Chapter 2
Major Land Use Issues in the Tropics, and the History of Agroforestry

Abstract Deforestation is the main land use issue facing tropical regions. Forest cover in Central Africa has been reduced from 248 538 000 ha in 1990 to 236 070 000 ha in 2005, and in West Africa, from 8 865 000 in 1990 to 7 437 200 ha in 2005. About 83 % of forest losses in Africa occurred from 1990 to 2000, mostly due to slash-and-burn practices that were employed to clear the land for agricultural uses. Similarly, 65 % of forest loss in Asia from 1990 to 2005 resulted from land use changes to agriculture. Twenty-three percent of this loss could be directly attributed to intensification of slash-and-burn agriculture, while 13 % was attributable to direct land use changes on small-size farms. In Latin America and the Caribbean, forest areas have been reduced from 923 807 000 ha in 1990 to 859 925 000 ha in 2005. The majority (47 %) of this loss was due to forestland conversion into large farms. In Brazil, the conversion of forest area to pastureland significantly reduced forest cover. Slash-and-burn agriculture, chemical inputs and extensive grazing are harmful to forest soils and biodiversity. The introduction of trees and/or livestock in agricultural plots was advocated to overcome the unsustainable use of natural resources and reduce poverty in the tropics. The World Agroforestry Centre (known as the International Centre for Research in Agroforestry, ICRAF, before 2002) was created to develop and promote agroforestry practices in the tropics and worldwide.

2.1 Introduction

Conservation of tropical forests is a global priority. Population growth and the poverty of local populations have led to increased pressures on natural resources in the tropics. Tropical forests provide land for agriculture, fuelwood, bushmeat, fruits and nuts, and other non-timber forest products (NTFPs) to local people for their everyday needs for food and cash. Non-timber forest products are not only consumed by farmers; these products are traded regionally and internationally, and provide substantial cash for stakeholders involved in the market chain. For these reasons, forest resources are increasingly exploited in the tropics. This chapter addresses the issue of sustainable management of tropical ecosystems, as well as alternatives to current unsustainable uses of these ecosystems. Agroforestry is one such promising alternative, and its history and rationale are discussed in this chapter.

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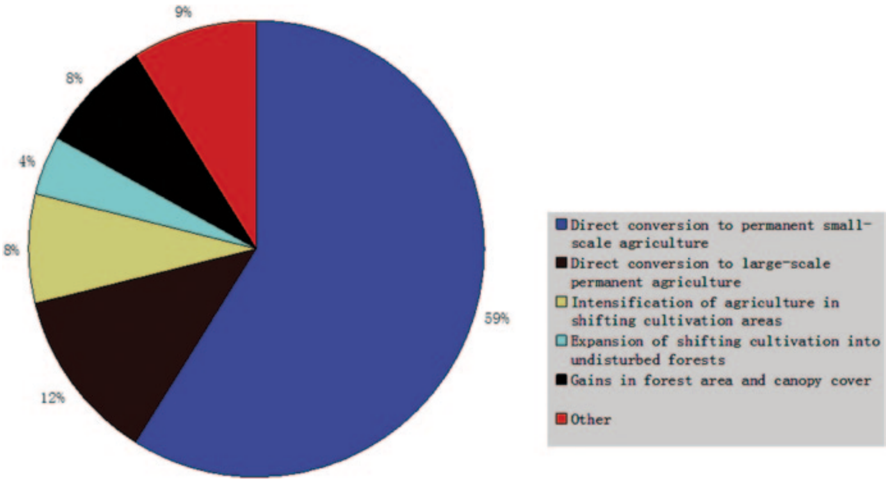

Fig. 2.1 Direct causes of forest area changes in tropical African countries between 1990 and 2000 (FAO 2001)

