3 Agroforestry to Enhance Livelihood Security in Africa: Research Trends and Emerging Challenges

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Abstract

Africa faces intricate challenges including severe shortage of food, fuelwood and fodder primarily due to increasing human and livestock population and subsistence agriculture. Deforestation, declining soil fertility and soil erosion are the crucial indicators of land degradation. Most of the dry regions experience food shortage due to low crop yields in the nutrient-depleted soils. Farmers are forced to extend cultivation to marginal and erosion-prone soil clearing the forests. Continuous cultivation has replaced the traditional shifting cultivation and fallow systems, which have been practised to regenerate soil fertility in most parts of Sub-Saharan Africa (SSA). Following the inception of the International Centre for Research in Agroforestry (ICRAF) in 1987, traditional agroforestry systems have been carefully documented through the diagnosis and design phase in the late 1980s, and new agroforestry innovations were tested at research stations and on farms mostly in tropical countries across the world. Many improved agroforestry options are now being disseminated and used by resource-poor farmers in

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SSA. In this chapter, both traditional and improved agroforestry systems in SSA, which form a basis of food security for resource-poor farmers, have been described briefly.

Tracing the linkages and prospects of agroforestry systems to enhance food security, attempt has been made to report existing status of indigenous forest and fruit tree species, domestication of indigenous fruit trees, utilisation and nutritional quality of tree products and fruit transformation into commercial products as reported in various studies. In this review, we highlight the state of research on different agroforestry systems, the role of trees in amelioration/reclamation of degraded lands, soil and water conservation, hydrological benefits, microclimatic modifications and biodiversity conservation. In addition, we identified constraints, issues of agroforestry adoption and technical areas still requiring scientific inputs. In a synthesis of research trends and emerging challenges, agroforestry has tremendous potential for food security, increasing land productivity and enhancing livelihood security particularly in degraded and dry regions of SSA. The widespread adoption of agroforestry technology supported by continued participatory research and dissemination can be instrumental to achieve the goals of poverty alleviation, food security, soil conservation and environmental sustainability in different regions of Africa, particularly in the scenario of climate change.

Keywords

Shifting cultivation · Taungya · Rotational woodlots · Homegardens · Community agroforestry · Domestication · Indigenous fruit trees · Fertiliser trees

3.1 Introduction

Rapid population growth coupled with rural poverty, youth unemployment, outmigration and urban growth will continue to drive changes in food and agricultural systems in SSA in the next decades. Nigeria, Ethiopia, Egypt, Democratic Republic of Congo and South Africa are the most populous countries. An estimated 821 million people, approximately one out of every nine people in the world, are undernourished (FAO 2018). According to available data, the number of people who suffer from hunger has been growing in almost all regions of Africa (256 million). In Africa, about 20.4% of people are undernourished. Mounting evidence points to the fact that climate change is already affecting agriculture and food security, which will make the challenge of ending hunger, achieving food security, improving nutrition and promoting sustainable agriculture more difficult as envisaged under the Sustainable Development Goals. A heavy reliance of the people to rain-fed agriculture (crops and rangelands) makes rural populations more vulnerable. Furthermore, in arid, semi-arid and dry subhumid areas, the impacts of human activities aggravate conditions leading to desertification and drought. In those regions, diversified agriculture involving agroforestry-based cropping systems may help in increasing crop production and food security, reducing poverty and mitigating climate change.

Almost all the soil orders are found in Africa. The highly weathered and leached acid infertile soils and dry sands and shallow soils without horizon development with low fertility predominate the soil types in Africa. A new Soil Atlas of Africa has been published in 2014 (https://www.isric.org/projects/soil-atlas-africa). Africa has, by far, the greatest amount of hyperacid land (~705 million ha), mainly the Sahara Desert. Other dry lands include rangeland and rain-fed agricultural land, and only 6% of the farm lands of the continent is irrigated (www.ifpri.org/irrigating-africa). Land degradation and desertification are among the world's greatest environmental challenges. It is estimated that desertification affects about 33% of the global land surface and that over the past 40 years, erosion has removed nearly one-third of the world's arable land from production. Africa is particularly vulnerable to land degradation and desertification, and it is the most severely affected region. Desertification affects around 45% of Africa's land area, with 55% of this area at high or very high risk of further degradation (ELD Initiative and UNEP 2015), and the results indicate that in the next 15 years, starting from 2016, inaction against soil erosion will lead to a total annual loss of NPK nutrients of about 4.74 million tonnes per year, worth approximately 72.40 billion PPP USD in present value, which is equivalent to 5.09 billion PPP USD per year.

In Africa, the forest cover is considered to be 624 million ha (600 million ha to be natural and rest planted), which is about 20.6% of the land area, and forest area is declining at the rate of 2.8 million ha per year [from 2010 to 2015 (http://www.southworld.net)]. Selective logging and clear cutting for timber, firewood, and agricultural land use; expansion of human habitats and urbanisation including infrastructure development and mining; and accidental fires and deliberate burning are the major reasons of deforestation. Declining soil fertility due to deforestation for expansion of agriculture is one of the root causes of low crop productivity. Due to rapid population growth and inequitable land distribution, the farmers now cultivate the same piece of land more frequently reducing the fallow phase to 1 or 2 years and in some cases cultivating every year, thereby exhausting the soil resources to support crop production. Without fertilisers and having no fallow period, productivity of food crops remains low, and many farm families cannot produce enough to feed themselves even during years of favourable rainfall. Drought and lack of dry season forages also constrain livestock production. At the same time, the native woodlands that provide timber, fuelwood, fruits, forage, medicine and other minor products for livelihood of rural people are overexploited or destroyed by intentional fires. The farmers in Africa must look for ways to overcome all these constraints to break out of the poverty cycle. They would have to adopt new techniques to improve the productivity of their lands and sustain their environment. Agroforestry may provide a set of viable options to solve the above-mentioned problems of poor small landholders.

Some of the traditional and improved agroforestry systems, constraints, methods of improvement in agroforestry systems and policy matters with special reference to African continent have been discussed here in this chapter.

3.2 Agroforestry Systems/Practices in Africa

Several traditional and improved agroforestry systems/practices have been often recorded in different agroclimatic situations across the world (Nair 1993; Akinnifesi et al. 2008a, b, c; Dagar 2014; Dagar et al. 2014a, b; Dagar and Minhas 2016; Dagar and Tewari 2016a, b, 2017a, b). A closer examination of the distribution of these systems in different ecological and geographical regions reveals that there is a clear relationship between the ecological characteristics of a region and the nature of the agroforestry systems of the region. For example, shifting cultivation, taungya, plantation-crop combinations, multilayer tree gardens and intercropping systems in humid low lands; silvopastoral systems, wind breaks and shelterbelts, multipurpose trees for fuel and fodder and multipurpose trees on farmlands in semiarid lowlands; and soil conservation hedges, silvopastoral combinations and plantation crop combinations in highlands have been listed and explained by many workers (Awodoyin et al. 2015; Dagar and Tewari 2017a; Dagar and Singh 2018). Some of the common agroforestry practices found in different regions of Africa have been described in the following sections in brief.

3.2.1 Shifting Cultivation (Slash-and-Burn Agriculture)

Shifting cultivation, one of the traditional agricultural practices, is followed in different agroecological conditions in various regions of the world. It refers to farming system in which land under natural vegetation (usually forests) is cleared by the slash-and-burn method, cropped with common arable crops for a few years and then left unattended while the natural vegetation regenerates. Traditionally, the fallow period is 10–20 years; recently due to population pressure, the fallow period was reduced to 3–5 years. The system is still the mainstay of traditional farming systems over vast areas of the tropical and subtropical Africa. Depending on the environmental and sociocultural conditions, the system is recognised by different names in the world. In Africa, it is addressed with names such as *masole* (Congo, Zaire river valley), *fang* (equatorial countries), *tavy* (Madagascar), *logan* (West Africa), *chitimene/chetemini* (Uganda, Zaire, Zambia, Zimbabwe, Tanzania, Malawi) and *proka* in Ghana (Okigbo 1985; www.jagaranjosh.com).

In the tropics, the system is dominant mainly in sparsely populated and lesser-developed area, especially in the humid and subhumid tropics of Africa and Latin America, and densely populated in Southeast Asia. Haokip (2003) mentioned that in the world, about 500 million people are estimated to practise shifting cultivation. Though exact figures about total area under shifting cultivation are not available, it is still applied in about 40–50 countries (Mertz 2009) and constitutes an important part of the 850 million ha of secondary forest in tropical Africa, America and Asia (FAO 2005).

Tropical humid forests during their growth accumulate huge quantities of nutrients in their vegetation, with a mature forest reaching steady-state values of 700–2000 kg N, 30–150 kg P and 400–3000 kg K, Mg or Ca ha^{-1} (Sanchez and

Palm 2002). The forest soil also contains large quantities of nutrients. Clearing of forests results in major disruptions of this process because large quantities of nutrients are removed from the system and nutrient cycles are disturbed. The magnitude of nutrient mining due to crop harvests in Africa is huge. Net losses of about 700 kg N, 100 kg P and 450 kg K ha^{-1} have been estimated for 100 million ha of cultivated land (Sanchez et al. 1995) in three decades. The dominant narrative recited by policy experts, nongovernmental organisations and many scientists is that this practice is a principal cause of deforestation in tropical Africa which is not always true (Ickowitz 2006). Recently, Heinimann et al. (2017) while exploring the global view of shifting cultivation estimated that these landscapes currently cover roughly 280 million hectares worldwide, including both cultivated fields and fallows, and in about 37% of tropical Africa, this form of cultivation remains widespread. Taungya, fallow cultivation and alley cropping are considered to be alternatives to shifting cultivation.

3.2.2 Taungya and Shamba Systems

The word ‘taungya’ originated in Myanmar, meaning hill (*taung*) cultivation (*ya*). Originally, it was the local term for shifting cultivation and was subsequently used to describe the afforestation method (Nair 1993). The system was later introduced into parts of India and later spread throughout Asia, Africa and Latin America. Wood and food production are immediate motivation of this system. In Jamaica, it is called as *agricultural contractors’ system* and in Tanzania *the licensed cultivator system.* In Nigeria, taungya consisted of interplanting of young *Gmelina* (*Gmelina arborea*) and/or teak (*Tectona grandis*) with maize, yam or cassava. Farmers cultivate the land during the early phase of tree establishment until canopy closure, usually 2–3 years. Ojeniyi and Agbede (1980) found that the practice usually resulted in a significant increase in soil N and P, a decrease in organic C and no change in exchangeable bases and pH as compared with sole stand of *Gmelina*.

Oduol (1986) described a modified form of taungya called the ‘Shamba system’, which is being practised on state forestland in Kenya. Under this system, each participant agrees to work for the forest department for 9 months each year to clear bush cover from an area of about 0.5 ha. The farmer is allowed to cultivate crops (usually maize, potatoes and vegetables) for a period of 2–3 years with the sole right to all such produce. The forest department plants trees in the cleared land. Within 2 years after clearing, farmers are allowed four Shambas of 0.5 ha each. The success of this system may be attributed to four main factors (MacDicken 1990): availability of arable lands; the presence of a willing, land-hungry farm population; ready markets for surplus produce; and security against wild animals. The widespread of this system contributed roughly 16% of Kenya’s maize production and about 38% of the nation’s total potato production.

Chamshama et al. (1992) studying the suitability of Kilimanjaro Forest Plantation of Tanzania reported that during the early stages of forest plantation establishment, intercropping of young trees with food crops is beneficial in terms of tree survival, food crop production, financial income to the peasant farmers and reduction of forest plantation establishment costs confirming the sustainability of the system. In most of the taungya systems, erosion hazards, rather than soil fertility, are likely to pose the greatest soil management problems. Oluwadare (2014) after analysing select 100 farmers revealed that agricultural production under *taungya* farming in Nigeria was profitable and productively and technically efficient and ensured the production of choice economic trees that would guarantee continuous production of such trees. The technical efficiency of the taungya farms would improve with improved education and increased technical assistance in form of extension visits. All these studies confirm the sustainability of the system and security of livelihood of resource-poor farmers.

3.2.3 Rotational Woodlot System

Trees grown in rotational woodlots is a form of *taungya* system, except that the trees have soil fertility improvement attributes or are used as fodders and shade for livestock. Rotational woodlots are promising agroforestry options that can be used to address the problems of deforestation and shortage of wood energy. Woodlots are sole stands of trees planted on farms, communal lands or degraded lands to rehabilitate the land as well as provide products and services. Woodlots have become important in other parts of tropical Africa (Nyadzi et al. 2003).

The rotational woodlot involves growing of trees and crops in three phases: (1) an initial tree establishment phase in which trees are intercropped with annual food crop (s), usually maize; (2) a tree fallow phase in which cropping is discontinued because of canopy closure and increased shading; and (3) a cropping phase after felling the trees and harvesting of wood (Kwesiga et al. 2003; Nyadzi et al. 2003). Each of the phases is managed to provide products and services that have economic, social and environmental value. The trees benefit from land preparation and weed management primarily for the annual crops.

In Tanzania, trees could be managed as the traditional ‘ngitili system’ during the first 2–3 years of fallow phase, in designated areas enclosed for natural regeneration of vegetation for livestock sustenance, or as fodder banks (Nyadzi et al. 2003; Otsyina et al. 2004). After harvesting trees, crops can be grown between the stumps or coppices to exploit accumulated nutrients in the litter fall, leaves and branches. The coppiced shoots may be pruned to reduced competition for light during this second cropping phase and incorporated in the soil for manure or harvested as fodder. However, the coppiced shoots may be allowed to grow for another cycle of the tree fallow phase. The quantity of biomass produced by some tree species is depicted in Table 3.1.

