rodríguez A, McAdam JH, Mosquera-Losada MR (eds) (2008) Agroforestry in Europe, vol 6, Advances in agroforestry. Springer, Dordrecht, 452 p

Rizvi RH, Dhyani SK, Yadav RS, Singh R (2011) Biomass production and carbon storage potential of poplar agroforestry systems in Yamunanagar and Saharanpur districts of north-western India. Curr Sci 100:736–742

Rosenzweig C, Hillel D (1998) Climate change and the global harvest. Oxford University Press, Oxford, 352 p

Russell AE (2002) Relationships between crop-species diversity and soil characteristics in southwest Indian agroecosystems. Agric Ecosyst Environ 92:235–249

Sadhale N (trans) (1996) Surapala's Vrikshayurveda (The science of plant life by *Surapala*). Agri-History Bulletin No. 1. Asian Agri-History Foundation, Secunderabad, 94 p

Saha SK, Nair PKR, Nair VD, Kumar BM (2009) Soil carbon stock in relation to plant diversity of homegardens in Kerala, India. Agrofor Syst 76:53–65

Saha S, Nair PKR, Nair VD, Kumar BM (2010) Carbon storage in relation to soil size-fractions under some tropical tree-based land-use systems. Plant Soil 328:433–446

Samra JS, Kareemulla K, Marwaha PS, Gena HC (2005) Agroforestry and livelihood promotion by co-operatives. National Research Centre for Agroforestry, Jhansi, 104 p

Scherr SJ (1999) Soil degradation—a threat to developing country food security by 2020? International Food Policy Research Institute, Washington, DC, 63 p

Semwal RL, Maikhuri RK (1996) Agroecosystem analysis of Garhwal Himalaya. Biol Agric Hortic 13:39–44

Shafieea S, Topal E (2009) When will fossil fuel reserves be diminished? Energ Policy 37:181–189

Shankar AV, Gittelsohn J, Pradhan EK, Dhungel C, West KP Jr (1998) Homegardening and access to animals in households with xerophthalmic children in rural Nepal. Food Nutr Bull 19:34–41

Shankarnarayan KA, Harsh LN, Kathju S (1987) Agroforestry in the arid zones of India. Agrofor Syst 5:69–88

Shiva V, Prasad R (1993) Cultivating diversity: biodiversity cultivation and seed policies. Natraj Publications, Dehra Dun

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

Singh VP (1995) Environmental hydrology. Water Science and Technology Library, Kluwer, Dordrecht, pp 1–12

Singh K, Yadav JSP, Singh B (1992) Tolerance of trees to soil sodicity. J Indian Soc Soil Sci 40:173–179

Tejwani KG (2008) Contribution of agroforestry to economy, livelihood and environment in India: reminisces of a life time between 1957–2008. Indian J Agrofor 10(2):1–2

Turkenburg WC, Beurskens J, Faaij A, Fraenkel P, Fridleifsson I, Lysen E, Mills D, Moreira JR, Nilsson LJ, Schaap A, Sinke WC (2000) Renewable energy technologies. In: World energy assessment of the United Nations, UNDP, UNDESA/WEC. UNDP, New York, pp 219–272

van Lynden G, Oldeman L (1997) Soil degradation in South and Southeast Asia. International Soil Reference and Information Centre for the United Nations Environment Programme, Wageningen, 41 p

Vencatesan J, Daniels RJR (2008) Western Ghats: biodiversity, people and conservation. Rupa & Co., New Delhi, 180 p

Wiersum KF (2006) Diversity and change in homegarden cultivation in Indonesia. In: Kumar BM, Nair PKR (eds) Tropical homegardens: a time-tested example of sustainable agroforestry. Springer, Dordrecht, pp 13–24

Yuretich RF, Batchelder GL (1988) Hydrogeochemical cycling and chemical denudation in the Fort River Watershed, Central Massachusetts: an approach of mass balance studies. Water Resour Res 24:105–114