2.1.1 Impacts of Traditional Natural Resource Use on Tropical Ecosystems

2.1.1.1 Deforestation

Deforestation is the long-term or permanent removal of forest cover, whether it be naturally or anthropogenically and conversion to a non-forested land use. In contrast, forest degradation implies changes within the forest which negatively affect the structure or function of the stand or site, thereby lowering the capacity to supply products and/or services (Puustjärvi and Markku 2002). Forest cover in Central Africa has been reduced from 248 538 000 ha in 1990 to 236 070 000 ha in 2005, and in West Africa, from 8 865 000 to 7 437 200 ha over the same 15-year period (FAO 2009). This change represents a 26 812 000 ha loss, or about an 8 %, reduction in forest cover. In total, Africa has registered forest losses of 63 949 000 ha from 1990 to 2005 (FAO 2009), with 83 % of this loss occurring from 1990 to 2000, as a result of changes in land use to agriculture (Fig. 2.1). Intensification of slash-and-burn agriculture practices in agricultural areas accounted for 8 % of forest cover losses, while an additional 4 % was the result of slash-and-burn practices in wild forests. Smallholders have reduced forest cover to the greatest degree, with 59 % of lost forest cover having been converted to small-sized farms. In Southeast Asia, forest area has been reduced from 245 600000 to 203 887 000 ha between 1990 and 2005. Oceania's forest cover dropped from 212 514 000 to 206 254 000 ha within the same time period (FAO 2009). The annual rate of net deforestation in the Congo Basin is estimated to be 0.09 % between 1990 and 2000, with of net degradation of 0.05 %. Between 2000 and 2005, annual net deforestation in the Congo Basin is estimated is estimated to be 0.17 % and annual net degradation, 0.09 % between 2000 and 2005 (de Wasseige et al. 2012; Ernst et al. 2013). The highest rate was observed in DRC (0.32 % $year^{-1}$) followed by Cameroon (0.17 % $year^{-1}$), and the Republic of Congo (0.16 % $year^{-1}$). Annual mean net deforestation rate in the Congo Basin during the same 5-year period was estimated to be 0.17 % $year^{-1}$ (Ernst et al. 2013).

In Asia, 65 % of forest loss was a result of land use change to agriculture (FAO 2009), with 23 % of this loss resulting directly from intensification of slash-and-burn agriculture, and 13 % from direct land use conversions to small-size farms (FAO 2009). In Latin America and the Caribbean, forest areas have been reduced from 923 807 000 ha in 1990 to 859 925 000 ha in 2005. The majority (47 %) of these losses was due to conversion of forestland into large farms. Achard et al. (2002) reported a mean (± Standard Error, SE) annual forest loss between 1990 and 1997 of 2.5 ± 1.4 million ha (0.38 % $year^{-1}$) in Latin America, 2.5 ± 0.8 million ha in Southeast Asia (0.91 % $year^{-1}$), and 0.85 ± 0.30 million ha (0.43 % $year^{-1}$) in Africa. Most of this forest loss was due to land use conversion to agriculture. Hansen et al. (2008) reported a total loss of forest area in the tropics of 27.2 ± 2.2 million ha (1.39 ± 0.08 %) from 2000–2005. Brazil showed the highest rate of forest loss, 47.8 %, followed by Indonesia at 12.8 %. Africa accounted for 5.4 % of forest loss during the same period. Large-scale application of slash-and-burn agriculture by farmers was one of the principal causes of deforestation in the tropics.

In Brazil, natural forest areas have been cleared and converted to pastures for cattle grazing. In the mid-1990's, the increase in cattle to 10 million head, which is double the numbers that were reported in 1950, forced an increase in pasture area from 3.5 to 9.5 million ha (Kaimowitz 1995). Grazing occupied about 50 million hectares in the Amazon Basin (Chomitz and Thomas 2001). Unfortunately, pastures that are established after deforestation have a limited life span because soil nutrients leach out rapidly. Over 50 % of these pastures have had to be subsequently abandoned due to soil degradation (Steinfeld et al. 1997).