Suitable trees species identified for the miombo ecozone of southern Africa include *Acacia crassicarpa*, *A. leptocarpa*, *A. auriculiformis* and *A. julifera*. These species are known to producing substantial amounts of fuelwood (Table 3.1). Likewise, in on-farm assessments in Tabora, Tanzania, *A. crassicarpa* woodlots produced high quantity of fuelwood ranging between 77 and 100 Mg ha^{-1} within

Table 3.1 Potential annual harvestable fuel produced by trees planted in woodlots, coppicing fallows and non-coppicing fallows (compiled from various sources)

Country	Site	Tree species	Tree age (years)	Quantity (Mg ha^{-1} $year^{-1}$)	References
Tanzania	Mganga	*Acacia crassicarpa*	5	22.4	Otsyina (1999)
	Kiwango	*Acacia crassicarpa*	4	24	Otsyina (1999)
	Dotto	*Acacia crassicarpa*	4	19.5	Otsyina (1999)
	Sanania	*Acacia crassicarpa*	4	21.0	Otsyina (1999)
	Shinyanga	*Acacia nilotica*	7	1.2	Nyadzi et al. (2003)
	Shinyanga	*Acacia polyacantha*	7	10.1	Nyadzi et al. (2003)
	Shinyanga	*Leucaena leucocephala*	7	12.7	Nyadzi et al. (2003)
Zambia	Chipata	*Senna siamea*	3	10.7	Ngugi (2002)
	Chipata	*Leucaena leucocephala*	3	9.7	Ngugi (2002)
	Chipata	*Sesbania sesban*	3	8.0	Ngugi (2002)
	Chipata	*Gliricidia sepium*	3	7.0	Ngugi (2002)

Source: Sileshi et al. (2007)

6–7 years (Nyadzi et al. 2003), suggesting that using fast-growing trees in rotational woodlots can help reduce pressures on the natural forests and woodlands. Additional benefit from rotational woodlot with N-fixing legumes includes increased crop yields and fodder.

3.2.4 Improved Tree Fallows

The rate and extent of soil-productivity regeneration depend on the length of the fallow period, the nature of fallow vegetation, soil properties and management intensity. Bishop (1982) described an agro-silvopastoral system from Ecuador, in which 2 years of food crops were followed by 8 years of fallow consisting of *Inga edulis* interplanted with bananas and a forage legume. In Peru, biomass production from *Inga* was reported to be greater than that of herbaceous fallow, as well as equalling or exceeding the natural forest (Szott et al. 1991). Various approaches have been suggested as improvement and alternatives to shifting cultivation (Robinson and McKean 1992) and the importance of retaining or incorporating the woody vegetation into the fallow phase (even in the cultivation phase) as key to the maintenance of soil productivity. Long-term fallows of 20–30 years are no longer feasible, and shorter natural fallows up to 10 years do adequately replenish soil fertility. In modern times, improved or managed short-term fallows of 1–3 years have been developed in many regions to allow for rapid replenishment of soil fertility. Leguminous *Sesbania sesban*, *Tephrosia vogelii*, *Gliricidia sepium* and *Leucaena leucocephala* have been identified as the most promising N-fixing shrubs for this purpose (Kwesiga et al. 1999, 2005; Rao et al. 1999).

The techniques for integrating these species as short-duration planted fallows in rotation with crops to build up N-capital in farmers' fields are now in place. These fallows help farmers in increasing crop yield and replenishing soil fertility. In experiments conducted over a period of 15 years in Zambia, maize yields in three normal rainfall years after 2 years of *Sesbania* fallow averaged 5.6 Mg ha^{-1} compared to 2.0 Mg ha^{-1} in unfertilised continuous maize and 4.1 Mg ha^{-1} when maize was fertilised with 112 kg N ha^{-1}, 20 kg P and 16 kg K ha^{-1} (Kwesiga et al. 1999). Two-years *Sesbania* fallows produced 15 Mg ha^{-1} of fuelwood (Place et al. 2002) and required less than half the amount of labour needed for 1 ha of continuously cropped maize. Further, it was reported that high maize yields following such fallows are primarily due to increased organic matter input into the soil and nitrogen supply to crops (Barrios et al. 1996). In some other fallows in southern Africa, the increase in maize yield ranged from 40 to 317% over unfertilised control (Table 3.2).

In Zimbabwe, several planted tree fallow options, including *Acacia angustissima*, *Cajanus cajan* and *S. sesban*, were compared with grass fallow and continuous cropping with or without fertilisers (Mafongoya and Dzowela 1998). The tree fallows increased the subsequent maize yields over the control crops, maize after grass fallow and continuous maize without inorganic fertilisers. Financial results proved that these improved fallow systems were highly profitable. Planting *Sesbania sesban* for 2 years emerged as most profitable option. Of various species, *Tephrosia vogelii* was most preferred by farmers because it is both a soil improver and a pesticide (Kwesiga et al. 2003). *Cajanus cajan* was also ranked high because it provides food in addition to improving the soil. A number of species that could be established once and then managed for a long duration (>15 years) through coppicing included *Gliricidia sepium*, *Leucaena leucocephala*, *Senna siamea*, *Calliandra calothyrsus* and *Flemingia macrophylla. Sesbania sesban* triumphed over all the coppicing options as well as the controls with respect to increase in maize yields (Table 3.3) and suppression of weeds (Kwesiga et al. 2003).

Akinnifesi et al. (2010) reviewed several studies conducted both on-station and on-farm and synthesised the results in terms of improvements in soil physical, chemical and biological properties and crop yield in response to fertiliser trees. The yield increase due to nitrogen-fixing perennials was significantly higher as compared to without trees (Table 3.4). The major findings included (1) fertiliser trees added more than 60 kg N ha^{-1} per year through biological nitrogen fixation; (2) nutrient contributions from fertiliser tree biomass can reduce the requirement for mineral N fertiliser by 75%, translating to huge savings on mineral fertilisers; (3) fertiliser trees were also shown to substantially increase crop yield; and (4) fertiliser tree systems are profitable and also have higher net returns than the farmers' de facto practice, i.e. continuous maize cropping without fertiliser. Thus,

Table 3.2 Impact of improved tree/short-term shrub fallow-based options on maize yields at different sites in southern Africa

		Soil type			Yield	
Site	Rainfall (mm)	Mg ha^{-1}	Planted fallow	Control	Percentage increase	
Chipata, Zambia	950	Alfisols	2-years *Sesbania sesban*	Maize without fertiliser	3.8	317
			2-years *Cajanus cajan*		1.7	155
			2-years *Tephrosia vogelii*		2.1	191
Makoka, Malawi	980	Alfisols	2-years *S. sesban*	Grass fallow	2.8	255
Domboshawa, Zimbabwe	750		2-years *S. sesban*	Grass fallow	3.0	188
			2-years *C. cajan*		1.8	113
			2-years *Acacia angustissima*		1.0	63
Tabora, Tanzania	700	Ultisols	2-years *S. sesban*	Maize without fertiliser	2.0	120
			2-years *C. cajan*		0.5	50
Shinyanga, Tanzania	800	Vertisols	2-years *S. sesban*	Maize without fertiliser	0.5	40

Source: Kwesiga et al. (2003)

Table 3.3 Aboveground biomass at the end of 3-years fallow period and maize yields following tree fallows

Fallow species	Biomass (Mg ha^{-1})	Maize yield (Mg ha^{-1})
Sesbania sesban	23.5	5.6
Gliricidia sepium	20.5	3.8
Flemingia macrophylla	17.8	3.5
Leucaena leucocephala	29.0	3.7
Calliandra calothyrsus	11.5	2.6
Senna siamea	59.0	2.1
Grass fallow	17.2	2.2
Groundnut–maize rotation	–	3.1
Continuous maize without fertiliser	–	2.0
Continuous maize with fertiliser (112, 20 and 16 kg ha^{-1} year^{-1} N, P and K)	–	4.1
SED	8.8	0.33

Source: Kwesiga et al. (2003)

Table 3.4 Increase in maize yield (Mg ha^{-1}) with nitrogen-fixing trees as compared to the yield without trees

Tree species	Country	No. of sites	Yield (Mg ha^{-1})	Yield increase[a] (Mg ha^{-1})	Yield increase[a] Percentage increase
Gliricidia sepium	Malawi	5	3.9	2.9	345.6
	Tanzania	2	2.3	0.8	55.8
	Zambia	4	2.8	1.8	349.7
Sesbania sesban	Malawi	7	2.5	1.3	161.4
	Tanzania	2	1.2	0.7	171.4
	Zambia	9	3.2	2.2	480.0
	Zimbabwe	4	3.0	1.9	583.1
Tephrosia vogelii	Malawi	9	2.0	1.1	232.7
	Tanzania	2	2.0	0.9	80.1
	Zambia	8	1.7	0.8	198.4
	Zimbabwe	5	3.6	0.2	17.7

Source: Akinnifesi et al. (2010)
[a]Yield increase is the yield difference between the treatment (T) plot and the unfertilised control (C) plot, which is farmers' de facto practice. Percentage increase (%I) was calculated as follows: %I = 100((T − C)/C)

the widespread adoption and scaling up of fertiliser trees can reduce the amount of mineral fertiliser needed, maintain the soil ecosystem and positively impact on the livelihoods of farm households in southern Africa.

With consistent efforts of many workers (Franzel et al. 2001; Amadalo et al. 2003; Kwesiga et al. 2005), farmers adopted successfully the short fallows of 2–5 years and could sustain the crop yields improving the soil properties in deforested and degraded areas. They raised one or more woody species in these fallows along with field crops. The woody species mostly shrubs included *Sesbania sesban*, *Tephrosia vogelii*, *Cajanus caja*n and *Acacia angustifolia* in eastern Zambia, Zimbabwe and southern Malawi; *Calliandra calothyrsus* in Kenya and Cameroon; *Leucaena leucocephala* in many African countries as alley crop; *Senna/Cassia siamea* and *Flemingia macrophylla* in Ghana; and *Acacia angustifolia*, *A. mangium*, *Inga edulis*, *Sclerolobium paniculatum*, *Gliricidia sepium* and *Leucaena leucocephala* in Tanzania, Nigeria and many other countries. Other species included *Tephrosia candida*, *Desmodium uncinatum*, *Crotalaria juncea*, *C. grahamiana*, *C. paulina* and *C. striata*. In many locations, herbaceous cover consisting of tropical *Canavalia ensiformis*, *Calopogonium mucunoides*, *Mucuna pruriens*, *Dolichos lablab*, *Macroptilium atropurpureum* and *Crotalaria* spp. is frequently grown to improve the fallow, which also control weed infestation. Recently, Sileshi et al. (2011, 2014) have given a comprehensive account of the fertiliser trees and their role in yield increase of crops such as maize when cultivated with these trees.

In the densely populated Shire Highlands of southern Malawi, farm sizes are extremely small (0.1–0.5 ha) with traditional maize cultivation without fertilisers and intercropping with legumes such as *Cajanus cajan* (Rao et al. 1999). In order to overcome the problem of replanting *Sesbania sesban* every year, *Gliricidia sepium* with an impressive coppicing performance was chosen as an alternative as management on the basis of its high (4%) foliage N content (Kwesiga 1994). It was planted evenly spaced (0.9–1.5 m) throughout the field and cut at 30 cm above ground such that no area was forfeited to the hedgerow. Long-term results showed that maize yield began to exceed those of maize planted alone with and without fertiliser by the third season after tree establishment, often doubling those of the control by the 4th year and subsequently. *Gliricidia* maintained foliage biomass at 2–5 Mg ha^{-1} per season during an 8-year period, without the need of replanting (Rao et al. 1999).

In parts of Zimbabwe, Tanzania and northern Zambia, biomass transfer (mulching or green leaf manuring using foliage of trees and shrubs cut and carried to cropping areas) is a traditional practice. The application of *Gliricidia* biomass to cabbage and onion in *dimbas* followed by growing a maize crop during the dry season was found to be profitable (Kuntashula et al. 2004). *Tephrosia vogelii* is a coloniser of wastelands in Malawi, and use of its biomass for crop production could be turned into a profitable venture (Kwesiga et al. 2003). In one well-conducted experiment in Zambia for degraded Acrisols, Chirwa et al. (2003) reported that mono-species fallows of *Sesbania sesban* (non-coppicing), were poorly adapted and *Gliricidia sepium* (coppicing) was superior to other species (*Leucaena leucocephala* and *Acacia angustissima*). At the end of 3 years, sole *G. sepium* fallow produced the greatest total biomass of 22.1 Mg ha^{-1} and added 27 kg ha^{-1} more N to soil than *G. sepium* + *S. sesban* mixture. The latter increased water infiltration rate more than sole *G. sepium*. Although sole *G. sepium* produced high biomass, it was *G. sepium* + *S. sesban* mixed fallow which resulted in 33% greater maize yield in the first post-fallow maize showing the superiority of the system.

Improved fallows are considered successful because of three major factors, viz. their effects on improving household welfare (livelihood); the various environmental services they provide (improve soil properties in terms of organic matter, higher infiltration rate, increased aggregates stabilising soil, carbon sequestration, etc.); and the development of an institutional mechanism, an adaptive research and dissemination network of government, NGOs and farmer organisations, to sustain adoption of the practice (TECA 2003). The crops and other food items are almost organic or with limited use of fertilisers and insecticides (produced from organic source like from leaves of *Tephrosia vogelii*) and also reduce pressure from woodlots. The main limiting factor in Africa is clearly the supply of germplasm of improved fallow species for large number of farmers ready to adopt the system. This must be overcome through large-scale seed orchards and nursery development and assistance from the government and policymakers.

3.2.5 Alley (Hedgerow) Cropping

Alley cropping, though considered a modern system, is not a new concept. During the 1930s, the Dutch colonial government introduced contour terracing using

Leucaena leucocephala hedgerows planted 3 m apart for erosion control and soil fertility improvement on the island of Timor in eastern Indonesia (Metzner 1982). The introduction initially was not accepted locally because in short time the plant colonised widely due to lack of management. During the 1970s, the International Institute of Tropical Agriculture (IITA) in Nigeria conducted investigations to assess the potential of intercropping woody species with food crops as a land use system to manage fragile uplands for continuous crop production in the humid and subhumid zones and to improve the traditional bush fallow slash-and-burn cultivation system. This led to research on the alley cropping system in detail (Kang et al. 1981, 1990), which became a precursor of several soil-fertility-improving agroforestry practices in tropics, including improved fallow system (Kwesiga et al. 2003), fertiliser tree system (Akinnifesi et al. 2008a, b, 2010; Sileshi et al. 2012) and evergreen agriculture (Garrity et al. 2010).

