Chapter 4
Major Agroforestry Systems of the Humid Tropics

Abstract More than one hundred agroforestry systems (particular land-use systems involving integrating production of trees with crops and/or livestock, which are characterized by the environment, plant species and their arrangement, management, and socio-economic functions) have been recorded yet, with about 30 agroforestry practices (distinct arrangements of agroforestry components in space and time). Agroforestry systems and practices are often used simultaneously. Major agroforestry practices or technologies in the humid tropics include homegardens, perennial crop based systems, shifting cultivation, alley cropping, improved fallows and rotational tree fallows. Other agroforestry systems are valued in the humid tropics, including relay cropping, multilayer tree gardens, multipurpose trees on croplands and plantation-crop combinations. Since the mid-90s, the participatory domestication of high-value and multipurpose indigenous forest species using agroforestry techniques has been gaining momentum in the humid tropics.

4.1 Introduction

An agroforestry system is a particular land-use system involving integrated production of trees and crops and/or livestock, characterized by the environment, plant species and their arrangement, management, and socio-economic functions. In contrast, an agroforestry practice reflects a distinct arrangement of components in space and time. Similar practices are found in various systems under different situations. More than one hundred agroforestry systems have been identified in the tropics and temperate regions, together with about 30 agroforestry practices (Table 4.1). The distinction between agroforestry systems and practices is often unclear, and these terms are often used interchangeably, with both referring to forms of land use.

One particular agroforestry practice that has gained momentum in the tropics since the mid-1990's is the participatory domestication of high-value and multipurpose indigenous forest species. These species have provided local communities with food, income, medicine, and shelter (Leakey and Newton 2004; Leakey et al. 2005; Tchoundjeu et al. 2006). This practice is a form of agro-technology (a scientific term for an intervention that changes a practice or an existing system), which modifies the practice of introducing multipurpose trees and grasses on farms. The principles, rationale, and methods of agroforestry systems will be explained in Chap. 7. Several studies have been carried out since the 1980's to understand the

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Table 4.1 Major agroforestry practices or technologies and their main characteristics (Adapted from Nair 1993) (Source: Khasa (2001))

Agroforestry practice	Brief description or arrangement of components	Major groups of components (i.e., W: woody; H: herbaceous)	Agroecological adaptability
A. Agrisilvicultural systems (Agrisilviculture): woody perennials and agricultural crops			
1. Improved fallow	Tree or shrub species planted and left to grow during the fallow phase	W: fast-growing, preferably leguminous (e.g., *Leucaena leucocephala*) H: common agricultural crops	In shifting cultivation areas (Tropics)
2. *Taungya*	Combined stand of woody and agricultural species during early stages of establishment of plantations	W: usually plantation forestry species (*i.e.*, *Tectona grandis*); H: common agricultural crops	In all ecological regions where *Taungya* is practiced; several improvements possible
3. Alley cropping (or hedgerow intercropping)	Woody species in hedges; agricultural species in alleys between hedges; microzonal or strip arrangement	W: fast-growing legumes, that coppice vigorously H: common agricultural crops	Subhumid to humid areas with high human population pressure and fragile soils
4. Relay cropping	Agricultural crops are interplanted with woody species which is harvested before the next rainy season and ramial chipped wood incorporated the soil	W: short rotation, preferable leguminous H: common agricultural crops	Tropical areas
5. Multilayer tree gardens	Multispecies, multilayer, dense plant associations with no organized planting arrangements	W: different woody components of various forms and growth habits; H: usually absent; shade-tolerant ones present	Areas with fertile soils, good availability of labor, and high human population pressure
6. Multipurpose trees on croplands	Trees scattered in cropland (e.g., maize in parkland) or according to some systematic patterns on bunds, terraces, or plot fields boundaries	W: multipurpose trees and other fruit trees Common agricultural crops	In all ecological regions, especially in subsistence; also commonly integrated with animals

Table 4.1 (continued)

Agroforestry practice	Brief description or arrangement of components	Major groups of components (i.e., W: woody; H: herbaceous)	Agroecological adaptability
7. Plantation crop combinations	1. Integrated multi-storey (mixed, dense) mixture of plantation crops 2. Mixtures of plantation crops in alternate or other regular arrangement	W: plantation crops such as cacao, coconut, rubber, coffee, palm, fruit trees, fuelwood or fodder species	In humid lowlands or tropical humid/subhumid highlands (depending on the plantation crop concerned); usually in small-holder subsistence system
8. Homegardens	Intimate, multi-storey combinations of various trees and crops around homesteads	W: Fruit trees and vegetables predominate H: shade tolerant agricultural species	In all ecological regions
9. Woody perennials in soil conservation and reclamation	Woody species on bunds, terraces, raisers, etc., with or without grass strips; woody species for soil reclamation	W: multipurpose and /or fruit perennials H: common agricultural species	In sloping areas, especially in highlands, reclamation of degraded, acid, alkali soils, and sand-dune stabilization
10. Sloping agriculture land technology	Planting of field and permanent crops in 3-5 m bands between double-contoured rows of woody plants to help control soil erosion and increase crop yields	W: woody species preferable leguminous H: agricultural crop of the locality	Southeast Asia, particularly in the hilly uplands
11. Hydro-agrisilviculture	Woody plant (e.g. *Sesbania rostrata*) is sequentially inter-cropped with wetland rice	W: flood-tolerant leguminous H: wetland rice	In Southeast Asia, also sometimes integrated with fishes (e.g. carp)
12. Irrigated agrisilviculture	Crop combination with fruit bearing woody perennials	W: fruit bearing woody plants (e.g. olive trees) H: agricultural crops of the locality (e.g. cereals)	Semi-arid, arid and Mediterranean regions (e.g., Sahel, Northern Africa, Middle East)
13. Shelterbelts and windbreaks, living hedges	Woody plants around farmlands/plots; multi-layers strips of trees and/or shrubs planted at several rows to alter wind flow	W: combination of tall-growing spreading types H: agricultural crops of the locality	In wind-prone areas

Table 4.1 (continued)

Agroforestry practice	Brief description or arrangement of components	Major groups of components (i.e., W: woody; H: herbaceous)	Agroecological adaptability
14. Fuelwood production	Interplanting firewood species on or around agricultural lands	W: firewood species H: agricultural crops of the locality	In all ecological regions, except in rainforest zones, where fuel wood is available (in the forest)
B. Silvopastoral systems (Silvopasture or silvopastoralism or silvipasture): woody perennials and pasture and or livestock			
15. Woody perennials on range land or pastures	Woody perennials scattered irregularly or arranged according to some systematic pattern	W: multipurpose trees, of fodder value Fo: present L: present	Extensive grazing in tropical and temperate areas
16. Protein banks	Production of protein-rich fodder/forage on farm/rangelands for cut-and-carry fodder/forage production	W: leguminous fodder woody perennial H: present Fo: present L: present	Usually in areas with high person: land ratio
17. Plantation crops with pastures and livestock	Livestock under woody perennials (e.g. coconuts, oil palms, pines and *Eucalyptus* spp.)	W: plantation crops Fo: present L: present	In areas with less pressure on plantation crop lands
18. Living fences of fodder woody perennials and hedges	Livestock browsing living hedges	W: fast-growing and coppicing fodder shrubs and trees L: present	In all ecological regions, very common in the tropics
C. Agrisilvopastoral or agrosilvopastoral systems			
19. Homegardens involving livestock	Intimate, multi-storey combinations of various woody species and crops, and livestock, around homesteads	W: fruit perennials predominate; also other woody species L: present	In all ecological regions with high density of human population
20. Multipurpose woody hedgerows	Woody hedges for browse, mulch, green manure, soil conservation	W: fast-growing and coppicing fodder shrubs and trees H: similar to alley cropping and soil conservation L: present	Humid to subhumid areas with hilly and sloping terrain
21. Dehesa or montado	Wooded pastures also producing Non-Timber Forest Products	W: multipurpose trees dominate	Spain and Portugal

Table 4.1 (continued)

Agroforestry practice	Brief description or arrangement of components	Major groups of components (i.e., W: woody; H: herbaceous)	Agroecological adaptability
Other Systems			
D. Forest farming systems			
22. Entomoforestry	Insects with woody species for honey production (apiforestry) or for pollination	W: melliferous woody perennials (other components may be present)	Depending on the feasibility of apiculture
23. Mycoforestry	Fungal spawn inoculated on trees of cultivated logs	W: living trees or logs Em: edible mushrooms	Temperate and Mediterranean regions and could be developed in tropical regions
24. Herboforestry	High-value specialty herbs cultivated under woody perennials	W: shade-woody species H: specialty shade-tolerant herbs	In all ecological regions
E. Aquaforestry			
25. Silvo-fish farming	Woody perennials liming fish ponds, tree leaves being used as forage for fish	W: woody perennials preferred by fish (other components may be present) Fi: fish and shrimps present H: grass planted on bunds	In all ecological regions especially in lowlands with a lack of animal proteins
26. Agrisilvopastoral fishery	Trees lining fish ponds, micro livestock raised around the ponds and temporal sequence for raising fish and agricultural crops in the ponds	W: woody perennials preferred by fish H: agricultural crops of the locality (e.g. vegetables and wetland rice) Fi: fish and shrimps present H: grass planted on bunds	In the humid Tropics, especially in Southeast Asia
27. Mangrove management	Plantation establishment and rehabilitation of degraded mangrove formations to mitigate erosion and reduce flooding, protect fish and shrimp ponds	W: mangrove woody perennials (e.g. *Rhizophora* spp., *Avicennia* spp.) Fi: fish and shrimp present	Mangrove ecosystems occurring in the intertidal zones along sheltered coasts and river banks in coastal areas in the tropics and sub-tropics

Table 4.1 (continued)

Agroforestry practice	Brief description or arrangement of components	Major groups of components (i.e., W: woody; H: herbaceous)	Agroecological adaptability
F. Hydroforestry			
28. Multispecies buffer strips riparian zone management	A buffer strip, which includes rows of trees and or shrubs, and a strip of native prairie grass to stabilize the stream, and serve as a sink for non-source pollutants from agricultural fields; woody perennials and grasses increased biodiversity for wildlife and provide biomass energy	W: short-rotation woody crops (e.g., *Populus* spp.) with shrub species H: native prairie grass	In all ecological regions in need to protect stream, riverbanks and lakes
29. Multispecies water catchment management	Planting of selected hydrophilic species for rehabilitation of water catchment	W: hydrophilic woody perennials (e.g., black spruce)	In swamped areas
30. Multipurpose woodlots	For various purposes (wood fodder, soil protection, soil reclamation)	W: multipurpose species; special location-specific species (other components may be present)	Various
31. Community forestry	Tree planting on common lands by local people	W: multipurpose tree species	In tropical regions

W *woody*; H *herbaceous*; Fo *fodder/forage for grazing*; Fi *fish*; L *livestock*; Em *edible mushrooms*

mechanisms underlying the functioning of existing agroforestry systems in order to fine-tune those systems. Systems that have been studied include alley cropping, improved fallows, *Taungya*, homegardens, windbreaks, and parklands together with cocoa, coffee and tea or rubber farms.

The spatial structure of farm compounds in forest areas in the humid tropics is as follows:

- Houses
- Homegardens
- Cash crops
- Food crops and fallows
- Forests

Fig. 4.1 An example of a homegarden in Cameroon (Source: Ann Degrande)

The most common agroforestry systems in the humid tropics include homegardens, perennial crop based systems, farm woodlots, alley cropping, improved fallows, and rotational tree fallows. Some agroforestry systems are specific to Amazonia (such as small-scale intensive farming systems, which is a form of homegarden) and to Southeast Asia (such as *Taungya*). Major agroforestry practices or technologies and their main characteristics are given in Table 4.1.

The aforementioned land-use systems that we have listed are described in detail in the sections that follow, starting with homegardens, which are an important component of homesteads in the tropics.

4.2 Homegardens

A homegarden can be defined as an intimate association of multipurpose trees and shrubs, annual or perennial plants, or livestock within the household compound, with the whole unit being managed by family labor (Fernandes and Nair 1986). Homegardens consist of an assemblage of trees, shrubs, and vines and herbaceous plants that are managed around the home compound (Fig. 4.1) by the household, and the products of which are used primarily for family consumption. This agroforestry system can also provide shade for livestock or serve ornamental purposes. Most homegardens are agrosilvopastoral systems. Kumar and Nair (2004) have suggested that homegardening is a generic concept (i.e., a group of terms), much like agroforestry itself. Homegardens are "structurally and functionally the closest mimics of natural forests yet attained" (Ewel 1999; Table 4.2).