Logging has remained a serious cause of deforestation in the tropics. Africa supplied 19 % (658 million m^3) of world log production in 2006. Most of this production has come from natural forests, and the International Tropical Timber Organization (ITTO 2006) estimated that only 6 % of natural production forests standing on permanent public areas were managed sustainably. Moreover, 600 000 km^2 (representing 30 %) of forests were under logging concessions for industrial exploitation in Central Africa in 2003 (Laporte et al. 2007). Logging not only reduces forest area, but also selectively removes species of high commercial value. Species targeted by logging included *Aucoumea klaineana* Pierre (Burseraceae), *Entandrophragma spp*. (*E. angolense*, *E. candollei* et *E. cylindricum*, Meliaceae), *Lovoa trichilioides* (Meliaceae), *Lophira alata* (Ochnaceae), *Erythrophleum ivorense* (Leguminosae), *Millettia laurentii* De Wild. (Fabaceae), *Guibourtia tessmannii* Benn. (Fabaceae), *Pericopsis elata* (Harms) van Meuwen (Fabaceae), *Milicia excelsa* (Welw.) C.C Berg, (Moraceae), *Guarea cedrata* (A. Chev.) Pellegrin (Meliaceae), *Guarea laurentii* (Meliaceae), *Guarea thompsonii* Sprague & Hutch. (Meliaceae), *Gossweilerodendron balsamiferum* (Verms.) Harms (Fabaceae), *Pterocarpus soyauxii* Taub. (Fabaceae; in Africa), *Dalbergia spp*. (Fabaceae), *Tectona grandis* L.f. (Lamiaceae), *Pterocarpus spp*. (Fabaceae; in Southeast Asia), *Symphonia globulifera* L.f. (Clusiaceae), *Swietenia macrophylla* King (Meliaceae), *Cedrela odorata* L. (Meliaceae), *Swietenia humilis* Zuccarini (Meliaceae), *Manilkara bidentata* (A.DC.) A.Chev. (Sapotaceae), *Dipteryx odorata* (Aubl.) Willd. (Fabaceae), and *Apuleia leiocarpa* (Vogel) J, F. Macbr., Fabaceae; in Latin America; Global Forest Watch 2000a, b; Hall et al. 2003). Selective logging caused an annual forest loss of 1,200 km^2 in areas under conservation, and loss of between 12 075 to 19 823 km^2 of forests in the Amazon in Brazil in 1992 (Asner et al. 2005). Another effect of logging is the reduction of fauna species diversity (Willott et al. 2000).

2.1.1.2 Grazing

Grazing affects savanna ecosystems, by altering floristic composition and physiognomy, and incurring ecosystem degradation (Skarpe 1991). Indeed, degradation of rangeland occurs under intensive livestock grazing. Dyksterhuis (1949) reported a replacement of relative palatable perennial grasses by less palatable or annual ones in savannas that were exposed to intensive grazing.

Browsing occurs in tropical savannas. Indeed, large herbivores including African elephant (*Loxodonta africana* Cuvier, Elephantidae), African buffalo (*Syncerus caffer* Sparrman, Bovidae), blue wildebeest (*Connochaetes taurinus* Burchell, Bovidae), cattle (*Bos taurus* L., Bovidae), giraffe (*Giraffa camelopardalis* L., Giraffidae), impala (*Aepyceros melampus* Lichtenstein, Bovidae), kudu (*Tragelaphus strepsiceros* Pallas, Bovidae), waterbuck (*Kobus ellipsiprymnus* Ogilby, Bovidae), and zebra (*Equus burchelli* Boddaert, Equidae), feed on leaves and twig of trees and shrubs in tropical savannas. Intensive browsing results in defoliation that may induce plant defenses through the secretion of substances reducing twig and leaf palatability; it may also result in further browsing, thereby reducing the woody layer of the savanna.

2.1.1.3 Effects of Unsustainable Use of Ecosystem Resources on Soil, Groundwater and Fauna

Slash-and-burn agriculture, the most common agricultural practice in the tropics, has negative effects on soil fertility and microfauna. A 30 % reduction in carbon, nitrogen and phosphorus contents of a soil that had been cultivated for 6 years using this practice was reported by Tiessen et al. (1992). The authors found that 8–10 years of fallow were needed to restore fertility levels to those similar to the original site conditions prior to cultivation. Substantial annual losses of soil fertility in the sub-Saharan region have been reported. In the two-year period between 1982 and 1984, there was a loss per hectare per year of 22 kg of nitrogen, 2.5 kg phosphorus and 15 kg of potassium (Stoorvogel et al. 1993). Demographic growth exerts a pressure on land, and the length of the fallow period decreases, resulting in an increase of deforestation for agriculture. However, long-term fallows may be able to maintain fertility levels in soils under slash-and-burn agriculture for more than 200 years (Lawrence and Schlesinger 2001). Slash-and-burn agriculture also increases runoff and loss of nutrients from watersheds (Gafur et al. 2003). Chemical inputs like fertilizers and pesticides are harmful to microfauna and pollute watercourses and groundwater. Heavy machinery used for logging compacts soil, and fragments forests by opening skid trails for log extraction. Diesel and fuel oils used in vehicles and agricultural machines may contain heavy metals that pollute forest ecosystems.