After more than three decades of research on alley cropping in various parts of the tropical and subtropical regions, better understanding has emerged about the potential and limitations of this technique, and areas requiring further research attention have been identified. The most encouraging results obtained so far have been from high base status soils. With proper husbandry and use of suitable hedgerow species, it is feasible to sustain yields of crops, such as maize, for some time with low fertiliser input. There is sufficient evidence to show the beneficial effects of alley cropping on soil fertility maintenance under high base status soils (Atta-Krah 1990; Kang and Ghuman 1991; Dagar 1995) and for controlling soil erosion to greater extent (Young 1989; Lal 1989; Dagar et al. 2014a, b). The magnitude of effects, however, varies with the hedgerow species used because this influences the quantity and quality of the prunings produced. Quality factors such as C/N ratio, lignin and, to a lesser extent, polyphenol contents determine the decomposition and nutrient release patterns of the prunings (Kang 1993). Lal (1989) and Kang and Ghuman (1991) showed that *Leucaena leucocephala*-based system maintained higher soil organic matter, extractable P and exchangeable cation status than the tilled treatment.

Several species such as *Leucaena leucocephala*, *Gliricidia sepium*, *Cajanus cajan*, *Desmanthus virgatus*, *Flemingia macrophylla*, *Inga edulis*, *Senna siamea*, *S. spectabilis*, *Calliandra calothyrsus*, *Alchornea cordifolia*, *Dactyladenia barteria*, *Sesbania grandiflora*, *S. sesban*, *Erythrina variegata*, *E. indica* and *E. poeppigiana* have been tested as hedgerow species in different parts of the tropics. There are great variations in the estimates of biomass yield and nitrogen fixation by different species. The nitrogen contribution of woody perennials, particularly leguminous species, is the most important source of nitrogen for agricultural crops in unfertilised alley cropping systems. Some data on biomass and nutrient yield (Table 3.5) by alley crops have been reported by Kang et al. (1989, 1990), Kang and Mulongoy (1992), Akinnifesi et al. (2010) and Sileshi et al. (2011, 2012) which prove *G. sepium* and *L. leucocephala* as ideal hedgerow woody perennials. Species such as *Alchornea cordifolia*, *Dactyladenia barteri*, *Gliricidia sepium*, *Leucaena leucocephala*, *Calliandra calothyrsus*, *Senna/Cassia siamea* and *Flemingia macrophylla* produced average pruned biomass of 3.77, 2.07, 5.18, 8.64, 6.13 and 21.3 Mg ha^{-1}, respectively, in an experiment conducted at the International Institute of Tropical

Table 3.5 Annual inputs of the major nutrient (kg ha^{-1}) from biomass[a] from fertiliser trees added to the soil

Tree species	N	P	K	Site (country)	Source[b]
Alchornea cordifolia	85	6	48	IITA, Ibadan (Nigeria)	Kang and Mulongoy (1992)
Cajanus cajan	82	–	–	Chikwaka (Zimbabwe)	Akinnifesi et al. (2010)
Calliandra calothyrsus	218	–	–	IITA (Nigeria)	Kang and Mulongoy (1992)
Dactyladenia barteri	41	4	20	IITA (Nigeria)	Kang and Mulongoy (1992)
Flemingia macrophylla	149	–	–	IITA (Nigeria)	Kang and Mulongoy (1992)
Gliricidia sepium	169	11	149	IITA (Nigeria)	Kang and Mulongoy (1992)
	33.7	2.0	21.4	Muheza (Tanzania)	Akinnifesi et al. (2010)
	67.3	–	–	Kalunga (Zambia)	Akinnifesi et al. (2010)
	72.1	–	–	Kagoro (Zambia)	Akinnifesi et al. (2010)
	74.4	5.2	42.5	Makoka (Malawi)	Akinnifesi et al. (2010)
	69.2	4.6	25.9	Msekera 2 (Zambia)	Akinnifesi et al. (2010)
	69.9	4.6	26.2	Msekera 1 (Zambia)	Akinnifesi et al. (2010)
Leucaena leucocephala	44.3	2.5	20.6	Mzekera (Zambia)	Sileshi et al. (2011)
	52.2	3.2	–	Machakos (Kenya)	Sileshi et al. (2011)
	57.5	3.5	27.4	Mzekera (Zambia)	Sileshi et al. (2011)
	74.6	4.7	29	Mzekera (Zambia)	Sileshi et al. (2011)
	75	4.0	22	Matomb (Cameroon)	Sileshi et al. (2011)
	200	10.0	–	Ibadan (Nigeria)	Sileshi et al. (2011)
	206	6.8	136	Ibadan (Nigeria)	Sileshi et al. (2011)
	247	2.0	184	Ibadan (Nigeria)	Sileshi et al. (2011)
	253	13.0	66	Calavi (Benin)	Sileshi et al. (2011)
	247	19	185	IITA (Nigeria)	Kang and Mulongoy (1992)
	301	19.3	156	Ibadan (Nigeria)	Sileshi et al. (2011)
	324	15.0	143	Ibadan (Nigeria)	Sileshi et al. (2011)
	343	17.0	211	Ibadan (Nigeria)	Sileshi et al. (2011)
	65.6	3.6	30.9	Msekera 1 (Zambia)	Akinnifesi et al. (2010)
Senna siamea	398	–	–	IITA Ibadan (Nigeria)	Kang and Mulongoy (1992)
Sesbania sesban	38	–	–	Chikwaka (Zimbabwe)	Akinnifesi et al. (2010)

[a]The prunned biomass of a plant added to soil
[b]Source: Adapted from Kang and Mulongoy (1992), Akinnifesi et al. (2010) and Sileshi et al. (2011)

Table 3.6 Amount of N fixed and derived from the atmosphere by some fertiliser trees in southern Africa

Species	N fixed (kg ha^{-1})	% Ndfa	Site (country)	References
Acacia angustissima	122	55–79	Chikwaka (Zimbabwe)	Chikowo et al. (2004)
	210		Chipata (Zambia)	Mafongoya et al. (2006)
Cajanus cajan (pigeon pea)	NA	65–84	Chikwaka (Zimbabwe	Chikowo et al. (2004)
	64	96–99	Nyambi (Malawi)	Adu-Gyamfi et al. (2007)
	85	94–97	Ntonda (Malawi)	Adu-Gyamfi et al. (2007)
	34	66–96	Gairo (Tanzania)	Adu-Gyamfi et al. (2007)
	54	95–99	Babati (Tanzania)	Adu-Gyamfi et al. (2007)
Gliricidia sepium	212	NA	Chipata (Zambia)	Mafongoya et al. (2006)
Leucaena collinsii	300	NA	Chipata (Zambia)	Mafongoya et al. (2006)
Sesbania sesban	84	55–84	Chikwaka (Zimbabwe)	Chikowo et al. (2004)
Tephrosia candida	280	NA	Chipata (Zambia)	Mafongoya et al. (2006)
Tephrosia vogelii	157	NA	Chipata (Zambia)	Mafongoya et al. (2006)

Source: Akinnifesi et al. (2010)
Ndfa nitrogen derived from atmosphere, *NA* not available

Agriculture (IITA), Ibadan, Nigeria. The nutrient contribution by these species ranged from 41 to 398 kg ha^{-1} year^{-1} N, 4 to 19 kg ha^{-1} year^{-1} P, 20 to 185 kg ha^{-1} year^{-1} K, 14 to 98 kg ha^{-1} year^{-1} Ca and 5 to 17 kg ha^{-1} year^{-1} magnesium (Kang and Mulongoy 1992).

Akinnifesi et al. (2010) stated that the legumes used in the sequential (e.g. fallow, relay) and simultaneous (e.g. intercrop) systems contribute to soil N through biological nitrogen fixation and capture of subsoil N (otherwise unutilised by crops). Estimates of the amounts of N accumulated by some fertiliser trees reviewed are given in Table 3.6. Out of the N accumulated, 55–84% is N derived from the atmosphere. Yield stability was determined for three long-term field trials (12–13 consecutive years) conducted at Makoka Research Station in southern Malawi and Msekera Research Station in eastern Zambia by Sileshi et al. (2012). At Makoka, the most stable yield was recorded in maize–*Gliricidia* intercrops. Average yield was highest for maize–*Gliricidia* intercropping amended with 50% of the recommended N and P fertiliser, and this was comparable with the yield recorded in monoculture maize that received inorganic fertiliser. On the two sites at Msekera, the highest yield was recorded in fertilised monoculture maize, followed by maize–*Gliricidia* intercrops. Yields were more stable, however, in maize–*Gliricidia* intercropping than fertilised maize on both sites at Msekera. It was concluded that maize yields remain more stable in maize–*Gliricidia* intercropping than in fertilised maize monoculture in the long term, although average yields may be higher with full fertilisation. Well-nodulated woody legumes such as species of *Sesbania* can fix 134–274 kg, sometimes even more, N ha^{-1} $year^{-1}$ in the field. This represents an average of 45% of their total N content. Thus, without taking into consideration differential partitioning of nitrogen fixed in the plant, when 10 Mg of prunings (3.5% N) are applied per hectare, there is an input of 160 kg N ha^{-1} from the atmosphere to the system.

This indicates that nitrogen-fixing woody perennials have considerable potential to supply N to the associated crops in the system. Besides soil improvement, studies conducted by Lal (1989) in Nigeria indicated that the soil erosion from *L. leucocephala*- and *G. sepium*-based plots was, respectively, 85 and 73% less than in the case of the plough-tilled control plots. *Leucaena leucocephala* contour hedgerows planted 2 m apart were as effective as non-tilled plots in controlling erosion and runoff. The infiltration rate was increased after 3 years of alleys, and bulk density decreased as compared to sole cropping. These studies also showed that, during dry season, the hedgerows acted as windbreaks and reduced the desiccating effects of 'harmattan' winds; soil moisture content at a 0–5 cm depth was generally higher near the hedgerows than in non-alley cropped plots. Limited results reported from the lowland semiarid zone have shown less potential for alley cropping as compared to the humid and subhumid zone (Kang 1993). However, the pruning of *G. sepium* (cut at 30 cm above ground) was incorporated in soil as manure during crop planting in Malawi, and the trees were managed to produce more green foliage, and the system acted as 'fertiliser factory' for over 15 years (Kwesiga et al. 2003). Thus, alley cropping system in addition to sustaining the yield of crops with low fertiliser inputs maintaining soil fertility and controlling soil erosion and weed control also provides various auxiliary products, such as fodder, staking material and fire wood.

3.2.6 Intercropping

Intercropping of fertiliser trees with cereal crops is an improvement building on the characteristics and advantages of alley cropping but minimising the biophysical limitations, such as 'hedge effect', competition and tree management (Akinnifesi et al. 2006, 2010). In intercropping, fertiliser trees are managed by means of periodic pruning. Pure stands of N-fixing species are normally planted in narrow spacing to allow planting of annual crops, and the fallows are left to grow for 2–3 years. At the end of the fallow period, the trees are cut, and the leaves and twigs are incorporated into the soil with a hand hoe. During the crop phase, the resprouting twigs are cut, and the coppice biomass (also called prunings) is incorporated into the soil. A cereal crop, usually maize, is planted between the tree stumps. It has been found that 33.7 to

Table 3.7 Annual inputs of the major nutrients (kg ha^{-1}) from biomass[a] of fertiliser trees added to the soil

Species	Tree management	Nutrient input			Site	References
		N	P	K		
Gliricidia sepium	Coppicing	33.7	2.0	21.4	Muheza (Tanzania)	Meliyo et al. (2007)
	Pollarding	71.9	4.4	45.8	Muheza (Tanzania)	Meliyo et al. (2007)
Leucaena leucocephala	Coppicing	65.6[b]	3.6	30.9[b]	Msekera 1 (Zambia)	Sileshi and Mafongoya (2006a)
	Coppicing	44.3[c]	2.5[c]	20.6[c]	Msekera 2 (Zambia)	Sileshi and Mafongoya (2006a)
Gliricidia sepium	Coppicing	69.9[b]	4.6[b]	26.2[b]	Msekera 1 (Zambia)	Sileshi and Mafongoya (2006a)
	Coppicing	69.2[c]	4.6[c]	25.9[c]	Msekera 2 (Zambia)	Sileshi and Mafongoya (2006a)
	Coppicing	72.1	–	–	Kagoro (Zambia)	Chirwa et al. (2003)
	Coppicing	67.3	–	–	Kalunga (Zambia)	Sileshi and Mafongoya (2006b)
	Coppicing	74.4	5.2	42.5	Makoka (Malawi)	Akinnifesi et al. (2006)
Sesbania sesban	Non-coppicing	38.0	–	–	Chikwaka (Zimbabwe)	Chikowo et al. (2004)
Cajanus cajan	Non-coppicing	82.0	–	–	Chikwaka (Zimbabwe)	Chikowo et al. (2004)
Gliricidia sepium	Coppicing	–	2.2	13.2	Msekera (Zambia)	Sileshi and Mafongoya (2006b)
	Coppicing	–	4.3	25.3	Kalunga (Zambia)	Sileshi and Mafongoya (2006b)

Source: Akinnifesi et al. (2010)
Msekera 1 and 2 represent experiments during 1992–1993 and 1997–2003, respectively
[a]In the case of coppicing species, this represents only coppice biomass, while in non-coppicing, both litter and standing leaf biomass are considered
[b]Average of 9 years
[c]Average of 5 years

82 kg of nitrogen, 2.0 to 5.2 kg of phosphorus and 13.2 to 45.8 kg ha^{-1} of potassium is added annually into the soil by different fertiliser species (Table 3.7).