Several terms have been used to describe agroforestry practices that are undertaken around homes, including mixed-garden horticulture (Terra 1954), homegarden (Ramsay and Wiersum 1974), mixed-garden or house garden (Stoler 1975), Javanese homegarden (Soemarwoto et al. 1976; Soemarwoto 1987), compound farm (Lagemann 1977), kitchen garden (Brierley 1985), household garden (Vasey

Table 4.2 A comparison of the ecological attributes of climax forests, homegardens and conventional agricultural systems (Kumar and Nair 2004)

Parameter	Natural climax vegetation (humid tropics)	Homegardens	Conventional agricultural systems
Biogeochemistry	Nutrient inputs equal outputs	Inputs and outputs balance each other	Outputs far exceed inputs
Biotic stress	Low	Low	High
Canopy architecture	Multistrata	Multistrata	One- or two-layered
Disturbance regimes	Rare except natural disturbances such as tree fall, wind throw etc.	Intermediate	High
Diversity	High	Intermediate	Low
Ecological succession	Normally uninterrupted, reaches a stable end-stage, e.g. climatic climax	Consciously manipulated	Arrested, succession does not proceed beyond the early stage
Entropy	Low	Low (?)	High
Floristic spectrum	Shade tolerant and intolerant	Shade tolerant and intolerant	Mostly shade intolerant
Input use	No external inputs	Low	High
Overall homeostasis	High (Odum 1969)	High	Low
Site quality	Progressive improvement (e.g., facilitation)	Progressive improvement	Steady decline
Standing biomass/net primary productivity (NPP)	Highest among the terrestrial ecosystems (mean NPP: 200 g m^{-2} $year^{-1}$)	Comparable to the climax formations but firm estimates are lacking[a]	Low (mean NPP: 650 g m^{-2} $year^{-1}$; Leigh 1975)
Sustainability	Sustainable	Sustainable	Unsustainable

[a]However, a lone report on this (Christanty et al. 1986), *cf* Torquebiau (1992), provides a value of 5.23 kJ (=1250 cal) m^{-2} yr^{-1} for the *pekarangan* gardens in Java. Clearly, this is lower than the annual energy fixation in both cultivated lands and tropical rainforest (i.e., 11.3 and 34.6 MJ m^{-2} yr^{-1}, respectively; Leigh 1975)

1985), and homestead agroforestry (Achuthan and Streedharan 1986; Leuschner and Khalique 1987).

Numerous types of homegardens have been described (Soemarwoto et al. 1976; Lagemann 1977; Bavappa and Jacob 1982; Wiersum 1982; Michon 1983; Fernandes and Nair 1986; Fernandes et al. 1984; Okafor and Fernandes 1986; Reynor and Fownes 1991; Tchatat et al. 1995), indicating that this system is widely distributed in the tropics and has been practiced for millennia. Because the primary function of a homegarden is subsistence, they most often contain vegetables, tuber crops, medicinal plants, multipurpose plants and indigenous fruit trees. Perennial crops such as cocoa, coffee or palms are frequently found in homegardens, but these gardens lack the operational size of cash crop farms. An inventory of the structures and functions of homegardens in the tropics was conducted by Fernandes and Nair (1986). The inventory subsequently was used to classify homegardens by region, depending on biophysical and socio-economic factors, and to describe the different compositions of homegardens (Table 4.3).

Table 4.3 Floristic elements of homegardens in different regions of the world (Kumar and Nair 2004)

Region/location and the floristic spectrum sampled	Number of species per garden	Total for geographical location	Source
South Asia			
Pitikele, Sri Lanka (edible species)	–	55	Caron (1995)
Kandy, Sri Lanka (woody species)	4–18	27	Jacob and Alles (1987)
Thiruvananthapuram, Kerala, India (all species)	–	107	John and Nair (1999)
Same as above	26-36	–	D. Jose (pers. comm., 1992)
Kerala, India (woody species)	3-25	127	Kumar et al. (1994)
Bangladesh (perennial species)	–	30	Leuschner and Khalique (1987)
Same as above	–	92	Millat-e-Mustapha et al. (1996)
Kerala, India (all species)	–	65	Achuthan and Sreedharan (1986)
Southeast Asia			
West Java (all species)	–	195	Abdoellah et al. (2001)
Northeastern Thailand (all species)	15–60	230	Black et al. (1996)
Chao Praya Basin, Thailand (all species)	26–53	–	Gajaseni and Gajaseni (1999)
West Java (all species)	–	602	Karyono (1990)
Central Sulawesi, Indonesia (all species)	28–37	149	Kehlenbeck and Maas (2004)
Cianjur, West Java (all species)	4–72	–	K Sakamoto (pers. comm., 2003)
Cilangkap, Java (all species)	42–58	–	Yamamoto et al. (1991)
South/CentralAmerica and the *Caribbean*			
Quintan Roo, Mexico (all species)	39	150	De Clerck and Negreros-Castillo (2000)
Cuba (all species)	–	80	Esquivel and Hammer (1992)
Central Amazon (woody species)	–	60	Guillaumet et al. (1990)
Belize (all species)	30	164	Levasseur and Olivier (2000)
Masaya, Nicaragua (all species)	–	324	Méndez et al. (2001)
Santa Rosa, Peruvian Amazon (all species)	18–74	168	Padoch and de Jong (1991)
Yucatan, Mexico (all species)	–	133–135	Rico-Gray et al. (1990)
As above	–	301	Rico-Gray et al. (1991)
Chiapas, Mexico (all species)	30	241	Vogl et al. (2002)

Table 4.3 (continued)

Region/location and the floristic spectrum sampled	Number of species per garden	Total for geographical location	Source
Cuba (all species)	18–24	101	Wezel and Bender (2003)
Other regions			
Catalonia, Spain (all species)	–	250	Agelet et al. (2000)
Southern Ethiopia (all species)	14.4	60	Asfaw and Woldu (1997)
Bungoma, Western Kenya (all species)	–	253	Bakes (2001)
Soqotra island, Yemen (all species)	3.9–8.4	–	Ceccolini (2002)
Democratic Republic of Congo (all species)	–	272	Mpoyi et al. (1994)
Bukoba, Tanzania (woody species)	–	53	Rugalema et al. (1994a)
Central, eastern, western and southern Ethiopia (all species)	–	162	Zemede and Ayele (1995)

[a] All except Catalonia are tropical

Homegardens contain a wide variety of species, which approximates the range of species encountered in natural forests (Gajaseni and Gajaseni 1999). In one example, 101 plant species were identified in 31 homegardens in Cuba, with each garden containing about 18 to 24 different species (Wezel and Bender 2003; Table 4.4). Similarly, the mean number of woody taxa that are found in homegardens in India can range from 11 to 39, with greater floristic diversity present in the smaller homesteads (Kumar et al. 1994). Homegarden diversity is strongly related to its age and other specific garden characteristics, household socio-economic features, and access to planting material (Coomes and Ban 2004). The average homegarden includes about four canopy strata (Tchatat et al. 1995; Gajaseni and Gajaseni 1999; Figs. 4.2 and 4.3), and their average area is frequently less than one hectare in size (Fernandes and Nair 1986).

Homegardens are carefully structured systems. For example, in Nigeria (West Africa), homegardens have a four-strata canopy that is dominated by fruit trees (Okafor and Fernandes 1987). Another example of a homegarden is the intensive small-scale system that is described in sect. 4.1.1. The structure and composition of a homegarden will depend upon its position in the overall farming system and on the livelihood strategies of its inhabitants. Rural transformation results in changes in livelihoods and farming systems, which has further impacts on homegarden function and composition (Wiersum 2006). Factors that affect the structure and composition of homegardens are listed in Table 4.5.

The choice of species to be included in a homegarden depends upon the products that these species provide (Gajaseni and Gajaseni 1999). The choice of species, together with their arrangement and management, can vary within a community or village (Méndez et al. 2001). Tchatat et al. (1995) have described the homegardens

Table 4.4 Factors impacting the structure and composition of homegardens with special reference to Indonesian homegardens (Wiersum 2006)

Factors	Conditions	Examples and remarks
Geographic location	Urban versus rural location	Urban homegardens often smaller and more aesthetically oriented
Environmental conditions	Climate conditions	Variation in annual crops cultivated only in favorable climatic seasons is mostly less pronounced than in permanent crops that have to be adapted to variable climatic conditions over much larger periods
	Soil conditions	With decreasing soil fertility crop diversity tends to decrease and the effect of competition by trees on understorey becomes more pronounced. Dense tree gardens occur mostly in volcanic soils, while on tertiary soils tree gardens are open
Role in farming systems	Degree of complementarity to open field cultivation systems	If homegardens are the only land asset more inclusion of staple food crops
	Established versus incipient farming system	Incipient gardens first dominated by annual crops, with time increased incorporation of tree crops
Socioeconomic conditions of the household	Wealth status	With increased wealth, increased importance of commercial and aesthetic crops
	Access to markets	Commercial crops stimulated by good market access
	Access to off-farm employment	In case of access to financially lucrative employment decreased, importance of commercial crops
	Gender-related issues	Gardens of female-headed households often more household oriented (for consumption)
Cultural factors	Food preferences	Cultural preferences in respect to consumption of vegetables and spices

of lowland rainforests of Cameroon as following a floristic and structural approach as well as a socio-economic approach. Homegardens in this area consist of a front yard for ornamental plants, and a larger backyard where food crops and fruit trees are grown. Three groups of species characterized the homegardens in this area, depending on the garden's life history and usage.

The first species group is primarily composed of maize (*Zea mays* L., Poaceae), which can be combined with other annual crops such as the common bean (*Phaseolus vulgaris* L*., Fabaceae*) and groundnut or peanut (*Arachis hypogaea* L., Fabaceae). The second group consists of multi-annual food crops such as plantain (*Musa* spp.), and cassava or manioc (*Manihot esculenta* Crantz, Euphorbiaceae). The third group contains mainly fruit species such as safou or African pear (*Dacryodes edulis* H.J. Lam; Burseraceae), mango (*Mangifera indica* L., Anacardiaceae), or citrus (Rutaceae) trees, and other trees with various uses. These homegardens are mainly intended to produce food for the household, whereas *Chagga* homegardens in Tanzania, for example, tend to be commercial and consist mainly

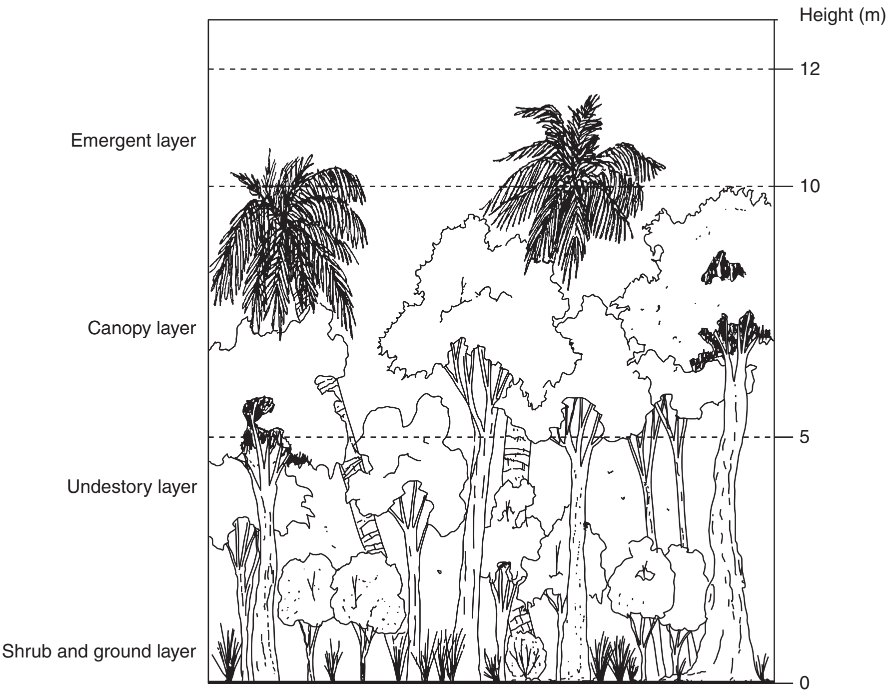

Fig. 4.2 Vertical physical structure of vegetation in a homegarden system of Sristachanalai, Thailand (Gajaseni and Gajaseni 1999)