Plant root systems redistribute water from the lower wetter layers to the upper drier layers in tropical savanna, a phenomenon that is referred to as 'hydraulic lift' (Jackson et al. 2000). Intensive grazing destroys the grass layer of savannas, which reduces water uptake by grasses, and may result in the modification of hydraulic lift. Hydraulic lift increases evapotranspiration in tropical savannas (Jackson et al. 2000; Ryel et al. 2002); therefore, any damage to grassland in tropical savannas will influence the local microclimate, and affects fauna and soil properties.

2.1.1.4 Effects of Unsustainable Use of Resources on Plants and Biodiversity

Intensive grazing for extended periods of time (hereafter, overgrazing) is widespread throughout the tropics and has deleterious effects on the ecosystem, such as biodiversity reduction. The restriction of cattle's grazing in pasture areas most often results in overgrazing. Ranchers are then forced to create new grazing areas to increase animal productivity. When no new pasture can be found, growth in animal production is made by increasing the size of the herd on the same grazing area, increasing the pressure on the land (Steinfeld et al. 1997). For that reason, overgrazing increases the risk of biodiversity loss and soil degradation. As demand grows for cow meat, economic pressure pushes production beyond the limits of the rangeland, thereby exceeding the carrying capacity of pasture areas. Overgrazing causes soil compaction, soil erosion and depletion of soil fertility.

Unsustainable use of resources also includes deforestation, which is one of the primary reasons for the loss of biodiversity in the tropics (Brooks et al. 2002; Pandit et al. 2007). Deforestation causes habitat loss for a number of animal species. Brooks et al. (2002) suggested that, owing to habitat loss, endemic plant species and diversity hotspots would be destroyed, resulting in the extinction of many species on the IUCN Red List. It is estimated that only 10 % of the Indian Himalayas will still have dense forests by the year 2100 due to deforestation, and that 366 endemic vascular plants as well as 35 endemic vertebrate taxa will have their habitat destroyed (Pandit et al. 2007).

2.1.2 History of Agroforestry

The history of agroforestry up until 1993 has been well-documented in Nair (1993). In this section, we briefly review agroforestry history, drawing heavily upon Nair (1993) and focusing on new developments in this discipline since his review.

Agroforestry has arisen from a need to conserve tropical forest conservation and to implement sustainable use practices. Indeed, agroforestry is '*a new word for an old practice*'. People have always tried to benefit from forest ecosystems and trees. In the Christian Bible, an example of a homegarden (i.e., association of multipurpose trees and shrubs, annual or perennial plants and/or livestock within the household compound; Fernandes and Nair 1986) is given (Adam and Eve lived in the Garden of Eden). Homegardens have long been widespread in Africa, South and Southeast Asia, and Latin America. For instance, native peoples in Central America have long managed "conucos," which are gardens where agriculture has been practiced in a traditional manner (Esquivel and Hammer 1988) for centuries (Reynoso 1881, cited in Esquivel and Hammer 1988; Ortiz 1985; Valdés 1986). In Europe during the Middle Ages, farmers practiced slash-and-burn agriculture and integrated trees into their farms. Another example of an agroforestry system is the practice of 'retaining' trees, the products of which have food, medicinal or commercial value when clearing land for farming. Such trees are left in the fields that are used for food or cash crops, and their products are harvested yearly. This practice is widespread throughout the Congo basin. After clearing a patch of forest for crops, farmers would burn the cleared vegetation, and then plant trees in association with other species on the same land (King 1987). In Latin America, associating trees and crops was an old practice (Wilken 1977). For instance, natives in Central and South America practice the chacra system, which consists of small-scale shifting cultivation that has evolved into a shaded agroforestry system (Denevan 1971; Porro et al. 2012). In this system, food crops such as cassava (*Manihot esculenta* Crantz, Euphorbiaceae) and banana (*Musa* spp. L., Musaceae) are cultivated under cacao (*Theobroma cacao* L., Sterculiaceae) and other shade trees, and forest tree species, which provide timber and bark. This swidden fallow management also included plots of peanut or groundnut (*Arachis hypogaea* L., Fabaceae), and pineapple (*Ananas comosus* (L.) Merr., Bromeliaceae), and perennial fruit trees such as peach-palm (*Bactris gasipaes* Kunth, Aeraceae), star apple (*Chrysophyllum cainito* L., Sapotaceae), avocado (*Persea americana* Mill, Lauraceae), guava (*Psidium guajava* L., Myrtaceae), and uvilla or 'little grape' (Denevan et al. 1984).