The best-known example is the *Gliricidia*–maize intercropping in Malawi and Zambia (see Chaps. 8 and 9 by Sileshi et al. in this volume). For instance, in a long-term trial at Makoka in Malawi, Akinnifesi et al. (2006) showed that *Gliricidia*

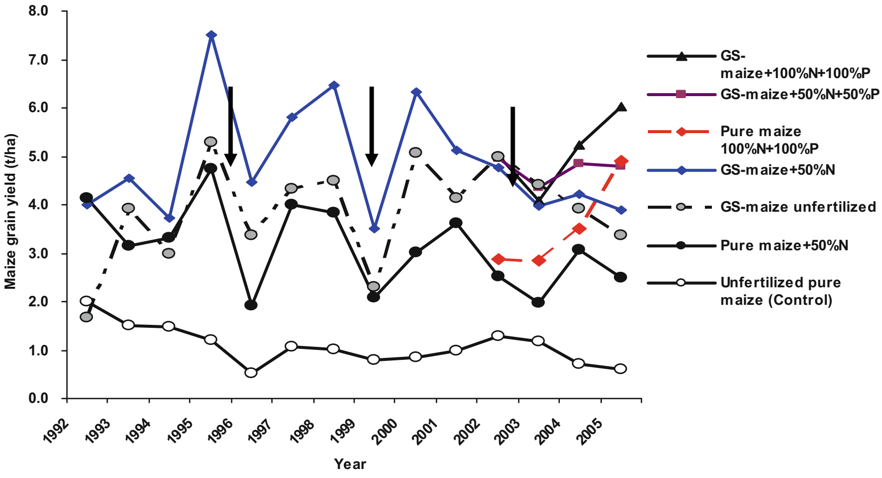

Fig. 3.1 Long-term maize grain yield as affected by fertiliser and pruning incorporations in a *Gliricidia sepium*–maize intercropping at Makoka, Malawi. Arrows indicate flood due to excessive rainfall in 1996/1997 and droughts in 1999/2000 and 2003/2004 seasons. *Gs Gliricidia sepium*, *N* nitrogen, *P* phosphorus (Source: Akinnifesi et al. 2010)

intercropping with maize increased maize yield in the ranged of 100 to 500%, averaging 315% over a 10-year period. Increase in yield is more evident in the 3rd year after tree establishment and onwards. The unfertilised plots not amended with *G. sepium* had steadily declined yield, and amendment with N and P could not sustain high maize yield over time (Fig. 3.1). Continuously cropped maize plot without *G. sepium* or fertiliser declined steadily from 2 Mg ha^{-1} at the start of experiment in 1992 to half a Mg in 2006. Unfertilised maize under *G. sepium* maintained yield at 3–4 Mg ha^{-1}. When the intercrop plots were amended with 46 kg N ha^{-1} and 40 kg P_2O_5 ha^{-1} (representing 50% N and 100% P, respectively), there was a 79% increase in grain yield over the recommended practice, indicating complementarity between applied fertiliser and organic inputs from *G. sepium* (Akinnifesi et al. 2007). The result agreed with a comprehensive meta-analysis on 94 peer-reviewed publications across SSA, reaffirming the superior performance of N-fixing fertiliser tree legumes (Sileshi et al. 2008a, b). The work compared published data over two decades involving more than 15 countries, 200 partner agencies and 50 multidisciplinary scientists working in discretely or loosely connected modes.

Soil biological processes (mediated by roots, microbial flora and fauna) are an integral part of the functioning of natural and managed ecosystems, and the soil biota is considered to be potential indicator of soil health and sustainability of the system. Soil microflora such as fungi and bacteria are responsible for the breakdown of plant litter and thin roots in the soil and the nutrients essential for the plants getting released. Fertiliser trees increase the biological activities in soil and also help in making nutrients available to the associated plants/crops. However, only few studies have examined the effect of fertiliser trees on soil biological properties. In one study conducted in Zimbabwe (Mafongoya et al. 1997) using leaf biomass of various fertiliser trees, microbial biomass carbon and nitrogen were not found differing among treatments. However, fungal actinomycete populations differed with the biomass of legume species used as well as the method of biomass application.

Among the macrofauna essential in soil processes in agroecosystems, probably the most important ones are the so-called ecosystem engineers (termites, earthworms and some ants) and the litter transformers including millipedes, some beetles and many other soil-dwelling invertebrates. Earthworms can be used as an integrative measure of soil health, assuming their importance in regulating soil processes which are vital to the continued formation of soil and as protection against soil degradation. These have been used to monitor changes in soil quality and to provide early warning of adverse trends and to identify problem areas. In five separate experiments conducted in eastern Zambia, the number of invertebrate orders per sample and the total macrofauna (all individuals per square metre) recorded were higher when maize was grown in association with tree legumes than under fertilised monoculture maize. Similarly, densities of earthworm and millipede were also higher than under monoculture maize (Sileshi and Mafongoya 2006a, b). Cumulative litter fall, tree leaf biomass and resprouted biomass under legume species appeared to explain the variation in macrofaunal densities (Sileshi and Mafongoya 2007). Litter transformer populations were found to be higher under *Gliricidia*, which produced good-quality organic inputs, than among the other fallow species. On the other hand, a higher population of ecosystem engineers was found under trees that produce poor-quality organic inputs (Sileshi and Mafongoya 2006a, b).

3.2.7 Homegardens

Tropical homegardens depict a transition stage between tropical forest ecosystem and arable cropping that mutually supports the sustainable agriculture and forest ecosystems. Tropical homegardens consist of an assemblage of plants, which may include trees, shrubs, palms, vines and herbaceous plants growing in or adjacent to a homestead or home compound. These are intended primarily for household consumption, and there is intimate association of woody perennials with annual and perennial crops and invariably livestock within the compounds of individual houses, with the whole crop–tree–animal unit being managed by family/labour. These are rich in biodiversity. Nair (1993) mentioned the local names to homegardens found in Africa. These include ‘compound farms’ in humid lowlands of southeastern Nigeria (rainfall 2000–4000 mm, mean management units 0.5 ha), ‘Chagga homegardens’ in highlands of north Tanzania (rainfall 1000–1700 mm, mean management units 0.68 ha) and ‘*Ka/Fuyo* gardens’ in semi-arid to subhumid regions of Burkina Faso (rainfall 700–900 mm, mean management units 0.5 ha). Most important function of homegardens is food production for daily need. However, there are several secondary outputs also. In some compound farms, out of 64 woody species, 62 were reported to be food producing.

Okafor and Fernandes (1987) reported 69 multipurpose wood species found in compound farms of southeastern Nigeria. These included bearing useful fruit, vegetables, oil, fodder, wood of commerce, fuelwood, fencing and thatching material, condiments and medicinal woody perennials. They also conducted an analysis of the edible parts (fruit, seeds and nuts) of some trees in these compound farms and reported that most of them contained substantial quantities of fat and protein. Seeds of *Irvingia gabonensis*, nuts of *Tetracarpidium conophorum* and the fruit pulp of *Dacryodes edulis* are rich in fat (44–72%), whereas nuts of *T. conophorum* and *Pentaclethra macrophylla* contain high quantities of protein (15–47%).

In *Chagga* homegardens, out of 53 woody species, 13 were found to be food producing, while in *Ka/Fuyo*, out of 7, there were 5 food-producing species. In these homegardens, reported herbaceous species were 73, 58 and 7, respectively. In southern Nigeria, yam, cocoyam and banana are main food crops, while kola (*Cola* spp.) and oil palm are cash crops. Goats, sheep and poultry are main animal constituents. In *Chagga* homegardens, banana, beans, *Colocasia*, yams and *Xanthosoma* are main food crops and coffee and cardamom the cash crops. Cattle, goats, pigs and poultry for meat are main animal constituents. The *Chagga* in the foothills of Mountain Kilimanjaro, the Matengo Ngoro-Pit system in highlands of Mbinga District and Ngitill system in western Tanzania are homegarden systems of Tanzania, and compound farms of West Africa growing multipurpose trees, fruits and food crops (yams, plantain, maize, etc.) along with animals are still popular (Boffa 1999; Nair et al. 2016). In the Chagga system, tall trees such as *Cordia abyssinica*, *Diospyros mespiliformis* and species of *Albizia* form upper storey; banana and coffee come in second storey; and food crops, fodder, cardamom, and medicinal herbs come in lower storey. In this system, there is high degree of nutrient cycling, and permanent cover on soil helps in conserving soil as well as moisture. These systems are valuable gene pool. There is plenty scope of introduction of improved apiculture practices and nitrogen-fixing trees in the system (Kitalyi et al. 2013). In *Ka/Fuyo* gardens, maize and red sorghum are main food crops, tobacco cash crop, and goats, sheep and poultry the animal constituents. The farm families supplement the nutrition in their diet from these products.

In Namibia, most of the households retain indigenous fruit trees such has marula (*Sclerocarya birrea*), jackal berry (*Diospyros mespiliformis*), manketti (*Schinziophyton rautanenii*), makalani palm (*Hyphaene petersiana*) and monkey orange (*Strychnos cocculoides*) near their households (Dagar 2003). Most of these are very rich in vitamin C, mineral and protein contents, and are part of famine food for the rural people. In an attempt to domesticate and improve indigenous fruit trees in southern Africa, Mateke (2000) reported the nutritional composition of selected fruit trees. The chemical and nutrient composition of some fruits compiled from different sources (Arnold et al. 1985; Wehmeyer 1986; Saka and Msonthi 1994; Keya et al. 2000; Akinnifesi et al. 2008c) has shown that many of these are rich in these contents. Most of the data generated in these systems are commodity based. A system approach should provide the basis for research on homegardens, and the studies must include both biological and socio-economic aspects. Changing species composition by introduction of new or improved tree or crop species, intensified cropping patterns (including multi-tiered system), inoculation of beneficial microorganisms such as VAM fungi and vermiculture, nutrition management and interaction of cattle or poultry are primary areas of improvement of these systems.

3.2.8 Trees Dispersed on Croplands (Parkland Systems)

Trees with multipurpose uses are often intentionally planted in crop fields or allowed to persist from natural regeneration or retained while clearing the natural forests for agricultural purposes. Wide range of tree species is often grown with staple food crops in random spacing. Although no definitive estimate exists, the parkland system, characterised by mature trees widely dispersed in cropped fields, is the largest single agricultural land use in SSA. Some parklands are monospecific (e.g. *Faidherbia albida* and *Borassus aethiopum*-based), but others have dominant tree species mixed with a range of tree and shrub species (Boyala et al. 2014). In some instances, the original species such as *Prosopis africana*, *Vitellaria paradoxa*, *F. albida* and *Parkia biglobosa* are retained, while in some other cases, cash plantations such as oil palm (*Elaeis guineensis*) are introduced, while in others (e.g. *Adansonia digitata*), even fruits and leaves are collected systematically, and these are improved as compared to traditional ones. So is true with *Acacia senegal* and *A. laeta* parklands of Sudan, where gum is collected from these trees and *F. albida* is intercropped successfully with maize. A view of parklands in Sahel is shown in Fig. 3.2.

Fig. 3.2 A view of the 'parklands' (scattered mature trees) in Sahel in Sub-Saharan Africa (Photo credit to Chris Reij)

Across the entire Sudano-Sahelian zone of West Africa, one finds crops planted under varying densities of mature trees. The ability of these parklands, or two-tiered systems, to enhance and stabilise crop production has been much studied over the past 30 years in West Africa. Kessler (1992) reported that approximately 20 different tree species are common in these parklands. Scientific studies on the interaction between such trees and the intercropped agricultural crops have been few and limited to a few tree species such as *Faidherbia* (*Acacia*) *albida* in West Africa (Vandenbeldt 1992). The crop yields under the trees are generally reported to be higher than in the open field. Kho et al. (2001) separating the effects of trees on crops in Niger found that millet production under *F. albida* canopy was about 36% higher than in open field. The nitrogen and phosphorus availability was, respectively, 200% and 30% higher than the open causing increase in production by 26% and 13%, respectively. The net effect via other resources was negligible. However, Kessler (1992) and Karter et al. (1992) studied the negative influence of *Vitellaria paradoxa* (shea butter/*karite*) and *Parkia biglobosa* (*nere*) in Burkina Faso and Mali. In both cases, sorghum grain yields were reduced by 50–70%, due to reduced light availability under the trees. The pruning of tree branches may be management option to reduce the magnitude of yield reduction. In Namibia, Chikasa et al. (2002) reported 76% increase in grain yield of pearl millet when grown with *Acacia nilotica* (pollarded), and highest stover yield of 161% was obtained from pearl millet grown with C*olophospermum mopane*.

3.2.9 Fodder Banks and Silvopastoral Systems

These are land use systems in which woody perennials are combined with livestock and pasture production on the same unit of land. Cut-and-carry (protein bank), live fence posts and fodder foliage and browsing and grazing are main components of these practices. Silvopastoral systems involving a large number of trub species and various management intensities, ranging from extensive nomadic silvopastoralism to very high intensity and improved cut-and-carry fodder systems, have been described at various sites. Livestock forms a major component of agricultural productivity in many developing countries of Africa. For example, livestock makes up to 30–40% (80% in Mauritania) of the agricultural gross domestic production in the Sudano-Sahelian countries of West Africa (Nair 1993) where most of the cattle population are raised primarily for food products. Basically, two types of silvopastoral systems exist in the semiarid tropics: those with a crop component and those without. In the Sahel, grazing on natural grass- and shrublands predominates in the northern arid regions and postharvest grazing on agricultural residues in parklands in southern zones with annual rainfall exceeding 350 mm. In the parklands, herded or penned livestock are maintained on fallow fields and surrounding grassland during the cropping season or herded, sometimes long distances, to arid but seasonal productive pastures to the north.

Throughout the semiarid tropics, animals are grazed on harvested fields. In dry season, they derive between 50 and 80% of their feed intake from crop residues

(Sanford 1987). In Botswana, Shorrock (1981) estimated that 25% of the total annual diet of livestock was composed of browse trees and shrubs. Le Houerou (1980, 1992) listed nutritional qualities of some tree and shrub fodders. Crude protein ranged from 12.3% in *Balanites aegyptiaca*, 14.7% in *Acacia albida*, 16.2% in *Combretum aculeatum*, 16.5% in *A. raddiana* and 21.4% in *Boscia angustifolia* to 22.5% in *Maerua crassifolia*. The chemical composition in the leaves of some trees (mostly legumes) being grown in Africa shows that many of them are rich in protein and other contents (Table 3.8).