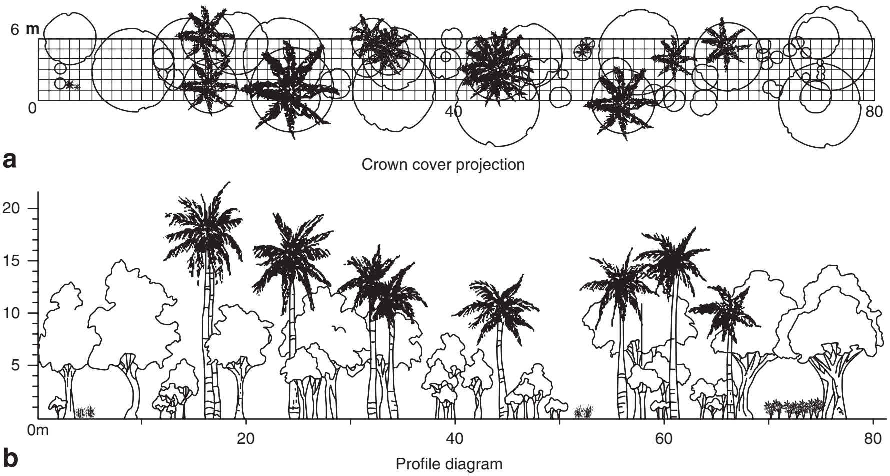

Fig. 4.3 Crown cover projection **(a)** and profile diagram **(b)** of homegarden systems in Sristachanalai, Thailand (Gajaseni and Gajaseni 1999)

Table 4.5 Annual litter and nutrient additions through multipurpose trees in homegardens in Kerala, India (Isaac and Achuthan 2006)

Species	Litterfall (kg m^{-2})	Nitrogen (g m^{-2})	Phosphorus (g m^{-2})	Potassium (g m^{-2})
Mangifera indica	0.87	8.8	0.42	2.8
Artocarpus heterophyllus	0.73	8.6		
Anacardium occidentale	0.72	8.8	0.17	1.1
Ailanthus triphysa	0.38	6.4	0.35	1.2
Artocarpus hirsutus	0.65	6.5	0.39	1.7
Swietenia macrophylla	0.64	6.8	0.42	2.6
Total	3.99	45.9	2.09	11.6

of arabica coffee (*Coffe arabica* L., Rubiaceae) and bananas (Fernandes et al. 1984). African homegardens that are intended for food production, as is the case in southeastern Nigeria, consist mainly of food crops such as yams (*Dioscorea* spp., Dioscoreaceae), manioc (*Manihot utilissima* Pohl, Euphorbiaceae), taro (*Colocasia esculenta* (L.) Schott, Araceae)), cocoyam or malanga (*Xanthosoma sagittifolium* (L.) Schott, Araceae), *Musa* spp., banana *(Musa* x *paradisiaca* L.), maize (*Zea mays* L.), okra (*Albemoschus esculentus* (L.) Moench = *Hibiscus esculentus* L., Malvaceae), squashes and pumpkin (*Cucurbita pepo* L., Cucurbitaceae), Thunberg's amaranth (*Amaranthus thunbergii* Moq., Amaranthaceae), and *Solanum* spp (Solanaceae). These homegardens also harbor trees and shrubs, small ruminants, poultry, and occasionally swine that are kept in pens. Manure from the animals is used as fertilizer for the plants. An analysis of nine fertility properties indicates that the soils in these gardens are healthier than those under fallow or surrounding secondary forests (Tchatat 1996; Tchatat et al. 2004). In central Sulawesi (Indonesia), 149 crop species were recorded in 30 homegardens that had been randomly selected from three villages, and the number of vegetation layers differed depending on the age and size of the homegarden (Kehlenbeck and Maass 2004). There is minimum export of soil nutrients in homegardens (Gajaseni and Gajaseni 1999), and production of nutrients from litter is very high (Fig. 4.4, Table 4.6), which indicates that litter from a homegarden has potential as an agricultural fertilizer.

Tropical homegardens have more favorable microenvironments than the surrounding areas, with lower soil and air temperatures and higher relative humidity. They also can be very productive, in India, for example, homegardens produced enough fuelwood to meet societal demands (Kumar et al. 1994).

4.2.1 Intensive Small-Scale Farming Systems

Altieri and Farrell (1984) reported on intensive small-scale farming systems that were located close to homegardens and food crop farms. Indeed, these farms are less than 1 ha in area and are located around homesteads. Common inter-cropping (maize and beans; garlic and onions, which are mixed with lettuce and cabbage; maize and potatoes) is practiced in these systems, which can include 5 to 10 tree

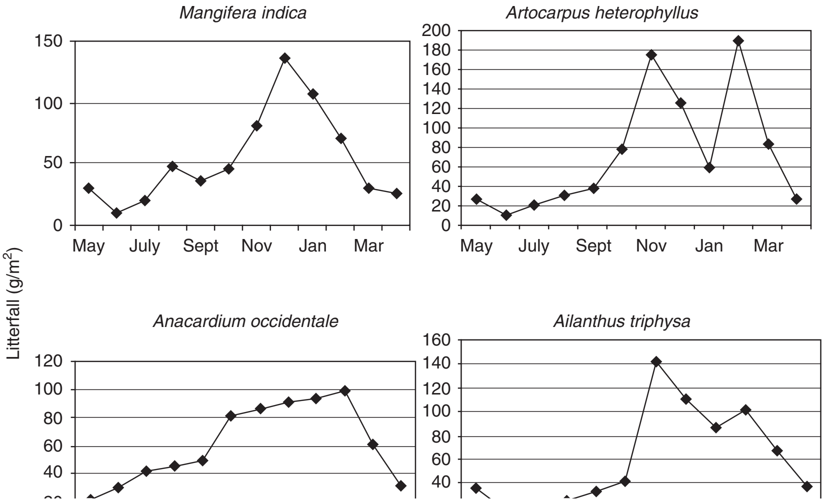

Fig. 4.4 Litterfall patterns of multipurpose trees in the homegardens of Kerala, India (Isaac and Achuthan 2006)

Table 4.6 Average species richness and diversity indices of trees per cocoa agroforest in three sub-regions of Southern Cameroon (Sonwa et al. 2007)

	Ebolowa (n=20 agroforests)	Mbalmayo (n=20 agroforests)	Yaoundé (n=60 agroforests)	Whole region	P-value
Species richness	21 (±1.8) a	26 (±2.3) a	15 (±1.2) b	21 (±1.1)	0.001
Shannon index	3.9 (±0.13) a	4.2 (±0.12) a	3.11 (±0.16) b	3.7(±0.96)	<0.001
Piélou equitability	0.73 (±0.02) a	0.72 (±0.02) a	0.60 (±0.03) b	0.70 (±0.02)	<0.001
Simpson index	0.10 (±0.01) a	0.08 (±0.01) a	0.19 (±0.23) b	0.12 (±0.01)	<0.001

n*=20 agroforests; n**=60 agroforests; P-values are the significance level of the Kruskal–Wallis test; n.s = not significant ($p>0.05$). Subregions not sharing a common letter in a row are significantly different at $P=0.05$

crops and 10 to 15 annual crops. This system also contains grape arbors to provide shade, and 3 to 5 animal species (chickens, ducks, rabbits and pigs). Such small-scale intensive farming systems can be found in the densely populated Kerala State of India (Achuthan and Sreedharan 1986). These intensive systems contain livestock, poultry, fisheries, and tree and plantation crops in mixtures on the same piece of land. Food crops are mostly arrow root (*Maranta arundinacea* L., Marantaceae), rice (*Oryza sativa* L., Poaceae), cassava, Chinese potato (*Coleus parviflorus* Benth., Lamiaceae), taro (*Colocasia* spp.), elephant yam (*Amorphophallus paeoniifolius* (Dennst.) Nicolson, Araceae) and sweet potato (*Ipomoea batatas* (L.)

Lam., Convolvulaceae) (Achuthan and Sreedharan 1986). Pulse crops are cultivated in these systems (for example: cowpea (*Vigna unguiculata* (L.) Walp., Fabaceae), pigeon pea (*Cajanus cajan* (L.) Millsp. Fabaceae), mung bean (*Vigna radiata* (L.) R. Wilczek, Fabaceae), together with breadfruit (*Artocarpus altilis* (Parkinson) Fosberg, Moraceae), annona (*Annona* spp., Annonaceae), banana, kokum (*Garcinia indica* Choisy, Clusiaceae), gooseberry (*Ribes uva-crispa* L., Grossulariaceae), guava (*Psidium guajava* L., Myrtaceae), and jackfruit (*Artocarpus heterophyllus* Lam., Moraceae)) (Achuthan and Sreedharan 1986). Nath et al. (2005) also reported small-scale homesteading in the densely populated Chittagong Hills Tracts of Bangladesh. Homesteading uses plantings of both horticultural (*A. heterophyllus*, *Citrus reticulata* Blanco, *Litchi chinensis* Sonn. (Sapindaceae), *Ananas comosus* (L.) Merr. (Bromeliaceae), banana, guava, and mango)) and timber species (*Gmelina arborea* Roxb. (Lamiaceae), *Tectona grandis* L.f. (Lamiaceae), *Albizia* spp. (Fabaceae), *Swietenia macrophylla* King (Meliaceae), and *Acacia* spp. (Fabaceae)).

4.3 Perennial Crop Based Agroforestry Systems

Agroforestry with a cultivated tree crop component is widespread in the tropics. In the humid tropic lowlands, it consists mainly of cocoa (*Theobroma cacao* L., Sterculiaceae) or robusta coffee (*Coffea canephora* Pierre ex A.Froehner, Rubiaceae), which is grown under the shade of several trees. In 2000, cocoa agroforests covered between 300,000 and 400,000 hectares in Cameroon (Kotto-Same et al. 2000). In the tropical highlands of Africa or South America, arabica coffee- or tea- (*Camellia sinensis* (L.) Kuntze, Theaceae) based systems are most common. Other examples of species that are used in perennial agroforestry systems in the tropics are: oil palm (*Elaeis guineensis* Jacq., Arecaceae), coconut (*Cocos nucifera* L., Arecaceae), cashew (*Anacardium occidentale* L., Anacardiaceae), rubber tree (*Hevea brasiliensis* Müll. Arg., Euphorbiaceae), black pepper (*Piper nigrum* L., Piperaceae), vanilla bean (*Vanilla planifolia* Jacks. Ex Andrews, Orchidaceae; in Madagascar), sisal (*Agave sisalana* Perrine, Asparagaceae), and carnauba palm (*Copernicia prunifera* (Mill.) H.Moore, Arecaceae; mostly in Latin America). They are mostly cash crops, and although some of these species originate in the tropics, their culture or their introduction coincided with the colonization of the region. Cacao, vanilla, and rubber originated in Latin America; while coffee likely originated in Ethiopia, the arabica species may be indigenous to Central Africa (Lashermes et al. 1999).

Over the last several years, research has been focused on finding methods to increase food crop production, but little has been done pertaining to the introduction of trees and animals into perennial crop farms where cocoa or coffee is grown. Farmers form the bulk of perennial commodity crop producers (cocoa in Ivory Coast, Ghana, Nigeria and Cameroon; coconut in Southeast Asia). Cocoa agroforests mix cacao with other crops and tree species; most of the latter are retained during land clearing. Forest trees that are retained when clearing land for farm establishment provide shade and other environmental services. In Ondo State, Nigeria, 487 non-cocoa trees belonging to 45 species and 24 families were recorded in 21 ha of cocoa agroforests, with 86.8 % of the trees producing edible fruits (Oke and Odebiyi 2007). Each cocoa farm has a multistrata structure (Fig. 3.7), and the flora is very diverse. In the humid forest zone of Cameroon, an inventory of 60 cocoa agroforest stands revealed the presence of 206 tree species, with an average of 21 species per agroforest (Sonwa et al. 2007), thereby demonstrating the high diversity found in the forests (Table 3.8). These figures are consistent with those of Bisseleua et al. (2008), who identified a total of 102 non-cocoa trees and 260 herbaceous species in five traditional cocoa agroforests in Cameroon. Food-producing tree species tend to be more frequently planted than other tree species in cocoa farms, and two-thirds of these food trees are native forest species (Sonwa et al. 2007).