Swidden cultivation, which is also known as slash-and-burn agriculture, has been widely practiced in tropical deciduous forests of Africa and Southeast Asia for centuries. In Southeast Asia, the *Taungya* management system is used as an alternative to slash-and-burn practices, through food crop integration into planted tree fields before canopy closure. *Taungya* replaced slash-and-burn agriculture in Myanmar (Burma) and India in the 1800s. Following numerous trials due to encroachment of forest reserves by farmers practicing slash-and-burn agriculture, the regeneration of teak (*Tectona grandis* L.f., Verbenaceae) was encouraged through the promotion of agriculture in forests (Blanford 1958; Nair 1993). Farmers had the right to cultivate food crops during the establishment and growth of trees, and could avoid prosecution for forest destruction. The *Taungya* system was created, which consisted of planting trees and food crops in the same area sequentially. Several years later, *Taungya* was introduced to other parts of Asia, and to Africa and Latin America.

The introduction of trees and/or livestock into agricultural plots appeared as an approach to preserving tropical forests. Worldwide awareness of the value of tropical forests, and the need for conservation through agroforestry practices increased the importance for the research, political, and financial support in the 20th century and beyond. In the late 1970s, the acceptance of agroforestry as a sustainable and promising land use system on both farms and in forests (Nair 1993), was facilitated by:

- A reappraisal of World Bank procedures;
- A re-examination of forest policies by the FAO;
- A growing interest in alley cropping and agro-pastoral systems;
- A deteriorating food supply in several developing countries;
- An increase in the spread of deforestation and degradation of forest ecosystems in the tropics;
- The energy crisis of the 1970is that led to increasing in commodity prices and a lack of fertilizers;
- The establishment by the International Development Research Centre (IDRC) of Canada of a project that was aimed at identifying research priorities for tropical forestry.

The World Bank recommended provision of financial aid to assist farmers in increasing food production (King 1979). International research centers in agriculture were established as a consortium in the 1960's to deal with problems of deforestation and ecological degradation, with the aim of improving the productivity of major crops or livestock in the tropics. As of today, the Consultative Group on International Agricultural Research (CGIAR) is a consortium of 15 international research centers. They are home to more than 8,000 scientists, researchers, technicians, and staff working to create a better future for the world's poor. These centers are: (1) Africa Rice Center, headquartered in Cotonou, Benin, (2) Bioversity International, headquartered in Rome, Italy, (3) Center for International Forestry Research (CIFOR), headquartered in Bogor, Indonesia, (4) International Center for Agricultural Research in the Dry Areas (ICARDA), headquartered in Beirut, Lebanon, (5) International Center for Tropical Agriculture (CIAT), headquartered in Cali, Colombia, (6) International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) headquartered in Andhra Pradesh, India, (7) International Food Policy Research Institute (IFPRI) headquartered in Washington, USA, (8) International Institute of Tropical Agriculture (IITA), headquartered in Ibadan, Nigeria, 9) International Livestock Research Institute (ILRI), headquartered in Nairobi, Kenya, (10) International Maize and Wheat Improvement Center (CIMMYT), headquartered in Mexico, D.F., Mexico, (11) International Potato Center (CIP), headquartered in Lima, Peru, (12) International Rice Research Institute (IRRI), headquartered in Los Baños, the Philippines (13) International Water Management Institute (IWMI), headquartered in Colombo, Sri Lanka, (14) World Agroforestry Centre (ICRAF), headquartered in Nairobi, Kenya and (15) WorldFish, headquartered in Penang, Malaysia. Of the 15 research centers, which each has its own charter, board of trustees, director general, and staff, ICRAF is the only one with a mission to generate science-based knowledge regarding the diverse roles that trees play in agricultural landscapes, and to use its research to advance policies and practices that benefit the poor and the environment.