Dulormne et al. (2003) assessed nitrogen fixation dynamics in a cut-and-carry silvopastoral system. Dinitrogen fixation ranged from 60 to 90% of the total N in aboveground tree (*Gliricidia sepium*) biomass depending on season. On an average, 76% of N exports in tree pruning (194 kg N ha^{-1} $year^{-1}$) originated from N_2 fixation. Grass production averaged 13 Mg ha^{-1} $year^{-1}$, and N export in cut grass was 195 kg N ha^{-1} $year^{-1}$. The total N fixation by *G. sepium* as estimated from the tree and grass N exports and increase of soil N content was 555 kg N ha^{-1} $year^{-1}$. Carbon sequestration averaged 1.9 Mg C ha^{-1} $year^{-1}$, and soil organic N in the 0–0.2 m layer increased at the rate of 166 kg N ha^{-1} $year^{-1}$, corresponding to 30% of nitrogen fixation by the tree.

Livestock pressure must be balanced as per carrying capacity of a rangeland. However, most grazing lands in semiarid Africa are communally exploited. *Faidherbia albida* is an important tree of the scattered tree or parkland systems in the Sahel. As discussed earlier, it helps in increasing productivity of croplands as well as pastures. Similarly, *Acacia tortilis*—grassland system in East Africa—has helped in improving soil fertility of grazing lands. Belsky (1994) concluded that nutrient (notably nitrogen) is a major limiting factor and that the fertility effect is most likely an important part of overall tree effect. Roothaert and Franzel (2001) reported that improved, stall-fed dairy animals were the dominate livestock type in the subhumid zone whereas communally grazed, local-breed cattle and goats in dry zone. A total of 160 local fodder trees and shrubs used by farmers have been reported. The most frequent criteria were the contribution towards animal health, palatability and drought resistance. Belsky et al. (1993) while studying the effects of widely spaced trees of *Acacia tortilis* and *Adansonia digitata* and livestock grazing on understorey environments in tropical savannas of Kenya reported that tree-crown zones at lightly and moderately grazed sites had a unique understory flora and higher plant biomass, lower temperatures and bulk density and higher levels of P, K, Ca and mineralisable N than their associated grassland zones. In the heavily grazed savanna, only few differences were found in these parameters. The beneficial effects of savanna trees on their understorey environments appear to diminish with increasing livestock utilisation.

Table 3.8 Chemical composition and nutrient contents (% DM basis) in leaves of some fodder trees and shrubs grown in tropical Africa

Species	Dry matter %	Crude protein	Neutral detergent fibre	Acid detergent fibre	Crude fibre	Lignin	Dry matter digestibility (in vitro)	N	P	K	Ca
Acacia nilotica	85.0	13.6	31.6	22.5	–	5.3	–	–	–	–	–
A. tortilis	89.4	13.0	32.4	24.2	–	4.8	–	–	–	–	–
Albizia lebbeck	–	22.1	44.2	–	–	–	–	–	–	–	–
Alchornea cordifolia	–	–	–	–	–	–	–	3.29	0.23	1.74	0.46
Azadirachta indica	36.0	15.0	–	–	13.8	–	–	–	–	–	–
Cajanus cajan	90.0	21.7	–	–	30.2	–	–	3.60	0.20	–	–
Senna siamea	–	12.4	45.6	43.5	–	25.3	–	2.52	0.27	1.35	–
Dactyladenia barteri	–	–	–	–	–	–	–	2.57	0.16	1.78	0.90
Erythrina poeppigiana	–	32.0	–	–	–	–	44.0	3.30	0.18	1.16	1.52
Faidherbia albida	88.0	14.3	37.4	27.9	–	4.5	–	–	–	–	–
Gliricidia sepium	19.9	27.6	36.1	27.8	5.3	2.1	61.5	4.21	0.29	3.43	1.40
Inga edulis	–	–	–	–	–	–		3.1	0.20	0.90	0.70
Leucaena leucocephala	69.0	22.0	–	–	18.3	–	–	4.33	0.28	2.50	1.49
Sesbania sesban	–	26.4	38.7	–	–	–	–	–	–	–	–

Source: Nair (1993)

3.2.10 Woodlots and Other Agroforestry Trees for Fuelwood Production

The developing world is facing a critical firewood shortage as serious as the petroleum crisis. Eckholm (1975) estimated (in early to mid-1970s) that no less than 1.5 billion people in developing countries derive at least 90% of their energy requirements from wood and charcoal and another billion people meet at least 50% of their energy needs this way. Since then, the situation in many countries has not changed much, and fuelwood use is certainly a contributory element to the degradation of land resources in agricultural regions where resource pressures are more. The results of tree planting projects for fuelwood production, however, have generally not been encouraging. The basic reason for this situation is that the small farmers' preference is always for trees that yield multiple outputs, and partially, it is because of the gender issue that is involved as men may not consider firewood shortage as a serious problem, but women do. Great potential exists for enhancing fuelwood production through agroforestry and social forestry programmes. In order to make such initiatives a success, fuelwood should be promoted as a subsidiary benefit rather than the prime end product, and the species selected should be locally adapted and accepted income-generating trees that yield multiple products. Akinnifesi et al. (2010) and Sileshi et al. (2014) have given detailed account regarding utilisation of several multipurpose trees as woodlots and in agroforestry systems in different regions of Africa.

3.3 Services Provided by Agroforestry Systems

The types of agroforestry systems are complex and diverse, and they are virtually innumerable. Nair et al. (2016) have reported a qualitative SWOT (strengths–weaknesses–opportunities–threats) analysis of the selected indigenous agroforestry systems showing several commonalities among them. While sustainability, multifunctionality and high sociocultural values are the common strengths, low levels of production and lack of systematic research and technological inputs to improve the systems are the major weaknesses. The opportunities emanating from strengths and weaknesses are also common to most of the systems, and threats to these systems arise mostly from ramifications of government policies. Besides the agroforestry systems/practices discussed earlier, some practices such as fuelwood lots, fodder banks, scattered multipurpose or fruit trees on farmlands/pastures, boundary plantation, live fences, tree planting for reclamation and improvement of problem soils, trees for windbreaks/shelterbelts, sand dune stabilisation and soil conservation and establishment of woody and herbaceous vegetation for rehabilitation of mine spoils are important. Some of these are discussed in brief in the following sections:

3.3.1 Agroforestry for Soil Conservation and Amelioration

Soil erosion has, in all livelihood, been a problem since time immemorial, but the soil conservation efforts were taken more seriously after formulation of the World Soil Charter by FAO (1982) and increased global emphasis on environmental issues and combating desertification. Today, soil conservation encompasses both soil-erosion control and maintenance of soil fertility. On highland situations, alley cropping has been undoubtedly proved a successful technique for soil conservation, sustainable production and maintaining soil fertility. Throughout the African continent, farmers use windbreaks to protect crops, water sources, soil and settlements on plains and gently rolling farmlands. Hedgerows of *Euphorbia tirucalli* are found grown very commonly to protect maize fields and settlements in dry savannas of Tanzania and Kenya. Tall rows of *Casuarina* may be seen along the canals and irrigated fields in Egypt, and multispecies shelterbelts are found grown in Chad and Niger for controlling the spread of deserts on croplands. Small live fences and hedgerows can also act as windbreaks for small sites such as homegardens and nurseries. The most effective windbreaks provide a semipermeable barrier to wind over their full height from the ground to the crowns of the tallest trees. An ideal windbreak should consist of a central core of a double-row planting of fast and tall growing species such as *Eucalyptus, Casuarina* or neem (*Azadirachta indica*) and two rows each of shorter spreading species such as species of *Cassia*, *Prosopis*, *Gliricidia* or *Leucaena* on both sides of central core. Species of *Agave* and *Euphorbia* are also used, especially on the outer rows, away from crop fields.

Diversifying the species in the windbreaks can also bring a wider variety of useful products to local users. Selection of species should be based on the compatibility, environmental hazards (such as insects and pests), palatability to wild and domestic animals, soil conditions, water management, microcatchments, etc. The widely mentioned study of windbreaks in the Sahel is that by CARE in the Majjia Valley in Central Niger where over 350 km of windbreaks protect 3000 ha of millet and sorghum fields by growing neem tree. When the wind breaks were 10 years old, the yields of millet from the protected area were 23% greater than the unprotected millet on a gross area basis (Vandenbeldt 1990). Lal (1989), Young (1989), Nair (1993) and Dagar and Singh (2018) have given detailed accounts on the role of agroforestry in soil conservation in various ecoregions. Soil amelioration by fertiliser trees dealt in earlier sections is equally relevant here.

3.3.2 Sociocultural and Recreational Value

The indigenous and traditional systems have been appreciated for ecological principles and sustainability, but very little attention has been paid towards the recreational and cultural values of the agroforestry systems. Some of the systems, for example, cultivation of ornamental fish and presence of coral reefs in association with mangroves, are the most attractive features in many coastal regions of the world. Many sacred groves are another socioreligious site in many localities across the globe. Many tribal people collect traditional forest non-timber produces such as leaves (making traditional plates, cups, etc.), medicinal drugs, honey and gum of commerce, from woodlots for their livelihood security without damaging the ecology. The aborigines also use fruits as food; ooze a fluid used as toddy or neera; and make jaggery from fruit juice and leaves are used for making brooms, baskets, fans, floor mats, etc. Thus, there are many unrecorded cultural tales associated with traditional agroforestry systems which need documentation. Urban and peri-urban forestry is another attraction in recent years.

3.4 Enhancing Livelihood and Nutritional Security

African countries face a worsening crisis in the availability of food for the fast-growing population resulting to poverty, food shortage, malnutrition and health problems. Periodic drought aggravates the situation, but even in years of favourable rainfall, most farm families cannot produce enough food to feed themselves. Due to frequent burning of forests, the indigenous fruit and other multipurpose trees are rapidly disappearing. Agriculture is still the main source of livelihood for more than three-fourth of the rural population. Agricultural production is currently constrained by unaffordable inputs (especially fertilisers), lack of irrigation facilities, lack of access to credit and minimum involvement of smallholders in the market economy and agricultural policies. The root cause of low per capita food production is soil fertility depletion. Smalling et al. (1997) reported that soils in Sub-Saharan Africa are being depleted at annual rates of 22 kg ha^{-1} for N, 2.5 kg ha^{-1} for P and 15 kg ha^{-1} for K. Sanchez et al. (1997) recommended a two-pronged strategy to stop the nutrient mining through replenishing phosphorus and nitrogen. About 530 million ha African soils are high phosphorus fixing which is now considered an asset rather than liability. Application of inorganic phosphorus fertilisers is necessary to overcome the depletion of this element (Jama et al. 1997). One-time application of phosphate rock can be helpful to desorb acids created by the decomposition of organic inputs like *Tithonia diversifolia* which produce organic acids to help acidify the phosphate rock. The organic sources like animal manure and compost, biomass transfer and efficient use of trees and shrubs may help in nitrogen replenishment, and their deep roots help in mining the minerals from subsoil depths beyond the reach of crop roots and transfer them to the top soil via decomposition of litter. By strategic planting of trees, nitrogen lost over the years can be replenished with nitrogen from agroforestry innovations such as hedgerow intercropping with *Leucaena* or *Gliricidia*, biomass transfer along with *Tithonia*, application of manure with foliage of *Calliandra calothyrsus,* and through improved fallow systems using nitrogen-fixing shrubs like *Sesbania sesban*, *Tephrosia vogelii*, *Cajanus cajan* and *Gliricidia sepium* as discussed earlier.

Thus, low-cost technologies and easily adaptable practices are needed for smallholders to sustain the productivity of their crop fields, pastures (including of livestock) and forest products. Agroforestry provides such options. The contribution of forest products (besides commercial timber) such as indigenous fruits and their products, medicine and thatching material to the rural household economies could be significantly high. Besides the importance of their nutritional value in balancing the diet of poor community people, many fruit tree species may be commercially exploited for better economic gains of their products such as juice, beverages, jam, jelly and alcoholic drinks. This requires strengthening of the domestication programmes of indigenous fruit trees which are plenty in natural forests and may be blended in various agroforestry systems. This will not only help in restoring the forest wealth (which otherwise is being deteriorated) for present and future generation but also help in providing food and nutritional security to poor people and conserving soil and environment. This aspect has been discussed in brief here.

3.4.1 Status of Indigenous Fruit Tree Species (IFTS) of Tropical Africa

The tropical subregions of the continent are diverse in their climate, soil, topography and vegetation and home to many valuable fruit and nut tree species, whose potential have not fully realised. Many of these are of local importance and have not yet domesticated though their economic produces are harvested from their wild stands or grown as volunteer stands in homegardens, farmlands and forest reserves (Dagar 2003; Meregini 2005). At least 477 edible fruit and nut species (including some exotics) are grown across the landscape of Africa (Bosch et al. 2002; Siemonsma et al. 2004) out of which some scanty researched local species have been identified and listed by Awodoyin et al. (2015). Based on the perusal of literature (mainly Palgrave 1983), extensive surveys and confirmation with other persons of various walks particularly Directorate of Forestry during visits to central and north-eastern regions of Namibia, Dagar (2003) listed 66 IFTS to be preferred among various communities living in the forest areas of Namibia for traditional uses of course mainly as fruits. Most of these are also common in countries of southern Africa. Many of these also have ethnomedicinal values and are used by local people in various ways. Species such as marula (*Sclerocarya birrea*), monkey oranges (species of *Strychnos*) and manketti (*Ricinodendron rautanenii*) have already been identified as potential and commercial species for domestication.