Some fast-growing food crops, such as plantain, are used for shade during cacao establishment. Other food crops like maize, sweet potato, malanga, and cucumber (*Cucumis sativus* L.) are often associated with cacao in the early years of its growth, to provide for the household's food needs. This involves optimizing of airspace and soil management for the benefit of the cocoa plants. Plantains provide shade for the seedlings, and as the cocoa plants grow, the soil volume free for cocoa plant root expansion will increase as the food crops are reaped. Species commonly planted to provide shade for cocoa or coffee are typically local fruit trees (e.g., *Garcinia kola* Heckel (Clusiaceae), *Irvingia gabonensis* (Aubry-Lecomte ex O'Rorke) Baill. (Irvingiaceae), *Cola acuminata* Schott & Endl. (Sterculiaceae), *Ricinodendron heudelotii* (Baill.) Heckel, Euphorbiaceae), and *Dacryodes edulis*), timber species (e.g., *Baillonella toxisperma* Pierre (Sapotaceae), *Milicia excelsa* (Welw.) C.C. Berg, *Terminalia superba* Engl. & Diels (Combretaceae), *Cedrela* spp. (Meliaceae), or multipurpose trees (e.g., *Allanblackia floribunda* Oliv., Clusiaceae). Cocoa is usually seeded at a density of 1,100 trees per ha, with canopy trees planted at 30 individuals per ha. Shade is beneficial for cocoa, as biomass production is higher in the shade. Isaac et al. (2007a) found that cocoa produced 41.1 Mg ha^{-1} of standing biomass under *Milicia excelsa*, compared to 22.8 Mg ha^{-1} when the plants were not shaded. The study also indicated that soil exchangeable K increased under *Newbouldia*, and N and P uptake increased under shade. Cocoa agroforests also have beneficial effects on the soil and litter faunal communities. Richness of the fauna is greater in the litter than in the soil (da Silva Moço et al. 2009). In Ghana, Isaac et al. (2007b) reported suppression of K uptake in cocoa foliage by inter-cropping under *Terminalia superba* and *Newbouldia laevis* (P. Beauv., Bignoniaceae). The same study revealed that intercropping has no effect on cocoa biomass production in comparison to monoculture cocoa, whereas artificial shading stimulated foliage and root production.

In the tropical highlands, arabica coffee and tea are the most common perennial crops, regardless of the size of the industrial farm, while coconut plantations are most commonly encountered in the Philippines, Indonesia, Sri Lanka, Malaysia, and the Pacific Islands. Woody perennials are grown among the coffee or tea plants for firewood or honey production (e.g., *Calliandra calothyrsus* Benth.). Arabica coffee farms typically result in multi-strata agroforests. Examples of crop or livestock integration into coffee farms have been reported in Ethiopia, Colombia, and

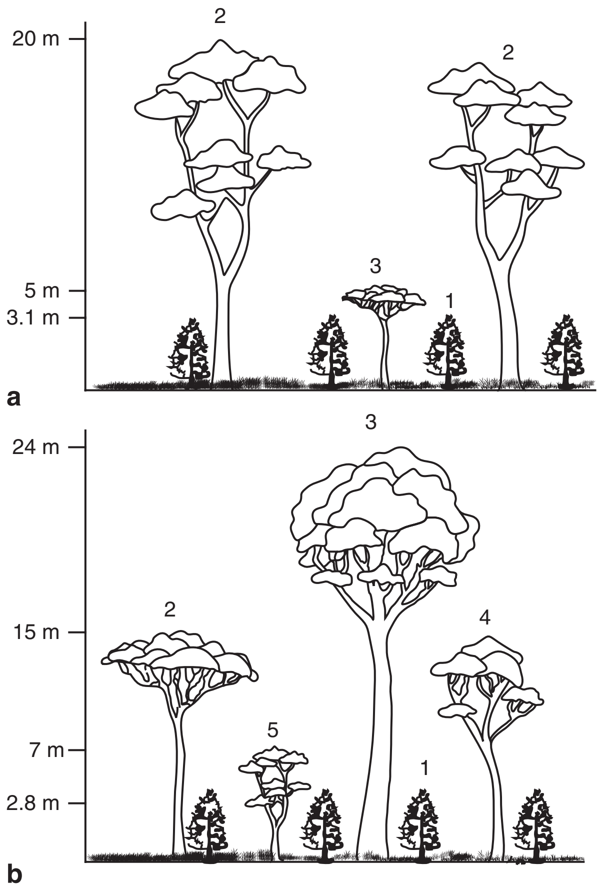

Fig. 4.5 The vertical structure of shade of two coffee systems in Chiapas, Mexico. **a** Most common species in an Inga system (IS): 1. Coffea arabica, 2. Inga latibracteata, 3. Heliocarpus appendiculatus. **b** Most common species in a rustic shade (RS) system: 1. Coffea arabica, 2. Inga latibracteata, 3. Heliocarpus appendiculatus, 4. Beliotia mexicana, 5. Croton draco. (Romero-Alvarado et al. 2002)

Kenya. However, in high altitudes, sensory attributes of Arabica coffee are negatively influenced by shade (Bosselmann et al. 2009). Coffee plants in mixed agroforests also have less branch growth and leaf production, and present earlier fruiting than coffee plants in monoculture systems (Campanha et al. 2004). In Costa Rica, Muschler (2001) found that, at low altitudes, an increase in shade results in an increase in fruit mass and bean size of *C. arabica.* He further postulated that at low altitudes, shade promotes slower and more balanced filling and uniform ripening of berries. Thus, the benefits of shade on coffee quality depend on altitude. Different shade structures can be encountered in coffee systems (Fig. 4.5) and, consequently, shade attributes and soil characteristics can vary according to the shade system (Table 4.7). Shade trees, especially indigenous trees with high leaf tannin concentrations, can also improve soil fertility in coffee systems (Teklay and Malmer 2004). Some timber species, such as silky oak (*Grevillea robusta* A.Cunn. ex R.Br., Proteaceae), can be inter-cropped with coffee without deleterious effects on coffee

Table 4.7 Mean values for shade attributes, soil variables, coffee-shrub characteristics and yields, in an Inga-coffee system (IS) and a Rustic-shade coffee system (RS) in Chiapas, Mexico (Romero-Alvarado et al. 2002)

Measured variables	IS	RS	Significance
Shade attributes			
Shade tree/ha	282±159	457±257	*
Shade-species richness in 100 m^2	1.6±0.7	3.0±1.4	***
Shade strata number	2.9±0.9	3.0±1.0	**
Shade cover (%)	76.9±5.7	71.2±8.8	*
Direct light (mol m^{-2} day^{-1})	18.2±4.4	21.9±6.3	*
Diffused light (mol m^{-2} day^{-1})	3.2±0.6	3.8±0.8	*
Shade-tree height (m)	11.3±3.9	11.0±4.7	N.S
Shade-tree diameter (cm)	27.0±14.1	23.6±11.4	N.S
Shade-tree basal total area (m^2)	0.7±0.8	1.0±1.3	N.S
Number of fruit trees ha^{-1}	100±74	200±10	N.S
Soil variables			
Litter density (cm)	3.2±1.7	2.2±0.9	*
pH	5.2±0.4	5.3±0.4	N.S
Organic matter (%)	6.7±0.9	6.0±1.5	N.S
Total nitrogen (%)	0.3±5.4	0.2±7.2	N.S
Extractable phosphorus (ppm)	4.8±4.2	2.4±2.0	N.S
Extractable potassium (meq 100 g^{-1})	8.7±2.9	12.0±4.8	N.S
Extractable calcium (meq 100 g^{-1})	9.0±8.7	9.9±9.5	N.S
Extractable magnesium (meq 100 g^{-1})	1.2±1.2	1.9±1.7	N.S
Exchangeable acidity (meq 100 g^{-1})	1.1±1.0	0.7±0.7	N.S
Aluminum (meq 100 g^{-1})	0.6±0.7	0.4±0.6	N.S
Coffee-shrub features			
Diameter at the central point of the stem (cm)	2.9±0.5	2.4±0.4	***
Central axis height (m)	3.1±0.4	2.8±0.4	*
Yields			
Clean coffee grains (kg ha^{-1})	1,900±1000	2,000±700	N. S

values in each column are means and their associated standard deviation * $P<0.05$; ** $P<0.001$; *** $P<0.001$; NS: $P>0.05$

production (at densities of 26, 34 and 48 stems ha^{-1}; Baggio et al. 1997). Shade trees that are grown in coffee farms are mostly used for firewood and as timber for local construction, as indicated by an inventory carried out in the Baoulé region of Côte d'Ivoire (Table 4.8).

Perennial crop farming is often associated with pastoral activities. In such cases, animal manure is used as fertilizer. For instance, in Malaysia, poultry farming is often practiced in coffee farms (Ismail 1986).

The choice of species to be introduced into a perennial crop farm depends on the canopy diameter of the trees and the rooting volume of the perennial crop during its growth phase, light levels (if the associated species is shade-tolerant), the possible interaction between the perennial species and the associated species, the life history of the perennial species, and the value (food, commercial, medicinal) of the associated species. Other factors such as parasites that are hosted by the associated crop are also considered.

Table 4.8 Tree species, according to their overall frequency in coffee and cocoa plantations (Modified from Herzog 1994)

Scientific name	Uses				Frequency (% of plantations)	
	W	F	M	C	Coffee	Cocoa
Planted trees						
Persea americana		*			42	67
Citrus reticulata		*			17	78
Mangifera indica		*			58	50
Citrus sinensis					8	67
Cola nitida	*	*	*		42	33
Cocos nucifera		*			25	0
Wild trees retained for their products						
Elaeis guineensis		*			83	100
Ricinodendron heudelotii	*	*	*		50	28
Alstonia congensis			*		8	6
Funtumia africana	*			*	0	6
Microdesmis puberula			*		8	0
Wild trees retained for shading						
Antiaris welwitschii var. africanum	*			*	67	28
Spondias mombin		*	*		67	11
Albizia adianthifolia				*	42	0
Cola cordifolia	*	*		*	8	17
Triplochiton scleroxylon	*	*	*	*	25	6
Anthocleista dialonensis	*	*			17	6
Musanga cecropioides	*				25	0
Spathodea campanulata	*	*			17	6
Sterculia tragacantha		*			8	11
Ficus mucuso	*	*			8	6
Lannea acida		*			17	0
Dialium guineense	*		*	*	8	0
Diospyros mespiliformis	*		*	*	8	0
Morus mesozygia	*	*		*	8	0
Terminalia superba	*	*		*	8	0
Wild trees too big or not worthwhile to be cut						
Ceiba pentandra			*		83	56
Milica excelsa	*				58	28
Bombax buonopozense		*	*		42	22
Dracaena manii		*			42	6
Ficus exaspera	*	*			17	6
Celtis mildbraedii	*			*	0	11
Cola gigantea				*	17	0
Cordia senegalensis	*			*	17	0
Blighia sapida	*	*		*	8	0
Bridelia ferruginea					8	0
Deinbollia pinnata			*		8	0
Holarrhena floribunda	*			*	0	6
Hunteria eburnea	*			*	8	0
Newbouldia laevis	*	*		*	8	0
Pterygota macrocarpa					0	6

W Fuelwood, *M* Medicine, *F* Food, *C* Construction, * use
(% of plantations): percentage of plantations on which a species was found

Fruit tree-based agroforestry systems are being more commonly adopted within the Congo Basin. In southern Cameroon, the majority of farmers grow safou or African pear (*Dacryodes edulis*) on their lands (Ayuk et al. 1999; Schreckenberg et al. 2002). Safou is a high value, indigenous fruit tree that produces a widely traded fruit. In the Makenene and Kekem areas of Cameroon, most farmers maintain orchards of safou. These orchards harbor other valuable timber and edible fruit trees, but safou is considered one of the main cash and staple food crops in these regions. Other valuable indigenous fruit trees, including *Irvingia* species, are common in orchards of lowland humid tropics of Africa. Agroforests that are based on bush mango (*Irvingia wombolu* Vermoesen = *Irvingia gabonensis* var. *excelsa*; also known as dika or ogbono) are found in the Ejagham region of Cameroon, as their seeds (dika nuts) are widely traded and consumed in the region. Fruit tree-growing strategies in the humid forest zone of Cameroon are strongly influenced by accessibility of markets to farmers (Degrande et al. 2006).

Trees with important food, medicinal, fodder, or timber values are retained when clearing land for food crop establishment in the tropics. This selective retention of high-value indigenous fruit trees is common in humid forest zones and tropical savannas. Therefore, croplands in the tropics most often harbor scattered tree species with food and commercial value. In the humid forest zone of Africa, indigenous tree species that are most frequently encountered in agricultural landscapes include *Irvingia wombolu*, *Dacryodes edulis*, *Baillonella toxisperma*, *Garcinia kola*, *Ricinodendron heudelotii* and *Cola* spp (mainly *C. acuminata*, *C. anomala* and *C. nitida*). In Southern African savannas, the most common indigenous fruit trees in farmlands include *Adansonia digitata* L. (Malvaceae), *Azanza garckeana* (F. Hoffm.) Exell et Hillc. (Malvaceae), *Ficus* spp. L. (Moraceae), *Diospyros mespiliformis* Hochst. Ex A. DC. (Ebeneceae), *Strychnos cocculoides* L. (Strychnaceae), *Strychnos madagascariensis* L. (Strychnaceae), *Strychnos spinosa* L. (Strychnaceae) and *Sclerocarya birrea* (A. Rich.) Hochst. (Anacardiaceae), whereas *Combretum imberbe* Wawra (Combretaceae), *Pericopsis angolensis* (Baker) Meeuwen (Fabaceae) and *Swartzia madagascariensis* Desv. (Fabaceae) are valued for timber (Campbell et al. 1991). Gradually, these tree-crop ecosystems are being transformed into tree-based agroforestry systems when food crops are harvested. Indeed, when the plot is left to fallow, the previous tree crop system becomes a tree fallow system, followed by a secondary forest system that is managed by farmers for the collection of non-timber or timber forest products. Such secondary forests with important fruit, nut, medicinal and timber trees are considered tree-based agroforestry systems.