It is worth noting that the Green Revolution, which occurred during the same period, had focused on the increased use of fertilizers and other chemical inputs to raise productivity to the detriment of poorer farmers who could not afford these inputs. As alternatives to this expensive farming system, alley cropping and integrated farming systems gained popularity. The growing interest in these alternative systems was further strengthened by several studies that demonstrated the benefits of intercropping non-legumes or legumes with annual crops (Papendick et al. 1976; Kang et al. 1981; Nair 1983). These findings led scientists to further investigate the feasibility of land-use systems that allowed trees to remain in the field, while examining the role of trees and grasses in the maintenance of soil productivity and soil erosion control, and livestock management practices on farms.

The International Development Research Centre (IDRC) of Canada was faced with the problem of the growing rate of deforestation in the tropics and its negative consequences, such as reduced soil fertility and increased soil degradation. Further, the FAO (1982) demonstrated that slash-and-burn agriculture accounted for 70% of deforestation. A mandate was given to John Bene, an IDRC official, to identify gaps in research and forestry education in the world, to formulate forestry research programs that would obtain results with considerable economic and social impact on developing countries, and to prepare an action plan for securing the support of donors (Nair 1993). Bene's team concluded that priority should be given to production systems that integrate forestry, agriculture and animals to optimize land use management in the tropics (Bene et al. 1977). The IDRC report strongly recommended the establishment of an international organization that would support, plan, and coordinate research involving land management systems in agriculture and forestry on a global scale. The International Council for Research in Agroforestry (ICRAF) was subsequently created in 1977, and was expanded in 1991 to become the International Centre for Research in Agroforestry. In 2002, a further expansion led to the establishment of the World Agroforestry Centre.

In the beginning, ICRAF focused its activities on creating an inventory of current agroforestry systems, collecting information, introducing new approaches and systems of agroforestry, fine-tuning existing agroforestry practices, and disseminating information on erosion control and soil fertility conservation and replenishment. Most research activities were focused on alley cropping, fallow systems with nitrogen-fixing species such as *Leucaena leucocephala* (Lam.) de Wit., *Calliandra calothyrsus* Meisn., and *Inga edulis* Mart., short fallows with pigeon pea (*Cajanus cajan* (L.) Millsp.), intercropping, promotion of multi-purpose species such as *C. calothyrsus* (which is used as a fodder source and as a nitrogen-fixing species in agroforestry systems), and the development of agro-pastoral systems that are adapted to the tropics.

Despite achievements in the development and popularization of intercropping and alley cropping, forest areas in the tropics have continued to shrink each year. The rural poor, who rely on agriculture and the forest for food, medicine and income, have placed increased pressure on natural forests due to the decline in cocoa and coffee prices in the late 1980's. The annual rate of deforestation in humid tropical forests of Africa between 1990 and 1997 reached 0.43 % year^{-1}, with an annual deforested area of 0.85 ± 0.30 (SE) million hectares, whereas the annual regrowth rate was estimated to be only 0.07 % during the same period (Achard et al. 2002). A solution was urgently needed to address this problem. The World Commission on Forests and Sustainable Development (WCFSD) began to provide more extensive support to community-based agroforestry to reduce the exploitation of primary forest for subsistence products (WCFSD 1999). This poverty-reduction and forest-protection strategy could be achieved through the development and cultivation of marketable and under-utilized "new crops" from the forests (Leakey et al. 2005). Surveys were carried out to identify and rank priority species that farmers would like to plant on their farms (Franzel et al. 1996; Leakey and Newton 1994; Simons and Leakey 2004). A worldwide domestication program of high-value, multi-purpose trees and indigenous tree species was created, which has been part of the main research focus of agroforestry since the mid-1990's. Research priorities of ICRAF in 2013 included (http://www.worldagroforestrycentre.org/research/overview accessed July 30, 2013):

- Agroforestry systems
- Tree products and markets
- Tree diversity, domestication and delivery
- Land health
- Climate change
- Environmental services

The ICRAF operates in 6 regions: West and Central Africa, East Africa, South Africa, South Asia, Southeast Asia, and Latin America. ICRAF has a partnership on research methods in agroforestry and livestock with the ILRI (International Livestock Research Institute), which is based in Nairobi, Kenya.

The future of tropical agroforestry has to deal with many issues, including which land tenure. Agroforestry is a system of natural resource management, and the right to land is most often different from that which is inherent to natural resources ownership in tropical countries. Further, land tenure is complicated because of the overlap between customary, colonial and post-colonial rights. Land tenure issues in tropical agroforestry will be discussed in detail in Chap. 17.

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