Despite of availability of local fruit and nut species, the fruit production in Africa is predominated by introduced species mainly from tropical Americas and Asia (NAP 2008). These include bananas (*Musa* spp.), *Citrus* spp., mango (*Mangifera indica*), papaya (*Carica papaya*), pineapple (*Ananas comosus*), pomegranate (*Punica granatum*), avocado pear (*Persea americana*), cashew (*Anacardium occidentale*), coconut (*Cocos nucifera*), carambola (*Averrhoa carambola*), custard apple (*Annona squamosa*), date palm (*Phoenix dactylifera*), guava (*Psidium guajava*), grapevine (*Vitis vinifera*), passion fruit (*Passiflora edulis*), jackfruit (*Artocarpus heterophyllus*), hog plum (*Spondias mombin*) and mulberry (*Morus alba*). These are commonly preferred because of availability of know-how of these species. Most African indigenous species have not been brought up to their full potential in terms of quality, breeding and selection, scale of production and distribution, value addition and availability. In terms of geographical spread except a few, these have not crossed African shores as compared to tropical fruits of other continents. There is urgent need of identification, evaluation, development of cultivation technologies, value addition and marketing of selected potential IFTS. A number of studies laid the foundations for domestication, by clarifying the role of fruit trees for rural livelihoods (Leakey and Simons 1998; Schreckenberg et al. 2006; Faye et al. 2010, 2011; Leakey et al. 2012) and setting priorities for domestication (Franzel et al. 2008). During the last four decades, attempts have been made to develop techniques for vegetative propagation (Sanou et al. 2004; Verheij 2004; Hartmann et al. 2007), management of genetic resources (Rao and Sthapit 2012; Ahuja and Ramawat 2014) and genetic improvement through establishment of provenance trials and using molecular markers (Sina 2006; Diallo et al. 2007). Some important examples have been mentioned later in this chapter showing the attention being paid to domesticate IFTS in tropical Africa and to bring them at the global market.

3.4.2 Domestication of Indigenous Fruit Trees

Tree domestication has been explained by many workers in their own way in the fields of agroforestry, agronomy, agroecology and plant breeding (Pauku 2005; Akinnifesi et al. 2008c). The World Agroforestry Centre (ICRAF) defines domestication as the socio-economic and biophysical processes involved in the identification, characterisation, selection, multiplication and cultivation of high-value tree species in managed systems (Garrity 2008). However, in more simple way, domestication is a process of naturalising or settling a species (whether plant or animal) from natural habitat as a member of household. In present context, cultivation of tree species growing naturally (in the wild) on farm or in homegardens for their anthropogenic change in the genetics to conform to human needs and agroecosystem (Awodoyin et al. 2015). Therefore, domestication of indigenous fruit tree species is a procedure involving the extent, identification, production, management and adoption of desirable germplasm. Strategies for individual species vary according to its extent in nature, functional use, profitability and biological and ecological adaptations in the targeted environment. Domestication of IFTS must aim at economic potential as a cash crop, fruit as such or its products, meeting the food and nutritional requirements of grower, and to provide incentive to subsistence farmers to grow such trees contributing towards poverty reduction.

The domestication of Kiwi (*Actinidia chinensis*) and mango (*Mangifera indica*) are classical examples of new horticultural fruits of international significance. Kiwi was first grown commercially in New Zealand in the 1930s, despite its more than 1000 years of history in China. Mango, with its many cultivars, was brought from different parts of the world and domesticated in the Sahel (Rey et al. 2004). The selection of the macadamia nut (*Macadamia integrifolia*) from Australia also began in 1934, motivated by promising market interests. Their wide adaptation across the globe is now history. These successes were achieved by farmer-led domestication and commercialisation efforts. The domestication of many other trees of the tropics was triggered by globalisation, especially during the colonial conquests, followed by growing market demands that promoted the research and cultivation, and propagation technologies were developed. Compared to this, local fruit tree species have only undergone intentional selection to a limited degree, and most of them must be underexplored or semi-domesticated in the genetic sense of the word. Selection in favour of superior trees by farmers may slowly have improved the productivity of the species (e.g. *Sclerocarya birrea* and *Vitellaria paradoxa*) but not to the extent that differences between improved and unimproved trees are easily observed (Raebild et al. 2011). However, a number of projects dealing with formal domestication of mainly indigenous species have recently been undertaken, and deliberate tree improvement programme involving specific interventions for useful characters has been advocated for some highly promising IFTS of West African Sahel and sub-Saharan regions (Kwesiga et al. 2000; Dagar 2003; Akinnifesi et al. 2004, 2008c; Raebild et al. 2011; Awodoyin et al. 2015). The extent of sufficient local resources, their detailed ecological and biological studies, proper identification and selection procedures, propagation technologies, value addition and proper marketing facilities and farmer-oriented policies are necessary for the success of domestication programmes. Some efforts have already been made and shown the path for success of such programmes. A brief account of some such attempts made is given here in the following text.

3.4.2.1 Extent of Resources

As mentioned earlier, it is very important to have the knowledge of the extent of available resources in the form of natural stands, i.e. vegetation. For that, we must study the ecology of the natural vegetation and ethnobiology and preserve the available biodiversity. For example, Mendelsohn et al. (2000) and Mendelsohn and El Obeid (2003) gave a detailed account of vegetation in north-central and the Kavango Region of Namibia where 35 vegetation types on an area of 84,608 km^2 are found out of which 849,901 ha area is fenced or cleared. The Kavango Region has been classified into 11 vegetation types. In many of these areas, there are the remains of old dunes, and the vegetation varies considerably between that on the sandy dunes and the more clayey soils in the inter-dune valleys. Thus, tall teak (*Pericopsis elata*), false mopane/*msivi* (*Guibourtia coleosperma*), *Burkea* (*Burkea africana*), kiaat/*mukwe* (*Pterocarpus angolensis*) and mangetti (*Schinziophyton/Ricinodendron rautanenii*) trees often dominate the deeper sands, while low-lying, more clayey soils are characterised by shrubby vegetation and patches of grasslands. *Diospyros* also prefers clayey soil. Most of these stands are rich in IFTS, which are used by the community people in many ways in their routine life. Nuts and fruits from between 35 and 50 different species are consumed in any one area. Most of these are taken only occasionally, but some, especially mangetti, marula, monkey oranges and *msivi*, provide relatively large quantities of food. Many IFTS also possess medicinal properties. But, unfortunately, most of the stands are burnt year after year, especially so in eastern Kavango and the Caprivi Strip. The average area burnt over 13 years (from 1989 to 2001) was reported to be 32% (Mendelsohn and El Obeid 2003). In this process, many fruit trees and their saplings are killed, and as a result in many stands, the tree population of many IFTS is becoming thin. With the exception of manketti, the availability of indigenous fruit species has decreased in the last 3 decades. *Guibourtia coleosperma* is frequently cut as it is a preferred wood species for woodcarvers, and people also use it for fencing and construction. Fruit trees that do not fruit (anymore) are often seen as useless and cut down for firewood or other purposes. It was furthermore informed that people even cut down indigenous fruit trees if they want to harvest but cannot reach the fruits. Small trees are not really cared for.

In the forests of north-central region, marula (*Sclerocarya birrea*), manketti (*Schinziophyton rautanenii*), *Berchemia discolor*, monkey oranges (*Strychnos cocculoides*, *S. pungens*) and *Diospyros mespiliformis* are prominent fruit trees. In the Caprivi region of Namibia, *Berchemia discolor*, *ibbu* (*Vangueria infausta*), *baobab* (*Adansonia digitata*), *Parinari curatellifolia*, *Ximenia* spp. and *Grewia* spp. are predominant in natural stands. These fruits are already consumed, stored and transformed in various products by the rural people. While commercialising a fruit product, it must be ensured that the particular fruit tree is planted (domesticated) in large area so that the same is not exploited in its natural habitats. This, in turn will also take care of environmental aspects. In southern Africa, *Uapaca kirkiana*, *Parinari curatellifolia*, *S. cocculoides* and *S. birrea* are in abundance and collected from the wild and consumed.

3.4.2.2 Traditional Uses

For a long time, indigenous fruit trees have been recognised as important species by farmers with smallholding, who have from time immemorial used their fruits to supplement their diets and income through selling to urban markets. Efforts in the past have largely been devoted to documentation of their utilisation at household level, traditional conservation practices of protecting the valued indigenous fruit trees, the informal marketing in southern African countries and ethnomedicinal uses. Most of the fruits are available mainly during the rainy season when crops are not ready for harvest and hence contribute significantly to the diets of the rural people. Besides fruits, some of the plants are used for food in the form of leaves, pods, seeds and roots. Dried fruits or kernels of some plants serve as porridge. Many serve as refreshing beverages or kind of liquor. Many fruits besides being consumed locally are also sold in local and roadside markets. Traditional fruits such as marula (*Sclerocarya birrea*), monkey orange (*Strychnos* spp.), bird plum (*Berchemia discolor*), *Diospyros* spp., *Grewia* spp. and manketti (*Schinziophyton rautanenii*) have become part and parcel of the life of rural masses. They use most of these IFTS in more than one way. Based on available literature including on ethnobotany (Palgrave 1983; Kwesiga and Kamau 1989; Maghembe and Seyani 1992; Maghembe et al. 1998; Tchoundjeu et al. 2008; Raebild et al. 2011) and the survey in FAO Project (Dagar 2003), the traditional uses of IFTS may be summarised under the following categories (there will certainly be a wider range of uses and species in different regions):

1. **Edible fruits consumed as dessert**: Ripe fruits of most of the species are consumed as such since time immemorial. Marula is found both naturally grown and cultivated (Fig. 3.3). Archaeological evidence suggests that the fruits of marula (*Sclerocarya birrea* subsp. *caffra*) were known and consumed by humans in southern Africa as far back as 9000 BC. It is the most widely

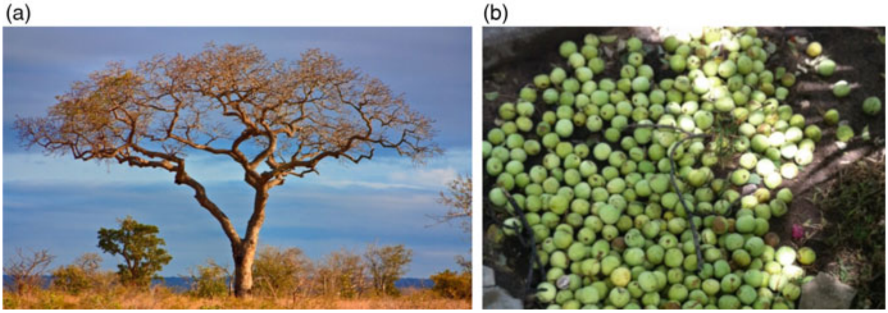

Fig. 3.3 (**a**) Marula tree grown near Skukuza in the southern Kruger National Park, Mpumalanga, South Africa. **Attribution:** Nicolas Raymond from Bethesda, Maryland, USA [CC BY 2.0 (https://creativecommons.org/licenses/by/2.0)] https://upload.wikimedia.org/wikipedia/commons/1/16/Kruger_Park_Scenery_HDR_%287645852578%29.jpg. (**b**) Marula fruits collected in Ongwediva, Namibia **Attribution:** Pemba.mpimaji [CC BY-SA 4.0 (https://creativecommons.org/licenses/by-sa/4.0)] https://upload.wikimedia.org/wikipedia/commons/a/a5/Marula_fruits_Ongwediva_March_2016.jpg

consumed fruit among rural masses. An alcoholic drink is also prepared from its fruit. Shackleton et al. (2002) reviewed all kinds of *marula* uses in folk life. The elephants also pluck the fruits and eat because of their alcoholic contents. Surprisingly, they never damage a marula tree.

Monkey oranges (species of *Strychnos*) are other fruit trees yielding delicious fruits in Kwango and Caprivi regions of Namibia and in Zimbabwe; the fruits are used to prepare juice and jam on commercial scale. Because of drought, *Berchemia discolor* is one of the most preferred fruit trees in the Katima Mulilo region. The manketti (*Schinziophyton rautanenii*) has stood as the tree of difficult times in the Kavango Region. *Annona senegalensis*, *Diospyros mespiliformis*, *Friesodielsia obovata*, *Grewia* spp., *Parinari curatellifolia*, *Securinega virosa*, *Syzygium cordatum*, *S. guineense*, *Vangueria infausta*, *Vangueriopsis lanciflora*, *Ximenia americana* and *Ziziphus mucronata* are among many others which are consumed raw when ripe in the southern African region. *Adansonia digitata*, *Parkia biglobosa*, *Tamarindus indica*, *Vitellaria paradoxa* and *Ziziphus mauritiana* are consumed and cultivated in dry West Africa.

2. **Nuts or kernels consumed raw or roasted or made into porridge**: Dried kernels of *marula* (*S. birrea*) and *manketti (Schinziophyton rautanenii*); dried fruits of *Berchemia discolor*, *Diospyros mespiliformis* and *Parinari curatellifolia*; arils of *Guibourtia coleosperma* and roasted seeds of *Kigelia africana*, *Bauhinia thonningii* and *Schotia afra* are consumed by rural people most of the time by making porridge, and dried fruits of *Grewia flava*, *G. flavescens* and *G. retinervis* are soaked in water, mashed and eaten as porridge. The white pulp inside the hard, woody shell of *Adansonia digitata* fruit is eaten raw and is considered that it makes one fatty. The fruits of *manketti* and *matu* (*Strychnos pungens*) are used to make porridge. Manketti fruits are cooked, its fruit pulp is pounded into flour that is used to make porridge, and it can be mixed

with juice of *matu*. Cooking a mixture of pounded *eembe*, *marula* kernels, water and salt can make the traditional cake/bread. The kernels of false mopane (*Guibourtia coleosperma*) can be put on hot ashes to separate the outer part from the inner. The latter can either be cooked and eaten like that or made into a kind of *peanut butter* by mixing it with peanuts, frying and pounding it. Traditional *bread* can be made using either a mixture of roasted *manketti* kernels and maize or *mahangu* and *Berchemia*. The ingredients are pounded and cooked with water. Nuts of *Vitellaria paradoxa* are transformed into butter used for cooking in West Africa.