Another system involving the association of annual crops and forest species during the early years of establishment of the plantation forestry is the *Taungya* system, the development of which was described by Nair (1993). The practice of '*Taungya*' (from the Burmese *taung* meaning hill and *ya* meaning cultivation) originated in Myanmar (Burma) and dates back to the early 20th century (Blanford 1958; Nair 1993). As Nair (1993) noted: "Originally this term designated shifting cultivation, and was subsequently used to describe afforestation methods. The land belongs to the state, which allows farmers to cultivate their species of interest (annual crops) in the plots, while dealing with forest tree seedlings such as *T. grandis*".

The agreement between government and the farmers would last two to three years, during which time the tree species would expand the canopy, soil fertility decreased, some surface soil was lost through erosion, and weeds infested the area, making the land less productive. Although wood is the ultimate product of a *Taungya* system, this system is an example of sequential culturing of woody plants and annual crops. The cultivation of annual crops in this system is dependent upon the availability of space and light, based on the spatial arrangement of trees. This system, which is native to southeast Asia, is basically an alternative to shifting cultivation, and is widespread throughout the tropics of Asia, Africa, and America, where it is known under different names, such as: *Tumpangsari* (Bahasa Indonesia) in Indonesia, *Kaingining* in the Philippines, *Ladang* (Bahasa Malaysia) in Malaysia, *Chena* in Sri-Lanka (Sinhalese), *Khumri*, *Jhooming* (or shifting cultivation Jhoom as practiced in northeastern India and Bangladesh), *Ponam*, *Taila* and *Tuckle* in India, *Shamba* in Kenya (meaning small farm in Swahili), *Parcelero* in Puerto-Rico, and *Consorciacao* (meaning intercropping in Portuguese) in Brazil (King 1968). *Taungya* systems can be classified as "partial" (participants' interests in crop establishment are primarily economic) or "full" (a more traditional system based on the lifestyle of the farmers). Forest plantations in the Congo Basin owe their origins to *Taungya*. The most common crops in a *Taungya* system are rice (*Oryza sativa*) in Asia, yams (*Dioscorea* spp.) and bananas in Africa, and maize (*Zea mays*) in the Americas. The major drawback to the system is the erosion of soil during early growth of forest species, which is during the years in which food crops are grown. However, there is potential for various combinations of species to sequester carbon through tree growth, such as coffee associated with food crops (Soto-Pinto et al. 2010).

4.3.1 Jungle Rubbers (Rubber Agroforests)

Noble and Dirzo (1997) defined jungle rubbers as "an enhancement of traditional slash-and-burn practices in which rubber trees, fruit and occasionally timber species are planted during the garden phase. Natural regeneration occurs, leading to an 'enriched' secondary forest." These perennial crop-based agroforestry systems (agroforests) are found in Southeast Asia, and produce fruits and rubber. However, rubber-based agroforestry systems are also encountered in Latin America and in the Congo Basin.

Private Dutch colonial estates introduced rubber trees (originally from Brazil, smuggled to Kew Gardens in the 18th century, distributed to India and other British colonies in the 19th century, and finally to Buitenzorg Botanical Gardens on Java in the early 1880's) into agricultural landscapes in Southeast Asia in the early 1900's, and farmers enriched their fallows with rubber trees. This cropping system became complex when farmers innovated with improved rubber farming practices and germplasm. Jungle rubbers are essentially rubber-based secondary forests, as their structure consists of a more or less closed canopy that is 20 m to 25 m in height and which is dominated by rubber trees and a dense undergrowth layer (Gouyon et al. 1993). These systems are very complex and high in terms of their biodiversity. Of the 268 plant species (other than rubber trees) that were recorded in a jungle rubber plot in Indonesia, 91 were tree species belonging to 22 families, including Anacardiaceae, Apocynaceae, Bombacaceae, Dilleniaceae, Euphorbiaceae, Fagaceae, Flacourtiaceae, Guttiferae, Lauraceae, Melastomaceae, Mimosaceae, Moraceae, Myrtaceae, Orchidaceae, Palmae, Papilionaceae, Proteaceae, Rubiaceae, Sapindaceae, Styracaceae and Theaceae (Gouyon et al. 1993). Jungle rubbers require low inputs, as tree species protect rubber from grasses.

Jungle rubbers, which are also known as rubber agroforests, are not specific to Southeast Asia. These agroecosystems were also reported in Amazonia (Schroth et al. 2003). Indeed, rubber plantations date back to the early 1900's in the Brazilian Amazon (Table 4.9); these rubber plantations, which resemble secondary forests, were planted on sandy riverbanks, or on humus or clay-rich soils. Cultivation in Amazonia is problematic though because of leaf blight (Dean 1987; Lieberei 2007).

4.4 Farm Woodlots

Woodlots are stands of trees that provide environmental services, including soil rehabilitation or fertilization, and wood for households, thereby replacing wood collected from off-farm stands or forests. Rotational woodlots are sequential agroforestry systems, as they involve three phases (Kwesiga et al. 2003):

- An establishment phase (trees are inter-cropped with annual food crops, i.e., maize, sorghum, millet, rice in tropical savannas or groundnut and cassava in humid forest zones);
- A tree fallow phase (no cropping);
- A cropping phase after harvest of trees.

The woody species used in rotational woodlots in the tropics of Africa include *Acacia auriculiformis*, *A. crassicarpa*, *A. julifera*, *A. leptocarpa*, *A. mangium*, *A. polyacantha*, *A. nilotica*, *Gliricidia sepium*, *Leucaena leucocephala*, *Senna siamea* and *Sesbania sesban* (Kwesiga et al. 2003; Nyadzi et al. 2003; Kimaro et al. 2007; Akinnifesi et al. 2008). Other examples of this successful sequential agroforesy system include the agroforestry Mampu village or the IBI clean development mechanism carbon sink project on the Bateke plateau in the Democratic Republic of the Congo (http://cdm.unfccc.int/filestorage/L/U/G/LUGSF92NSFDYLAC5AWRWQ2IO1RJTW5/PDD.pdf?t=NTh8bWxuNHl0fDAI_g_yoXMpOCpFsGDFyf07, http://www.mampu.org/historique_en.html, Bolaluembe Boliale 2009; Peltier et al. 2010). The selection of woody species to be used in rotational woodlots should be made on the basis of many criteria, including wood production and crop yield (Nyadzi et al. 2003). For instance, *L. leucocephala* produced more wood than the other studied tree species in a rotational woodlot experiment in Northwestern

Table 4.9 Planting periods of rubber (*Hevea brasiliensis*) groves on the sandy river bank of the more fertile slope and plateau soils of the Eastern side of the Tapajós river, Brazilian Amazon (Schroth et al. 2003)

Village	Sandy river bank		Clayey soils on slope and plateau	
	Until 1950	After 1950	Until 1950	After 1950
Cajutuba	*1948*–1960	1970–1987, 1974–1977, 1978–1999	Early 1900, *1918–1950*	1968
Aramanai				1957, 1993
Santa Cruz		1955–1980, 1970–1975, 1972–1979, 1974–1977	*~1900, 1930,<1950*	1955–1985, <1959,1960–1970
São Domingos		1966–1967, 1967–1971		
Maguari		1956, 1960–2002, 1973, 1975–1980	*1920*, <*1930*, *1945*, <*1950*, *1950*–1955	1969
Acaratinga		1965–1984, 1972–1988	<<*1950*	
Jaguarari	*1944*			
Pedreira	<*1950*	1956–1961, 1972–1977, 1982		1963–1978
Piquiatuba	<*1930*, *1948* (2), *1950*	1953, 1965, 1976, 1990–1992	*1939*	1956
Marituba	<*1950*	1967–1985, 1970, 1976, 1987	<<*1950*	
Bragança		1958, 1967, 1979		
Marai	*1930*, *1946*			1960–1965, 1977–1981
Nazaré		1970, 1970–1974, 1987		
Taurari	*1920*, <*1950*	1958, 1962, 1991		
Igarapé de Matancin	<*1940*, *1945*	1980, 1982 (2), 1990		
Prainha	*1936–1949*	1970–1991		

Each date represents one rubber grove. The villages are arranged from North to South; villages in the edaphic savanna without access to plateau soils were not included. For better visibility, plantings from 1950 or earlier were printed in bold; (2) indicates two planting dates; (~) approximately; (<) before; (<<) much before

Tanzania (Table 4.10); *L. leucocephala* also increased the subsequent maize yield over a three-year period in the same experiment (Fig. 4.6).

4.5 Annual or Biennial Food Crop Farms: Slash-and-Burn Agriculture

Shifting cultivation is widespread throughout the tropics (Grandstaff 1980; Padoch and De Jong 1987). The practice is described by various terms, depending on the locality (Nair 1993 page 56). Shifting cultivation consists of growing two or three seasons of food crops on a plot of land, and then leaving the plot in fallow for

Table 4.10 Growth and biomass of three tree species planted as woodlots at the age of seven years at Shinyanga, Tanzania (Nyadzi et al. 2003)

Woodlot species	3 years		7 years		
	Survival (%)	Biomass (Mg ha^{-1})	Height (m)	Wood (Mg ha^{-1})	
				Un-pruned	Pruned
Acacia nilotica	78	2.5	3.9	8.4	6.0
Acacia polyancantha	76	7.8	5.8	70.9	49.7
Leucaena leucocephala	80	15.4	7.7	88.9	34.6
SED	7.2	1.34	0.64	23.5	–

SED standard error of differences between means

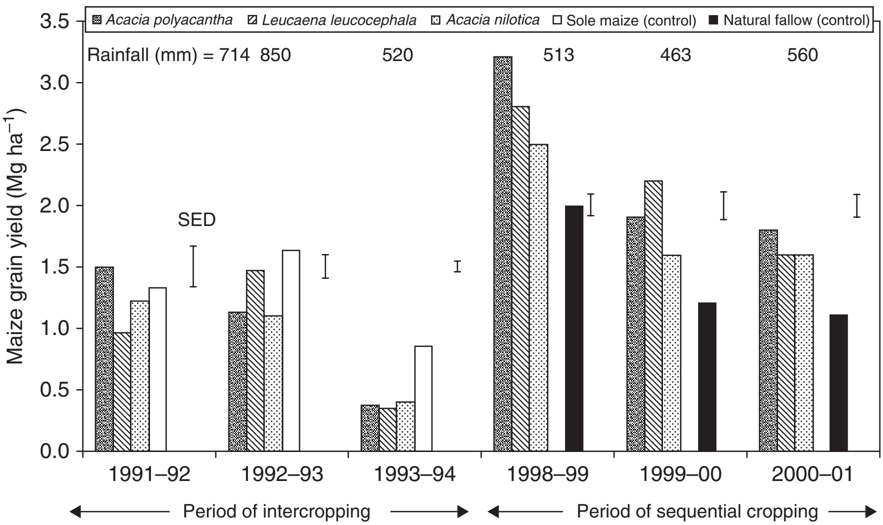

Fig. 4.6 Grain yield of maize intercropped between trees during the first three years of woodlots and after clearing woodlots at Shinyanga, Tanzania. Vertical bars are the standard errors of differences (SED) between treatment means in the respective years (Nyadzi et al. 2003)

several (7-10) years to restore land fertility, while other plots are being cultivated (crop rotation). Vegetation is removed by clearing and burning before food crop plantation. Crutzen and Andreae (1990) estimated that this method was being practiced by nearly 300-500 million people on 300 to 500 million ha of land in the tropics. Several crops are grown using this method in the tropics, the most important being cassava (*Manihot esculenta*), yams (*Dioscorea* spp.), rice (*Oryza sativa* and *O. glaberrima*), maize (*Zea mays*), groundnuts (*Arachis hypogaea*), plantains and bananas (*Musa* spp.), and cucumbers (*Cucumis sativus* L., Cucurbitaceae), all of which are primarily intended for consumption by farmers, and secondarily for sale. To this list, we could add tomatoes and other fruits (such as pineapple). Rice cultivation is predominant in Madagascar, as well as in the tropics of Asia and the Pacific Islands. Rice is also cultivated in West and Central Africa, whereas cultivation of cassava is widespread in Latin America and in the Congo Basin. Sometimes crop species are associated on farms. There is a spatio-temporal association of cassava, groundnut, and maize, which are grown at the same time on the same land in the rainforest zone of Africa. The groundnut fixes nitrogen in the soil, and has a short life cycle, allowing maize and groundnuts to be harvested after 3-4 months, while cassava is allowed to grow, and the leaves and tubers are harvested one year later. Very little shade is left intact, and previous vegetation is completely removed by the shifting cultivation. This technique is widespread in the tropics. The land previously occupied by dense vegetation, and containing large trees is cleared to make room for crops, and the wood ash from burning the cleared vegetation is used as fertilizer. However, this technique is destructive. Soil microfauna are destroyed, as is the humus. In addition, wood ash only acts as fertilizer for the first crop cycle, and a fallow period of at least 10 years is required to rebuild the original vegetation and restore soil fertility. This explains roaming techniques, whereby farmers cultivate on the same plot for 2-3 years, then move to an area that has been previously set-aside in primary or secondary forest.