3. **Edible oil**: Rural population most commonly uses manketti and marula oils as edible oils. A kind of cooking oil is extracted from the fruit of *nonzwe* (*Ochna pulchra*), which can be stored for about a year.
4. **Jam and jelly:** Marula is widely used to prepare the traditional jam from its fruits. The fruits of monkey orange are made into delicious jam. A jam is made out of *eenkwiyu* (*Ficus sycomorus*) and marula fruits by cooking them with sugar or by some other traditional method. The fruits of eenkwiyu make a tasty *ombike.* The fruits of *Ximenia caffra* make a tart jelly. The fruits of *Grewia* are mixed with fresh milk to make it into a kind of yoghurt. The pulp of *Vangueria infausta* is used to make puddings, and when mixed with a little sugar and water, it makes a good substitute for apple sauce. Fruits of monkey oranges (*Strychnos* spp.) and *eembe* (*Berchemia discolor*) can easily be transformed into juice and jam of commercial value.
5. **Beverages and alcoholic drinks:** Fruits of marula, manketti (kernels), *Grewia flava*, *G. bicolor*, *Dialium engleranum*, *Diospyros mespiliformis*, *Parinari curatellifolia*, *Garcinia livingstonei*, *Berchemia discolor*, *Strychnos cocculoides* and *Ziziphus mucronata* are extensively used for preparing alcoholic drinks. Fruits of *Adansonia digitata* soaked in water make a refreshing drink. Fruits of *Syzygium guineense* are used to prepare a kind of drink. Powdery pulp of *Dialium engleranum* mixed with water makes a refreshing drink. Arils and red skin of *Guibourtia coleosperma* removed with warm water make a kind of beverage. Young fruits of *makami* palm (*Hyphaene petersiana*) make an intoxicating drink. A sap exuded from spadix of *makami* palm and wild date palm (*Phoenix reclinata*) is converted into an alcoholic drink. Fruits of *Rhus lancea* pounded with water are fermented for a kind of beer.
6. **Crafting and thatching**: Leaves of *makami* palm (*Hyphaene petersiana*) and wild date palm (*Phoenix reclinata)* are widely used for making traditional storage baskets and thatch material for huts.
7. **Fencing**: Wood of many indigenous fruit tree species is part of the fencing of households.
8. **Ethnomedicinal/ethnoveterinary and other uses***:* Many IFTS are used in traditional medicines for treating various ailments including routine stomach trouble, serious diarrhoea, malarial fever, cough and cold and many other diseases. Some IFTS with ethnomedicinal and other minor uses have been reported by Palgrave (1983) and Leger (1997).

3.4.2.3 Commercial Uses of Important Species

The biggest single formal market for indigenous fruits is the factory Phalaborwa in South Africa that produces marula pulp for use in *Amarula liqueur*. It buys between 2000 and 3000 tonnes of marula fruit in a year. In Namibia, there is a limited formal market for marula kernels used to produce cold-pressed crude oil for international cosmetic markets. Currently, this is owned and controlled by the Eudafano Women's Co-operative (EWC), which is a registered community trade supplier to the Body Shop. Not only these two commercial products are produced from marula, but also it has been shown that marula fruits can also be transformed into juice and jam of commercial importance.

Another IFTS of commercial importance are monkey oranges—*maguni/matu* (*Strychnos cocculoides* and *S. pungens*). A formal market for monkey orange fruit has been created by the Namibian company that makes *maguni liqueur*, at present with a limited market of 5 tonnes a year. PhytoTrade Africa recently facilitated the supply of monkey orange fruit samples to a South African company with a large international market. This has created a hope of a much larger market in due course of time. Both a low-alcoholic (beer) and a high-alcoholic (*kashipembe*) drink can be made from the fruits. It has been proved that *maguni* and *eembe* (*Berchemia discolor*) fruits can be transformed with success into juice and jam of commercial importance. Juice can also be prepared from fruits of *mulutuluha* (*Ximenia americana*). Cooking oil of commercial importance is prepared from kernels of manketti and fruits of *nonzwe* (*Ochna pulchra*).

Kashipembe of commercial importance can be prepared from *eembe* fruit, manketti/*nongongo* (*Schinziophyton rautanenii*) nuts and *nonsimba* (*Dialium engleranum*) fruit. Fruit pulp of *Adansonia digitata* is exported from southern Africa and Senegal. A strong alcoholic drink (*ombike*) of commercial importance can be prepared from fruits of *eenyandi* (*Diospyros mespiliformis*) and *enkenkete* (*Ziziphus mucronata*). Palm wine (*omalungo*) can be prepared from makalani (*Hyphaene petersiana*) palm. Thus, there are several IFTS with commercial importance. But we cannot depend solely on availability of fruits from natural forests. We would have to domesticate these potential trees and grow them on suitable sites for commercial exploitation.

3.4.3 Preferred Species and Their Potential for Domestication

Historically, researchers with various degrees of self-interest have largely chosen which species of indigenous fruit trees should receive their attention. Such subjectivity has led to suboptimal use of resources, lack of planning and attention. The farmers based their preferences on the following factors:

- Availability of the fruit species in the area
- Food security especially during famine years
- Ability of fruits to generate income both in cash and kind
- Ability of fruits to be processed into various products

- Ability of the fruits to be processed and stored for later use (e.g. due to its hard shell, *Strychnos cocculoides* and *Diospyros mespiliformis* were reported to be easily stored and transported)
- Personal satisfaction when the fruits are consumed

Though the most preferred species are widely distributed in the local forests, all the preferred species are not found in all the localities. As per the survey conducted through participatory approach in Namibia (du Plessis and Den Adel 2003), it was clear that marula (*Sclerocarya birrea*) was predominant in natural sites of Oshikoto, Oshna, Ohangwena and Omusati and bird plum (*Berchemia discolor*) in Oshna, Ohangwena, Omusati and Caprivi while monkey oranges (*Strychnos cocculoides* and *S. pungens*) in Kavango and Caprivi regions. Though there are many useful IFTS found naturally distributed in forests of different regions of Namibia, their preference differs in different localities depending upon the preferences of the people. Marula (*Sclerocarya birrea*), bird plum (*Berchemia discolor*), monkey oranges (*Strychnos cocculoides*) and manketti (*Schinziophyton rautanenii*) are among most popular and preferred species. The fruit of manketti is consumed as dry nut and is not fleshy and juicy; therefore, the other three are identified as three most preferred species for domestication in north-central and north-eastern regions of Namibia. In the Kavango Region, *Strychnos cocculoides*, *S. pungens* and *S. spinosa* were in abundance and the most preferred fruits. These are even sold in local as well as urban markets. Manketti (*Schinziophyton rautanenii*) was also a preferred species for preparing local drink from its nuts. In the north-east, near Katima Mulilo, *Berchemia discolor* was the most preferred species along with species of *Diospyros*, *Grewia* and *Parinari curatellifolia*. Besides these, *Vangueria infausta*, *Azanza garckeana*, *Adansonia digitata*, *Ximenia americana*, *X. caffra*, *Ficus sycomorus*, *Vitex payos*, *V. mombassae*, *Syzygium cordatum* and *Garcinia* spp. are quite frequently used in different regions.

Nongongo (*manketti*) was rated as the most important indigenous fruit (tree) in Mile 20 of the Caprivi region mainly because one can survive on that tree only. Its products can be stored for years and kept for times of hunger. The nuts can be stored for 3–4 years. *Nonsivi* (*Guibourtia coleosperma*) was seen as important also because its main product can be stored for a year and eaten in times of hunger. *Maguni* (*Strychnos cocculoides*) is important because the tree carries a lot of fruits, which are highly appreciated because of its taste. The problem however is that the fruits cannot be stored well. One can keep them only 1–2 weeks after collecting. Kalahari podberry/*nonsimba* (*Dialium engleranum*) was rated high as well because of its long storage capacity. It was said that fruits could stay on the tree and be used for at least 2–3 years. The Kalahari podberry only bears fruits every 2–3 years. *Nonzwe* (*Ochna pulchra*) is seen as an important tree, mainly because of the cooking oil one can extract from the fruit and keep for about a year. In Kasheshe, *Berchemia* was rated as the most important tree, because of its taste, long storage, nutritional value and abundance in the area. It was also said that *Berchemia* is important because it is harvested before crops are ready and can therefore help people survive in periods of hunger. *Grewia* was rated second most important, because of the sweetness of the fruits and its abundance in the area. Its fruits can be eaten fresh, dried, and mixed with fresh milk to make it into a kind of yoghurt. *Ximenia* is relatively abundant, and its fruits can be eaten fresh or made into a juice. The main disadvantage of *Ximenia*, however, is that both the fruits and the juice must be consumed immediately. *False mopane* fruits can be made into a relish for meat and a kind of peanut butter, and its stamped kernels can be cooked and eaten.

In Eefa, *eengongo* was rated as the most important fruit tree in the area, because of its many uses and cultural importance. Its marula wine and cooking oil are very much appreciated, and people also eat the fruits fresh, make a juice and a porridge out of it, eat the kernels fresh, mix them with other food, make a soup out of it and eat the leftover kernel cake after oil processing. *Eembe* was rated important mainly because of the reason that people like the taste of the fruit and can store the fruits dry for at least 6 months. *Berchemia* fruits are eaten fresh and dried, they can be used to make strong alcoholic liquor (*ombike*) and one can make a *Berchemia*/marula cake. *Eenyandi* can be eaten fresh as well as dried. One can make porridge out of the fruits and produce a low-alcoholic (*omalovu*) and strong alcoholic drink (*ombike*). *Eenkwiyu* fruits can be eaten fresh and dried and be made into a very tasty *ombike*. Some people know how to make *eenkwiyu* jam. *Eendunga* fruits can be eaten dried or made into *ombike.* Some people used it to make palm wine (*omalunga*), but the tree dies in the process. Palm leaves are used for making baskets and mats, and the branches are often used as fencing material. *Enkenkete* fruits are only used for making *ombike in* Ohangwena, Omusati and Oshikoto regions of Namibia.

In the Kavango Region, *Strychnos cocculoides*, *S. pungens* and *S. spinosa* were in abundance and the most preferred fruits. These are even sold in local as well as urban markets. Manketti (*Schinziophyton rautanenii*) was also a preferred species for preparing local drink from its nuts. In the north-east, near Katima Mulilo, *Berchemia discolor* was the most preferred species along with species of *Diospyros*, *Grewia* and *Parinari curatellifolia*. Besides these, *Vangueria infausta*, *Azanza garckeana*, *Adansonia digitata*, *Ximenia americana*, *X. caffra*, *Ficus sycomorus*, *Vitex payos*, *V. mombassae*, *Syzygium cordatum* and *Garcinia* spp. are quite frequently used in different regions.

Although bush fires are common, and obviously destroying a large part of the natural resources in the area, people on general felt that the number of indigenous fruit trees had increased in short period, especially *Berchemia*, *Grewia* and manketti. In their tradition, it is forbidden to cut down fruit trees for construction, fencing or firewood, but now, people use trees for these purposes also. In the north-central regions, most indigenous fruit trees are tenured by people and grow either at homesteads (*egumbo*), crop fields (*epya*) or in the woodland areas within farms (*ekove*). In Onkani, only *mopane* trees grow naturally, with other species like marula, *Berchemia* and *Diospyros mespiliformis* increasing with the immigration of people. In Eefa, the most abundant indigenous fruit tree species both on- and off-farm is *Diospyros mespiliformis*. Marula, *Berchemia* and makalani palm trees are less abundant and mostly grow in crop fields and homesteads. Small marula and *Berchemia* trees are often protected if found in the homestead. When homesteads move, the trees are left and found in the crop fields. In general, there is little natural regeneration of trees in community lands.

Uapaca kirkiana, *Parinari curatellifolia*, *Strychnos cocculoides* and *Sclerocarya birrea* were identified by farmers and stakeholders as priority species in the southern African regions, and the five most preferred species in different countries of this region are shown in Table 3.9 (Franzel et al. 2008). *Adansonia digitata*, *Parkia biglobosa*, *Tamarindus indica*, *Vitellaria paradoxa* and *Ziziphus mauritiana* are the most preferred species for domestication in dry West African Sahel, and some projects have been initiated to popularise them (Raebild et al. 2011).

Most of the preferred IFTS have potential for domestication. Many of these can be propagated successfully from seedlings raised in nursery or from cuttings or grafting. According to social survey conducted (du Plessis and Den Adel 2003) in Onkani, Eefa and Mile 20 in Namibia, many community people planted marula using seeds, seedlings and truncheons. These propagules were often selected on the quality of the fruits (taste and juicy nature of the fruits and number of kernels in the seeds) of the mother tree. All the planting methods were successful, but planting through truncheons had more advantages. It makes trees fruit faster (some after 3 years); one can be sure that it is a female tree and that the traits of the tree and its fruits are identical to the mother tree. Manketti also could be planted from truncheons. *Berchemia* could not be grown from truncheons. It could be grown from seeds, which were also selected on the quality of fruits of the mother tree. A major advantage of planting *Berchemia* was said to be the fact that one can be sure that the tree will bear fruits; the disadvantage, however, is that it takes a long time before they start fruiting. People in Onkani informed that they could grow *Diospyros* within the homestead, and a few seedlings would then be transplanted into the fields. Most trees found outside the homestead were said to be there because of the shifting of homesteads. They also planted figs (*Ficus* species) from stem and root cuttings. The survey results of Kasheshe show that half of the respondents had tried to plant either *Berchemia* or manketti or both. Manketti was planted using truncheons and *Berchemia* with seedlings or seeds, and most of them planted the trees in the homestead. Half of the respondents had also looked after young trees, especially *Berchemia*.

Raebild et al. (2011) reported that in West African Sahel, grafting was successful in *Adansonia digitata* while in *Parkia biglobosa* the rate of success was low and raising from cutting was possible. *Tamarindus indica* could be propagated through grafting, cutting and layering. In *Vitellaria paradoxa*, grafting and layering technologies were developed successfully, and in *Ziziphus mauritiana*, both rooted cuttings and grafting were found successful.