Slash-and-burn agriculture is also a sequential rotation of trees and crops on the same plot. However, slash-and-burn techniques differ from *Taungya* because food crops are the primary objective of the system, and trees are not planted. A large number of cases (136) of slash-and burn were reported as part of a project on “alternatives to slash-and-burn”, (Fujisaka et al. 1996). These cases were classified according to country and fallow length (Tables 4.11 and 4.12). Slash-and-burn agriculture is known under different names depending on the country: *Chitimene* in Zambia, *Tavy* in Madagascar, *Masole* in Central Africa, *Milpa* in Mexico and Central America, *Conuco* in Venezuela, Roca in Brasil, *Ladang* in Indonesia, etc.

Fallow, a period during which a plot is left to stand between two phases of culture, is often associated with food crops. Fallow periods may extend for up to 10 years or more. Depending on the duration of the fallow period, it can be considered either as a fallow or a secondary forest if the duration is long enough. Fallow allows the rebuilding of physio-chemical soil properties related to fertility for a new crop-growing cycle. In the rainforest region of Madagascar, fallow periods decreased over 30 years (between 1969 and 1999) from between 8 and 15 years to 3 and 5 years. Fallow vegetation changed within 5-7 fallow/cropping cycles after deforestation from trees and shrubs, to herbaceous fallows with *Imperata cylindrica* and *Aristida* spp. L. (Poaceae) grasslands (Styger et al. 2007). Frequent use of fire when converting fallow lands to crop production also encourages the replacement of native species with exotic ones and favors grasses over woody species.

4.5.1 Alley Cropping/Intercropping Systems

Alley cropping was developed as an alternative to bush fallowing in the tropics (Kang et al. 1981). It was popularized during the 1980’s and 1990’s by ICRAF. Alley cropping is an agricultural system in which agricultural crops are grown in

Table 4.11 Coding cases of slash-and-burn agriculture for Table 4.12 (Fujisaka et al. 1996)

Variable	Coding	Descriptor
Initial cover	1.	Primary forest
	2.	Secondary/degraded forest, bush fallow, agroforest
	3.	Grassland/savanna
User	1.	Indigenous
	2.	Government sponsored colonist
	3.	"Spontaneous" settlers and ranchers
"Final" cover	1.	Fallow, secondary regrowth
	2.	Pasture
	3.	Perennial crops, agroforest
	4.	Plantation crops, taungya
Fallow length	0.	Not a cyclical pattern
	1.	Short (1-2 years)
	2.	Medium (3–8 years)
	3.	Long (more than 8 years)
High value crops	+	Vegetables, high value annual crops
	++	Coffee, fruit, other perennials, betel nut[a]
	+++	Drugs: opium, coca

[a] It is worth noting that this study was published when tree domestication activities were just started by ICRAF. For this reason, important indigenous fruit trees that were enrolled in the tree domestication program are not mentioned here

alleyways formed by hedgerows of various leguminous plants including trees and shrubs, and grasses. These plants are usually trees and shrubs, and can include legumes (*Acacia* spp., *Leucaena leucocephala*, *Gliricidia sepium* (Jacq.) Kunth ex Walp. (Fabaceae), *Sesbania sesban*, *Sesbania grandiflora* (L.) Poiret (Fabaceae), and *Calliandra calothyrsus* Benth. (Fabaceae)) and actinorhizal plants (*Alnus nepalensis* D.Don (Betulaceae), *Alnus acuminata* Kunth (Betulaceae), *Casuarina equisetifolia* L. (Casuarinaceae), Asteraceae family (e.g., *Tithonia diversifolia* (Hemsl.) A.Gray). The plants are pruned during a crop's growth to prevent shade, and to reduce competition for light, nutrients, and soil moisture between crops and legumes. A distinction is sometimes made between alley farming, which involves livestock production, and alley cropping, which does not involve animals. In the intercropping system, coppicing whereby trees are cut down, allowing the stumps to regenerate for a number of years, is not allowed. Commercial trees are managed through pruning and thinning in order to obtain a good quantity and quality of wood at the rotation age (e.g. winter wheat-*Paulownia* in China, beans-*Eucalyptus grandis* in Brazil).

The principle of alley cropping encourages nitrogen fixation by the legumes or actinorhizal plants to maintain soil fertility during cultivation or to replace nutrients exported by crops, while avoiding or mitigating competition between the legumes/actinorhizal plants and crops. Pruning twigs and leaves can enrich the soil when added as mulch, or are used as a source of fuelwood for the household. The pioneers of alley cropping in sub-Saharan Africa are B.T. Kang and D.U.U. Okali (International Institute of Tropical Agriculture, Ibadan, Nigeria), Bahiru Duguma (ICRAF, Cameroon), and Freddy Kwesiga and Bashir Jama (ICRAF East and Southern

Table 4.12 Classification of 107 cases of slash-and-burn agriculture from secondary data according to initial vegetative cover, user, "final" vegetative cover, and fallow length (Fujisaka et al. 1996). For coding, see Table 4.11

Ref*.	Initial cover	User	Final cover	Fallow length	Country
a. Primary forest, indigenous users, secondary regrowth					
4	1	1	1	2	Sri Lanka
58	1	1	1	?	Venezuela
b. Primary forest, settlers, natural regeneration, long fallow					
59	1	3	1	3	Indonesia
c. Primary and secondary forests, indigenous users, natural regeneration					
65	1-2	1	1	2	Madagascar
71	1-2	1	1	2	Philippines
44	1-2	1	1	2++	Malaysia
10	1-2	1	1	?	Venezuela
60	1-2	1	1	?	Thailand
31	1-?	1	1	?	Indonesia
33	1-2	1	1	?	Indonesia
81	1-2	1	1	?	Philippines
101	1-2	1	1	?	Philippines
77	1-2	1	1	3	Ivory Coast
85	1-?	1	1	?	Zambia
80	1-?	?	1	3	Sierra Leone
47	1-2	?	1	3++	Papua New Guinea (PNG)
d. Secondary forest, indigenous users, natural regeneration					
54	2	1	1	1+++	Thailand
7	2	1	1	2	Laos
67	2	1	1	2	Philippines
87	2	1	1	2	India
76	2	1	1	2	Philippines
46	2	1	1	2	Colombia
95	2	1	1	2	Colombia
17	2	1	1	2	Colombia, Ecuador
24	2	1	1	2	Panama, Colombia
62	2	1	1	2	India
36	2	1	1	2	Guyana
83	2	1	1	2	India
43	2	1	1	2	Laos
43	2	1	1	2	Laos
48	2	1	1	2	Colombia
89	2	1	1-3	2	India
88	2	1	1-3	2	India
90	2	1	1-3	2	India
32	2	1	1	3	Indonesia
41	2	1	1	3++	Mexico
56	2	1	1	3	Thailand
9	2	1	1	3	Zambia
20	2	1	1	3	Zambia
102	2	1	1	3	Democratic Republic of Congo (DRC)
51	2	1	1	3+	Mexico
25	2	1	1	3	Malaysia
26	2	1	1	3	Sarawak
70	2	1	1	3	Brazil

Table 4.12 (continued)

Ref*.	Initial cover	User	Final cover	Fallow length	Country
44	2	1	1	3	Thailand
76	2	1	1	3	Ivory Coast
27	2	1	1	3	Venezuela
44	2	1	1-3	3	Colombia
84	2	1	1	?	Zambia
5	2	1	1	?	Mexico
72	2	1	1	?	India
57	2	1	1	?	Belize
21	2	1	1	?	Zambia
103	2	?	1	2-3	DRC
97	2	?	1-2	3	Tanzania
47	2	?	1	3++	PNG
47	2	?	1	3++	PNG
47	2	?	1	3	PNG
47	2	?	1	3	PNG
47	2	?	1	3	PNG
47	2	?	1	3++	PNG
80	2	?	1	?	Congo
80	2	?	1-2	2	Madagascar
e. Secondary forest, colonists, natural regeneration					
18	2	3	1	2	Laos
29	2	3	1	2	Laos
66	2	3	1	2	Peru
f. Primary and secondary forest, indigenous and settlers, conversion to agroforest					
100	1	1	3	?[a]	Colombia
99	1	1	3	?	Colombia
23	1	1	3	?	Venezuela
35	1	1	3	?	Colombia
69	1	1	3	?	Brazil
53	1	1	3	?	Java
80	1	1	3	?	Guinea
34	1-2	1	3	3	Colombia
93	1-2	1-3	3	?	Peru
28	1-2	3	3	3	Peru
66	1-2	3	3	3	Peru
40	1-2	3	3	0++	Philippines
22	2	1	3	2	Java
96	2	1	3	3	Colombia
75	2	1	3	3	Philippines
52	2	1	3	3	Brazil
24	2	1	3	3	Colombia
49	2	1	3	3	Vietnam
37	2	1	3	?	Colombia
61	2	1	3	0++	Indonesia
55	2	1	2-3	?	Laos
1	2-?	1	2-3	?	Sudan
3	2	?	3	?	Nigeria
45	2	?	3	2	Java
47	2	?	3	3	PNG
6	2	?	3	3	PNG
16	2	3	3	0	Ivory Coast
49	?	2[a]	3	?	Vietnam

Table 4.12 (continued)

Ref*.	Initial cover	User	Final cover	Fallow length	Country
g. Secondary forest, colonists, conversion to plantation crops or taungya					
63	2	2	4	0	Sri Lanka
12	2	2	4	0	Thailand
80	2	2	4	?	Sierra Leone
80	2	2	4	?	Guinea
53	?	2	4	?	Java
84	?	2	4	?	Kenya
31	2	1[b]	4	0++	Indonesia
h. Primary and secondary forest (mostly), settlers, conversion to pasture					
94	1	3	2	0	Nicaragua
91	1	3	2	0	Brazil
2	1	3	2-3	0+++	Colombia
68	1	3	2	?+++	Colombia
38	1	?	2	0	Brazil
44	1-2	3	2	0+++	Thailand
75	1-2	3	2	?	Philippines
15	1-2	3	?	0++	Brazil
11	1-2	1	2	0	Venezuela
8	2	3	2	0++	Brazil
i. Grassland, indigenous and settlers, natural regeneration, pastures					
32	3	1	2	2	Indonesia
39	3	1	2	2	PNG
55	3	1	2	?	Laos
13	3	1	2	2	PNG
39	3-?	1	?	2	PNG
70	3	1	3	0	Brazil
30	3	1	?	?	Borneo
74	3	?	1	?	Zambia
47	3	?	1	3++	PNG
47	3	?	1	3	PNG
47	3	?	1	3	PNG
j. Others					
Other indigenous users					
73	?	1	1	2	Sri Lanka
68	?	1	1	?	Colombia
70	?	1	3	0	Brazil
42	?	1	3	0++	Indonesia
44	?	1	1-3	?++	Philippines
50	?	1	?	?	Zambia
Other primary forest users					
92	1	?	1	?	Venezuela
78	1	?	1	?	Kenya
80	1	1	?	?	Cameroon
82	1	2	?	?++	Vietnam
79	1	3	?	?	Guatemala
98	1	3	?	?	Brazil
80	1	?	?	?	Ghana
Other					
14	?	?	4	0	Cuba

[a] These agroforests have continued to be exploited for the perennial crops and could be re-used for annual cropping, although years of such "fallows" were generally not specified;
[b] "Rare" case of adoption of rubber trees by indigenous group;
* Publication number reporting a case

Fig. 4.7 Establishment of alley cropping. **a** Tree establishment: *Calliandra calothyrsus* or calliandra is planted alongside maize (*Zea mays*); **b** After harvest of maize, calliandra is left to grow for about 2 years; **c** During the fallow period, beehives are placed in the calliandra tree plot; **d** After the fallow phase, calliandra is cut back; **e** The best branches of calliandra are removed and used for staking of yams, tomatoes, etc; **f**. After the cutting back the calliandra trees, crops are planted in the alleys (Source: ICRAF-Cameroon)

Africa). The design and implementation of an alley cropping system in a given region should be determined by the following conditions:

- Identify the legume/actinorhizal plant suitable for the ecological area of interest. *Cassia siamea* Lamk (Syn. *Senna siamea* Irwin et Barneby, Fabaceae) is more appropriate than *Leucaena leucocephala* in a semi-arid climate (Jama-Adan et al. 1993). Similar studies found that *Calliandra calothyrsus* was a more appropriate choice than *Leucaena leucocephala* in the humid lowland forest zone of Africa, where the latter species became an invasive weed (Kanmegne and Degrande 2002).
- Determine the appropriate number of hedgerows per hectare and quantify the "loss of farm space" due to these hedges. Different arrangements are possible; the most common being 4×0.25 m, which gives 10,000 trees ha^{-1}, which seems quite optimal. Double rows are also possible. In that case they are spaced more widely apart. It is possible to establish in one ha 20 rows of *L. leucocephala,* 100 m in length, separated by 5 m (Duguma et al. 1988).
- Determine the optimal fallow-cultivation period, and the time required before the first pruning on leguminous species in the system.
- Determine the intensity and frequency of pruning (Duguma et al. 1988).
- Consider the slope in the region, as hedges are effective against erosion.
- Consider the labor intensity provided by households for the establishment and maintenance of the system.

Establishment of alley cropping is illustrated in Fig. 4.7.

In general, legumes are initially pruned one year after the system has been implemented and crops are grown in the corridors. Leguminous trees fix nitrogen to the soil, and studies have shown that it increases soil concentrations of P, K, Ca, and Mg (Nair 1993, page 126). Alley cropping also helped to increase plant production by over 8 tons of dry matter per hectare per year (Nair 1993, page 125). The dry matter can be used as mulch to increase soil organic matter content and improve soil chemical properties (Nair 1993, page 127). Species such as *C. siamea* and *Inga edulis* can be used to control erosion and to increase soil organic matter, due to the slow rate of decomposition of their leaves. The more rapid the decomposition of the dry matter that has been used as mulch, the faster the nutrients are released into the soil. The loss of soil nutrients in alley cropping is less marked than in soils that have been planted with conventional crops (Nair 1993, page 128). Some legumes, such as *Flemingia macrophylla* (Willd.) Merr. (Fabaceae), have a positive effect on soil temperature and moisture conservation (Nair 1993, p. 129). Various studies have observed increasing crop production through the practice of alley cropping (Nair 1993, p. 130; Kang et al. 1989, 1990; Kang and Duguma 1985). Therefore, alley cropping appears to be an alternative solution to four problems of natural resource management in the tropics: land tenure; reduced soil fertility due to short fallows; soil erosion; and lack of fuel wood. In addition, alley cropping provides nutrients to the soil.

In Cameroon, *Calliandra calothyrsus* is the shrub most commonly used in alley cropping (refer to the work of Bahiru Duguma and colleagues in 1988-1998). This species was selected after screening 10 species suitable for agroforestry common in the humid lowland rainforest of Cameroon (Duguma and Tonye 1994). *Calliandra* was planted in 4 × 0.25 m spacing, and then pruned down to 0.50 m height one year after implementation, with the prunings used as mulch. Early results were disappointing. Problems included poor growth of shrubs, low biomass production due to pruning being done too early, low impact on weed control, and high demand for labor (Degrande et al. 2007). Changes to the original method led to improvements; such changes include (1) delaying the first pruning until after 2 years, (2) alternating the cropping period with a year of fallow, and (3) pruning *Calliandra* down to only 0.05 m height. These modifications led to the evolution from the original alley cropping to a rotational tree fallow system (Kanmegne and Degrande 2002). Tests conducted on-station in Yaoundé showed that this system maintains high maize production (Table 4.12). However, performance in a farm setting was not as good as what had been observed on-station (Degrande et al. 2007), resulting in a low rate of adoption of the system by farmers (Degrande and Duguma 2000; Degrande et al. 2007). About 52 % of households involved in testing alley cropping and rotational tree fallows indicated that more than half of their soils were fertile, and respondents did not perceive the decline in fertility as a problem. About 73 % of households reported that they had enough land to meet their households' needs (Degrande and Duguma 2000). In reality, numerous problems arose with the adoption of alley cropping and rotational tree fallow in the area, especially in terms of labor demand.

The system is labor-intensive, with high labor requirements, especially for tasks such as filling polyethylene bags for seedlings, watering plants, especially during the dry season, and pruning. In addition, erosion is not a problem in humid lowland

Table 4.13 Fallow cropping cycle and maize grain yields (Mg ha^{-1}) on station, Yaoundé (Degrande et al. 2007)

Treatment	1990		1991		1992		1993		1994		1995		1996	
	1	2	1	2	1	2	1	2	1	2	1	2	1	2
T1a	1.52	NF	2.98	NF	3.54	NF	2.54	NF	2.17	NF	2.33	NF	2.69	NF
T1b	1.52	NF	2.98	NF	3.54	NF	2.54	NF	NF	NF	NF	NF	3.58	NF
T2	2.13	TF	3.70	TF	4.79	TF	5.09	TF	4.55	TF	3.33	TF	3.68	TF
T3	TF	TF	TF	TF	6.28	TF	6.09	TF	TF	TF	TF	TF	6.51	TF
T4	2.72	TF	4.48	TF	TF	TF	TF	TF	5.27	TF	4.82	TF	TF	TF
SED	0.38	–	0.28	–	0.14	–	0.44	–	0.14	–	0.36	–	0.35	–

NF natural fallow, *TF* tree fallow of *Leucaena leucocephala* and *Gliricidia sepium* mixture, *T1* control treatment of continuous maize cropping with 1 season of maize and 1 season natural fallow each year; in 1994 plots were split to allow the comparison with a 2-year natural fallow (T1b) in addition to continuous cropping (T1a), *T2* continuous maize cropping with 1 season of maize grown between the rows of trees (regularly pruned back as hedgerows) and 1 season of tree fallow during which the hedges were allowed to grow unchecked, *T3* 2 years of tree fallow followed by 2 years of cropping, as in treatment 2; T4 same as treatment 3, but starting with the cropping cycle

zones of Cameroon, where there are very low slopes and many trees. Livestock production is also not popular in the region due to the presence of the tsetse fly (*Glossina palpalis* Wiedemann, Glossinidae), which limits the usefulness of *Calliandra* leaves as fodder, one of the major benefits associated with this plant. Constraints on adoption of alley cropping and tree fallows are shown in Table 4.13. Additionally, there are constraints imposed by land rights. Poor farmers, who do not have long-term tenure, are unlikely to invest in improved fallows, because benefits are obtained only after a longer period of time. Wood production for fuel is also not a constraint in the humid tropic lowlands, due to the presence of a large amount of dead wood in farmers' fields. To overcome these difficulties, an alternative land-use system was suggested to farmers: improved fallows with legumes shrubs, such as pigeon pea (*Cajanus cajan*).

In Southern Africa, herbs or leguminous trees like *Sesbania sesban*, and *Tephrosia vogelii* have been used to restore soil fertility (Table 4.14). A fallow of 2 to 3 years with *S. sesban* planted at a spacing of 0.5 × 0.5 m proved effective in the maintenance of soil fertility in Southern Africa (Kwesiga and Coe 1994). This agroforestry system accumulates more nitrogen than do herbaceous fallows. It has proven to be successful in Zambia, and the number of farmers that were reported as using this practice increased from 200 in 1994 to 3,000 in 1997 (Kwesiga et al. 1999). *Sesbania sesban* not only restores soil fertility, but also provides fodder for cattle and wood for fuel. In Malawi, the adoption of this practice is low (Mafongoya et al. 2007), perhaps due to problems related to land tenure, labor shortages, and a long waiting time for benefits (2–3 years). The *Sesbania* fallow should be performed in rich soil (Goma 2003). Other species that provide organic inputs to the soil, such as *Gliricidia sepium*, *Leucaena leucocephala*, and *Calliandra calothyrsus,* are better suited for alley cropping in the region (Fig. 4.10).

Alley cropping with *Leucaena leucocephala* and *Calliandra calothyrsus* at densities of 6,680 trees per ha has been implemented successfully by farmers in East Africa (Shepherd et al. 1997). *Leucaena*, in association with maize (six rows

Table 4.14 Land-use constraints, farm conditions, and potential agroforestry solutions in West province, Cameroon (Degrande et al. 2007)

Constraint	Site	Solution
Poor soil fertility	Flat land: <0.5 ha	a. Improved fallow of *Sesbania*, *Cajanus* and *Tephrosia*
	Flat land: >0.5 ha	b.Improved fallow of *Calliandra*
Soil erosion	Slope	c. Rotational hedgerow
Poor soil fertility + erosion	Slope	d. Combination of (a) and (c) on same plot
Destruction of crops by wind	Flat land	e. Windbreak of *Calliandra* planted at 8-10 × 0.25 m
Destruction of crops by wind + soil erosion	Slope	f. Rotational hedgerow + windbreak of *Calliandra* planted 4 m × 0.25 m (alternate rows are managed as hedges and the other as windbreaks or for pole production)
Bee migration + need for income diversification	Flat land or slope	g. *Calliandra* plantation, serving as a constant source of nectar
Dry season fodder shortage	Pasture land	h. Enrichment planting
		i. Fodder bank or feed garden

of maize spaced at 75 × 25 cm between two rows of *Leucaena* spaced at 4 × 0.5m) gave better results than *Calliandra* planted at the same density as *Leucaena* (Mugendi et al. 1999a, b) on the humid highland slopes of Mount Kenya. *Leucaena* has also been used for alley cropping in the wet uplands of Western Kenya (Imo and Timmer 2000). This technique seems appropriate for the African highlands (Kang 1993), where problems include erosion and lack of suitable firewood, and the agricultural system is characterized by the cultivation of cereals (mainly maize) in combination with cattle grazing.

Mulching twigs from pruning provides excellent fertilizer for tropical soils (Mureithi et al. 1994). However, mulch from *Leucaena* pruning did not increase production of crops in alley cropping in the semi-arid tropics of India, where the primary benefit of alley cropping was fodder production during the dry season (Singh et al. 1988). This practice increases competition for soil water between *Leucaena* and crops, which negatively affects crop production (Singh et al. 1989). Soil moisture availability is a very important factor to consider in the implementation of alley cropping with shrubs in semi-arid tropics. The number of prunings conducted on the legume should be limited to three times, implying that nitrogen harvest would be sufficient to achieve substantial benefits for the crop (Nair 1993). The relationship between rainfall and alley cropping is illustrated by Nair (1993, p. 136). Alley cropping studies with *Faidherbia albida,* in association with maize and common bean, were also tested in coastal Kenya, with inconsistent results (Jama and Getahun 1991). Alley cropping would be appropriate in the highlands of the humid tropics, where agriculture and husbandry are practiced in rural areas, but inappropriate for the lowlands.

Other soil-improving agroforestry technologies that are well-suited to situations of poverty and other demographic pressures on the land include, simultaneous inter-cropping or coppiced fallows (trees are planted in between maize, and once properly established, the trees are cut back and the biomass is incorporated into

Table 4.15 N_2 fixed on smallholder farms in Southern Africa by various legumes (Mafongoya et al. 2007)

Legume	N_2 fixed (kg ha^{-1})	Source
Bambara nut (*Vigna subterranea* (L.) Verdc.)	52	Rowe and Giller (2003)
Cowpea (*V. unguiculata*)	47	Rowe and Giller (2003)
Groundnut (*Cajanus cajan*)	33	Rowe and Giller (2003)
Pigeon pea	39	Rowe and Giller (2003)
Pigeon pea	3-82	Mapfumo et al. (2000)
Pigeon pea	97	Chikowo et al. (2004)
Cowpea	28	Chikowo et al. (2004)
Acacia angustissima	122	Chikowo et al. (2004)
Sesbania sesban	84	Chikowo et al. (2004)
Gliricidia sepium	212	Mafongoya PL (Unpublished)
Acacia angustissima	210	Mafongoya PL (Unpublished)
Leucaena colinsii	300	Mafongoya PL (Unpublished)
Tephrosia candida	280	Mafongoya PL (Unpublished)
Tephrosia vogelii	157	Mafongoya PL (Unpublished)

the soil), annual relay (fallow) cropping of trees (i.e., fast-growing trees or shrubs are planted after the food crop is established), and biomass transfer (cut-and-carry system requiring separate areas where shrubs and trees are planted) (de Wolf 2010).

4.6 Improved Fallows and Rotational Tree Fallows

Improved fallows, which are sometimes called a sequential agroforestry system (Rae et al. 1998), consist of planting selected species or retaining them from natural regeneration. Short-duration fallows are characterized by fast-growing leguminous trees or shrubs for replenishment of soil fertility to support food crop production. Medium- to long-duration fallows harbor diverse species that have been established for amelioration of degraded and abandoned lands as well as for the use of tree products (Rao et al. 1998). Improved fallows tend to attain the objectives of natural fallows in a shorter time through the choice of tree species, spacing, density, pruning, and establishment. Fallow systems overcome constraints on crop production through maintenance of soil fertility during the cropping period by recycling and conserving nutrients, restoring the soil's physical properties, and controlling soil-borne pests and weeds (Buresh and Cooper 1999). Fallow processes for overcoming constraints to crop production that are used in the tropics were ranked by Buresh and Cooper (1999; Table 4.15). These processes can be achieved through the choice of an appropriate fallow system. Rotational tree fallow and short-rotation fallow are the most popular improved fallows in the tropics. Improved fallows should be distinguished from enriched fallows, which consist of planting certain tree species at low density into natural fallows in an effort to produce high-value products such as fruits, medicines, or high-grade timber that provide economic benefits to households during the fallow period (Brookfield and Padoch 1994). A summary of case studies of improved fallows in the tropics is illustrated in Table 4.16.

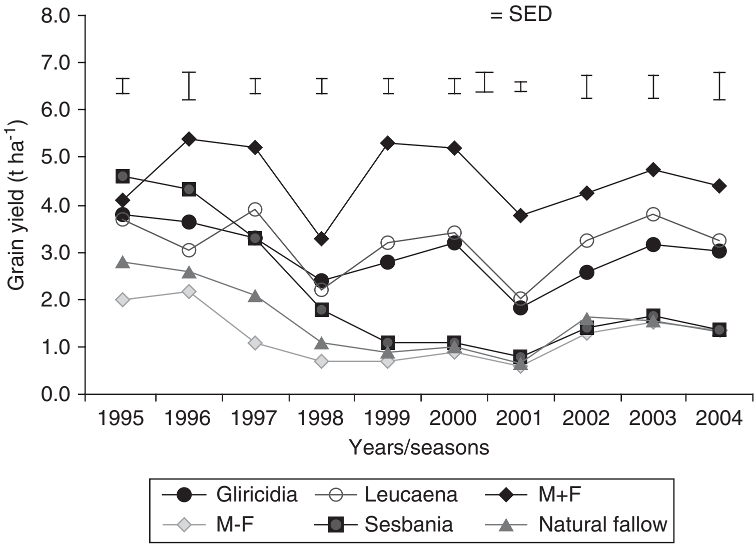

Fig. 4.8 Grain yield (Mg ha^{-1}) obtained from various fallow species for ten seasons at Msekera Research Station, Zambia. (Mafongoya et al. 2007)

It is important to note that, in certain cases, alley cropping is classified within improved fallows. This is the case when trees are allowed to grow, and a fallow period occurs between crops. Alley cropping is then referred to as rotational hedgerow inter-cropping or tree-based improved fallow if the trees are not in hedges but are planted in spacing of 1 × 1 m or 2 × 2 m. In the humid lowland forest zone of Cameroon, evaluation of alley cropping revealed several difficulties encountered by farmers. The system evolved into a rotational tree fallow, following the introduction of a fallow phase of at least one year (Kanmegne and Degrande 2002).

4.6.1 Improved Fallows with Herbaceous Legumes: the Case of Cajanus Cajan

Improved fallows agroforestry using *Cajanus cajan* shares similarities with the widespread groundnut (*Arachis hypogaea*, or peanut) farms in the humid tropic lowlands of Africa. A groundnut (or peanut) farm is a food crop farm where peanuts are grown in combination with cassava, maize, and a few other food crops. The primary crop consists of groundnuts, which are harvested after 3-4 months. The groundnut farm is a phase in the shifting cultivation system. The system cycle is (i) fallow or forest, (ii) farm establishment after clearing, logging, and burning, (iii) groundnut farm, in combination with cassava and maize, (iv) harvest of groundnut and maize, (v) cassava farm maintenance until the next year, (vi) harvest of cassava tubers and leaves, (vii) fallow. Sometimes, a second crop cycle is planted before the plot is left to fallow. The peanut, which is a legume, enriches the nitrogen in the soil.

Table 4.16 A ranking of fallow processes, listed in decreasing order of importance, for overcoming constraints to crop production in the tropics (Buresh and Cooper 1999)

High base status, N deficient soil		High base status, N and P deficient soil		Low base status, high Al soil	
Constraint/process	Potential of fallow	Constraint/process	Potential of fallow	Constraint/process	Potential of fallow
1) N supply		1) N supply		1) N supply	
N_2 fixation	High	N_2 fixation	High	N_2 fixation	High
Retrieval from subsoil	High	Retrieval from subsoil	High	Retrieval from subsoil	Low, ?
Capture of subsurface lateral flow	?	Capture of subsurface lateral flow	?	Capture of subsurface lateral flow	Low, ?
2) Weeds		2) P supply		2) P supply	
Fool propagules	? , L1	Chemical transformations	Low	Chemical transformations	Low
Reduce seed pools, germination	High	Reduce P complexation	Low	Reduce P complexation	High
Reduce weed vigor	High	Special acquisition mechanisms	?	Special acquisition mechanisms	?
3) Soil structure	Low, ?	3) Weeds		3) Cation supply	
4) Soil pests	?	Fool propagules	?	Retrieval from subsoil	Low, ?
		Reduce seed pools, germination	High	Al-organic acid interactions	Intermediate, ?
		Reduce weed vigor	High	CEC of soil organic matter	High, ?
		4) Soil structure	High	4) Weeds	
		5) Soil pests	?	Fool propagules	L1, ?
				Reduce seed pools, germination	High
				Reduce weed vigor	High
				5) Soil structure	High
				Soil pests	?

L1 may be locally important, *?* importance unknown

Improved fallow with *Cajanus cajan* (pigeon peas) has pigeon peas planted at 1 × 0.40 m spacing, and then maize is planted between rows of pigeon peas at the same spacing. After harvesting the maize, the pigeon peas are left on the plot for a second year. The pigeon peas are harvested the next year, the residues are burned or incorporated in the soil, and food crops (e.g., cassava, maize, peanut) grown. In the third year, the cycle restarts with the cultivation of pigeon peas being inter-cropped with maize. *Cajanus* fallow is illustrated in Fig. 4.9. Farmers in Edo State, Nigeria, combine pigeon peas with *Dioscorea*, maize or cassava in their homegardens and farms, and the occurence of *Cajanus*/cassava combinations can go up to 35% in

Fig. 4.9 *Cajanus cajan* fallow, one year after the pigeon peas were planted. (Source: Ann Degrande)

farms (Table 4.17 and 4.18). Pigeon pea is advantageous because it does not lower crop production. There is even an increase in crop production (80 % for maize and 97 % for peanut) after a *Cajanus* fallow. This increase has had a positive effect of the adoption of this technology (Degrande et al. 2007). Other reasons for adoption are soil fertility improvement and weed suppression (Degrande et al. 2007). Advantages listed by farmers include the reduction of the fallow period, the availability of pigeon pea beans for consumption, the ease of clearing of a *Cajanus* fallow, especially for the women, the ease of planting peanuts on a plot where *Cajanus* had previously been cultivated, and the direct seeding of *Cajanus,* that requires less physical effort than alley cropping establishment (Degrande et al. 2007). In addition, the increased crop production from the practice occurs quickly, and its profitability has been demonstrated (Degrande 2001).

In Nigeria, *Cajanus* fallows increased maize production by 200 % and that of groundnut by 350 % over 6 years. A *Cajanus* fallow, pruned at 60 cm, was also found to be suitable for livestock production in savanna zones (Agyare et al. 2002). In the same region, *Cajanus* fallows were found to increase maize grain yield between 0.43 and 2.39 Mg per ha in the first year after fallow, but yield decreases in the second year by 17.6–50 % (Abunyewa and Karbo 2005). The same study

Table 4.17 A summary of case studies of short-duration, improved fallows in the tropics in 1999 (Buresh and Cooper 1999)

Type	Location	Species	Duration	Products and services	Stage in the development and adoption process
Tree fallow	Eastern Zambia	*Sesbania sesban*	2–3 years	Soil fertility, fuelwood, weed control	Advanced farmer testing
		Tephrosia vogelii	2–3 years	Soil fertility, insecticide	
Tree fallow	Zimbabwe	*Cajanus cajan*, *Sesbania sesban*	2–3 years	Soil fertility, fuelwood, weed control	Early farmer testing
		Acacia angustissima	2–3 years	Soil fertility, fodder	
Tree fallow	Southern Malawi	*Sesbania sesban*, *Cajanus cajan*	8 months	Soil fertility, insecticide	Early farmer testing
(Relay cropping)		*Tephrosia vogelii*	8 months	Soil fertility, insecticide	
Tree fallow	South Cameroon	*Calliandra calothyrsus*	2 years	Soil fertility, fodder, honey	Early farmer testing
Tree fallow	Philippines	*Leucaena leucocephala*	4 years	Soil fertility, erosion control, fodder, fuelwood	Farmer adopting
Tree fallow (woodlots)	Southern Ghana	*Senna siamea*, Leucaena *leucocephala*,	> 3years	Fuelwood, soil fertility	Early farmer testing
Tree fallow (woodlots)	Tanzania	*Acacia* spp.	> 3years	Fuelwood, soil fertility	Early farmer testing
Enrichment	Eastern Amazonia, Brazil	*Acacia angustissima*, *Inga edulis*, *Acacia mangium*, *Clitoria racemosa*, *Sclerolobium paniculum*	2 years	Soil fertility	Researcher design
Alley farming—contour hedgerow	South-western Nigeria	*Leucaena leucocephala*, *Gliricidia sepium*, *Senna spectabilis*	0.5–10 years	Soil fertility, fodder, fuelwood, soil conservation, honey	Early farmer testing
Alley farming—contour hedgerow	North-western Cameroon	*Leucaena leucocephala*, *Gliricidia sepium*, *Senna spectabilis*	0.5–10 years	Soil fertility, fodder, fuelwood, soil conservation, honey	Advanced farmer testing
Herbaceous cover crop	Eastern Zambia	*Mucuna pruriens*, *Crotalaria* spp.	2–8 months	Soil fertility, weed suppression, fodder	Early farmer testing

Table 4.17 (continued)

Type	Location	Species	Duration	Products and services	Stage in the development and adoption process
Herbaceous cover crop	Tanzania	*Crotalaria* spp.	2–8 months	Soil fertility, weed suppression	Farmer adopting
Herbaceous cover crop	Uganda	*Mucuna pruriens*, *Crotalaria ochroleuca*, *Dolichos lablab*	2–8 months	Soil fertility, weed suppression, food, fodder	Early farmer testing
Herbaceous cover crop	Kenya	*Mucuna pruriens*, *Crotalaria* spp.	2–8 months	Soil fertility, weed suppression	Early farmer testing
Herbaceous cover crop	Benin	*Mucuna pruriens*	2–8 months	Weed suppression, soil fertility	Farmer adopting
Herbaceous cover crop	Honduras	*Mucuna pruriens*	2–8 months	Soil fertility, weed suppression	Farmer adopting

Table 4.18 Frequency of crop combinations in different farming systems in Edo State, Nigeria (Ogbe and Bamidele 2007)

Normal	Homegarden (%)	Near farm (%)	Distant farm (%)
Cajanus/Manihot	6	23	35
Zea/Cajanus	10	3	37
Discorea/Cajanus	4	18	25

revealed that after two years of a fallow period, there was an increase in organic carbon in the soil, as well as an improvement of total nitrogen by 48.5%, and CEC (Cation Exchange Capacity) by 17.8% (Abunyewa and Karbo 2005). There are two major constraints upon the adoption of this technique: seed supply, and storage of *Cajanus* seeds (Degrande et al. 2007). Cajanus fallow, along with other rotational fallows, has also been found to increase soil infestation of snout beetle (weevil, Curculionidea) in maize farms in Eastern Zambia (Sileshi and Mafongoya 2003). Snout beetle is a major pest for maize production; therefore, some landowners are likely to be discouraged from adopting *Cajanus* fallows because of this negative factor.

Other agroforestry practices used in the tropics include shelterbelts or windbreaks (rows of trees planted around farms to protect crops, animals and soil from natural hazards), silvopasture (Alavalapati et al. 2005) and contour tree buffer strips. For more details, please refer to Nair (1993).

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