Though there is success in vegetative propagation of IFTS, the knowledge of genetic parameters, especially of fruit traits, is almost absent, but the characterisation of genotypes is underway for some of species in West African Sahel (Raebild et al. 2011). Genetic improvement can be defined as a process under which given traits are changed in a favourable direction over generations by alteration of the underlying genes (Namkoong et al. 1988). Further, Eriksson et al. (2006) stated that among the initial steps required involve identification and selection of superior provenances

Table 3.9 The most preferred IFTS for domestication by farmers of some African countries [percent of households mentioning the species (value in parenthesis is average preference scores out of 10, for those households mentioning the species)]

Species	Nigeria	Cameroon	Ghana	Malawi	Tanzania	Zambia	Zimbabwe[a]
Adansonia digitata				12 (8.5)	1 (8.0)	10 (9.5)	3
Alstonia boonei		63 (3.6)					
Anisophyllea boehmii						75 (7.9)	
Annona senegalensis				19 (8.1)	1 (7.0)	5 (8.4)	7
Annona squamosa			58 (3.5)				
Artocarpus communis			67 (4.5)				
Azanza garckeana				20 (6.6)		11 (5.4)	52
Baillonella toxisperma		77 (6.0)					
Chrysophyllum albidum	56 (6.8)		46 (3.0)				
Dacryodes edulis	64 (6.2)	67 (4.6)					
Dacryodes klaineana			25 (1.9)				
Dennettia tripetala	30 (3.7)						
Diospyros mespiliformis						8 (8.6)	28
Entandrophragma cylindricum		60 (2.6)					
Flacourtia indica				29 (7.4)	3 (7.0)	19 (6.5)	26
Garcinia afzelii			29 (2.0)				
Garcinia kola	39 (4.6)						
Guibourtia demeusei		37 (3.4)					
Irvingia gabonensis	86 (7.8)	86 (6.0)					
Milicia excelsa	64 (5.8)	37 (1.8)					
Newbouldia laevis	30 (3.0)						
Ocimum gratissimum	11 (2.5)						
Parinari curatellifolia				55 (8.4)	43 (8.9)	80 (9.0)	57
Physalis peruviana				2 (6.5)		35 (4.7)	
Raphia spp.		23 (1.5)					

(continued)

Table 3.9 (continued)

Species	Nigeria	Cameroon	Ghana	Malawi	Tanzania	Zambia	Zimbabwe[a]
Ricinodendron heudelotii		67 (4.1)	42 (1.9)				
Solanum indicum			33 (1.8)				
Spondias mombin			42 (1.8)				
Strychnos cocculoides				32 (7.0)	64 (8.2)	52 (7.7)	78
Strychnos pungens						16 (5.0)	31
Synsepalum dulcificum			42 (1.8)				
Syzygium guineense				11 (7.4)	1 (8.0)	39 (5.4)	28
Tamarindus indica				10 (5.9)	33 (8.9)	7 (8.3)	
Tetrapleura tetraptera			54 (2.9)				
Treculia africana	28 (3.9)						
Uapaca kirkiana				77 (9.3)	53 (9.3)	85 (9.5)	70
Uapaca nitida				1 (1.0)		35 (6.0)	
Vangueria infausta				19 (7.3)	16 (6.5)	3 (9.0)	4
Vernonia amygdalina	62 (5.6)						
Vitex doniana				8 (6.4)	26 (8.1)	1 (5.5)	
Vitex mombassae					46 (9.0)	1 (5.0)	
Vitex payos				1 (7.0)			34
Ximenia americana				7 (7.6)	1 (6.0)	27 (4)	

Source: Modified from Franzel et al. (2008)
[a]Preference score not available

through series of testing. This is followed by the breeding phase where superior genotypes are crossed by either crossed or random mating and the recurrent phase where progenies from these crosses are tested in the field and new selections made, crossed and evaluated over successive generations. This, however, requires long period. Knowledge of the heritability and the phenotypic variability for different fruit characters is, therefore, important in order to determine which traits are worth selecting for. Based on selected commercial cultivars of several tropical IFTS, Yao and Mehlenbacher (2000), Hardner et al. (2001), Thaipong and Boonprakob (2005), Silva et al. (2007) and Raebild et al. (2011) reported large heritability in fruit size or kernel weight.

3.4.4 Domestication Strategies

The most important aspect of domestication is the availability of accredited germplasm in sufficient quantity and at reasonable cost. The improvement of IFTS entails the applications of silvicultural, horticultural and tree-breeding skills to obtain the most valuable domesticable fruit trees as quickly and inexpensively as possible. In the process, farmers must be involved in collection of superior germplasm through appropriate selection process, propagation and dissemination in participatory mode. Suitable number of high-standard nurseries must be established for both propagation and skill development. The domestication programme is both market-oriented and farmer-led, but it has both research and developmental components also. These aspects are closely linked but need different approaches. The main goal of the developmental component is to obtain suitable fast-growing trees that can give early returns to the farmers, thereby accelerating wider adoption. The research goal is to ensure a solid scientific basis for domestication process, whereas the production goal is to ensure proper exchange and delivery of germplasm to farmers (Akinnifesi et al. 2004). The following basic steps are essential to follow:

- Identification of priority species involving regional experts, farmers and those who ensure marketing
- Selection and collection of superior phenotypes of individual trees from the wild involving experts and farmers
- Nursery development by raising the rootstock or vegetatively or by seeds and generating sufficient germplasm of the concerned species
- Management or cultivation on-station and on-farm
- Dissemination and adoption of planting materials and knowledge through literature and training
- Training and skill development for value addition
- Raising plantation
- Harvesting, value addition and marketing

3.4.5 Transformation

The success of domestication of IFTS will depend on nutritional and transformation value (into juice, jam and jelly) and economy of the produce. In an attempt to domesticate and improve IFTS in Botswana, Mateke (2000) analysed the nutritional composition of selected fruit trees. It was obvious from the data that marula fruit and manketti nut are rich in vitamin C and total carbohydrates and marula were found a potential candidate for juice production. African chewing gum (*Azanza garckeana*) is rich in fibre and protein contents and moderate amount of carbohydrates. Saka and Msonthi (1994) also determined chemical composition of the pulp and nuts of some indigenous fruits of Zomba with the intention of their domestication. *Ibbu* (*Vangueria infausta*) peel and pulp like marula also have commercial potential. The carbohydrate contents of *eembe* (*Berchemia discolor*) fruit pulp and peel are higher than that of either the marula or the *ibbu* fruits and make it good candidate for juice and fermented products. In a major economic breakthrough, Barion et al. (2001) prepared country wine from dried *eembe* fruit purchased from Katima Mulilo open market using commercial wine yeast. The fruit produced a wine with 8.6% alcohol content when no sugar was added. The addition of sugar increased the alcohol content of the wine, and all the batches produced dry wine. It was possible to use dried *eembe* fruit in the production of the country wine of acceptable standard. In the event that transportation of the ripe fruit proves difficult, it was recommended that the fruit be dried at the place of harvesting and later utilised in fermentation in wine making. The success of domestication of IFTS will solely depend on nutritional and economic improvement of the people. In New Zealand, the domestication process of kiwi fruits was made possible through the availability of commercial cultivators, planting materials and grower's organisations, which facilitated awareness through dissemination. In ICRAF, studies on marketing and the production economics of indigenous fruit tree products were initiated with following activities (Kwesiga et al. 2000):

- Identification of the factors determining the marketing chains in terms of prices and margins at the different marketing levels
- A better understanding of consumer's attitude and preferences for IFTS
- Description of the existing policy setting and its influence of the marketing of IFTS
- Determining the contribution of IFTS to household income and food security of small-scale farmers
- Access of the economic performance of investments in planting IFTS by small-scale farmers taking into account uncertainty in biological and economic parameters
- Evaluating the contribution of technological improvements in the multiplication and management of IFTS

These studies indicated that although IFTS may contribute substantially to household income and food security, there is a wide range of policy issues that need to be addressed, for example, government policies on concessions or subsidies and the interpretation of the laws about indigenous fruits as communal property or otherwise. To ensure food security of the local people, the proper chemical and nutrient analysis of the fruits and their products is essential. Besides being the sources of everyday food, many of the IFTS provide processed products such as jam, juice and alcoholic beverages, which fulfil the local demands and also generate cash. Marula (*Sclerocarya birrea*), *Ziziphus mauritiana* and *Uapaca kirkiana* are probably the best examples of fruit trees that have become important in the production of commercial beverages in Malawi, South Africa and Zambia.

3.4.6 Products Marketed and Marketing Systems

For the first time ever in Namibia, marula juice (for *omaongo* production) was extracted mechanically using small hydraulic presses designed by Katutura Artisans' Project (KAP) and disseminated by CRIAA SA-DC. The presses far exceeded expectations under field conditions. Some operators achieved up to 200 l a day—more than 300% the predicted daily production. Rolf Behringer of the Solar Stove Project at Valombola Vocational Training College developed a prototype of a solar batch pasteuriser. Once the prototype is scaled up, it can be combined with the small juice press into a technology package theoretically capable of producing around 50 l of pasteurised marula juice a day. This will enable producers to sell *omaongo* in local or national markets at any time of the year (du Plessis 2002).

Den Adel (2000) conducted other interesting socio-economic survey regarding use of marula products for domestic and commercial purposes by households in north-central Namibia, where marula is considered a tree of life. The community people use the tree and its fruits in so many ways as discussed earlier. The importance stretches from the social to the cultural, the economical and the nutritional aspects. The survey results clearly showed that the use of marula products in north-central Namibia and elsewhere in southern Africa is very common. One hundred percent of the interviewed households make marula wine, juice, cooking oil and a kernel soup, and they mix the kernels with other food, and almost all the households eat the fruits, the kernels and the cake and use the marula wood as the source of fuel. People sale marula products and use the cash for paying school fees of children, hospital expenditures, basic goods and supplementary sources of food. The existing marketing of indigenous fruits and their products is informal and multifaceted. Different levels of 'marketing' typically coexist.

Marula might be more valued as a resource, but bird plum (*Berchemia discolor*) is the favourite fruit, eaten by everyone when in season and used for jam and cake and *ombike* distillation. When dry, it is sold in informal market for about N$ 10 per kg. After several years of inconclusive market exploration, a serious and well-resource development partner in the form of a major multinational has finally taken an active research and development interest in manketti and *Ximenia* oil. The production of *Ximenia* oil in Namibia was systematically studied for the first time (du Plessis 2002), and it is possible that it may proceed to a significant commercialisation. There is a need for a better understanding of the distribution and potential production of *Ximeni*a in Namibia and for carefully differentiated collection of various species and subspecies for comparative analysis.

It is likely that bigger markets will be created for baobab (*Adansonia digitata*) and *Kigelia africana*. There are at least four small enterprises in neighbouring countries producing baobab oil. The Body Shop sells Baobab Bath Oil. In Namibia, baobab is only common in parts of western Omusati region and also reported to be found in north-eastern Otjozondjupa and parts of Caprivi. The potential of *Kigelia* is much larger than the current demand. It is easy to grow and starts fruiting after 7 years. du Plessis (2002) in his report submitted to the Indigenous Plant Task Team gave a brief and meaningful information regarding scope of commercial exploitation of some priority species. The Department of Food Science and Technology in University of Namibia has already been contributing and may contribute further to make the fruit products (like jams and jellies, juice, beer, wine) from preferred indigenous fruit trees of commercial acceptance.

It is clear from the above account that marula (*Sclerocarya birrea*), bird plum-eembe (*Berchemia discolor*), monkey orange (*Strychnos cocculoides*), manketti (*Schinziophyton rautanenii*), ibbu (*Vangueria infausta*), baobab (*Adansonia digitata*), *Ximenia* spp. and *Kigelia africana* have commercial potential in Namibia and are the forerunner candidates for domestication. These may play an important role in rural economy. As manketti nut is not consumed as desert fruit, therefore, the remaining IFTS are most suitable preferred indigenous fruit trees. Research efforts are also needed to find commercial uses of *Diospyros mespiliformis* and *Parinari curatellifolia* fruits, which are already consumed, stored and transformed in various products by the rural people.

3.4.7 Nutritional Value of Fruit Trees

Data on chemical composition of fruits and kernels (Table 3.10) of some indigenous fruit trees from different resources (Shone 1979; Arnold et al. 1985; Wehmeyer 1986; Saka and Msonthi 1994; Keya et al. 2000; Chadare et al. 2009; De Caluwe et al. 2009, 2010) show that many indigenous fruits are important sources of proteins, carbohydrates and water. Some are important sources of energy. The energy content of fresh fruits of some species like *Schinziophyton rautanenii*, *Vangueria infausta*, *Parinari curatellifolia*, *Ziziphus* spp., *Grewia* spp. and *Hyphaene petersiana* is superior to that of *Sclerocarya birrea* and other commonly marketed fruits juice in southern African countries such as *guava* juice. Others

Table 3.10 Chemical composition of some indigenous fruit tree species (compiled from various sources)

Species	*Berchemia bicolor*				*Hyphaene petersiana*	*Sclerocarya birrea*				*Schinziophyton rautanenii*		*Strychnos cocculoides*	*Strychnos pungens*
Component %	Raisin	Fresh fruit	Peels/ pulp	Shell/ kernel	Fresh fruit	Fresh fruit	Peels	Pulp	Kernel/ nut	Fresh fruit	Nut	Fresh fruit	Fresh fruit
Moisture	18.4	78.8	17.8	7.5	6.6	85.0	74.2	84.5	8.7	8.6	4.2	80.4	72.1
Ash	2.8	1.0	3.5	1.7	9.0	0.9	5.8	6.8	4.0	5.2	4.1	0.5	1.0
Protein	4.0	1.1	2.7	4.1	4.9	0.5	2.5	1.5	19.0	7.8	26.3	0.7	1.1
Fat	3.5	0.6	1.3	24.0	0.4	0.4	2.6	1.0	56.6	0.5	58.1	0.1	0.3
Fibre	69.6	2.8	5.6	64.5	9.6	1.2	15.0	8.9	18.0	2.9	2.2	0.9	6.2
Carbohydrates	20.1	15.7	86.8	5.7	69.5	12.0	74.1	81.7	2.33	75.0	4.6	17.4	18.9
Energy (KJ/100 g)	–	305	–	–	1265	225	–	–	2703	1410	2715	308	367
Minerals content (mg 100 g^{-1})													
Calcium	–	88.6	–	–	103	20.1	–	–	118.0	85.0	223	9.41	29.3
Magnesium	–	30.9	–	–	197	25.3	–	–	462.0	214	493	26.9	38.1
Iron	–	2.24	–	–	2.04	0.5	–	–	4.87	2.54	3.42	0.18	0.62
Sodium	–	6.04	–	–	–	2.24	–	–	3.81	2.39	3.35	0.89	2.00
Potassium	–	270	–	–	2560	317	–	–	601	2145	674	188	478
Copper	–	0.20	–	–	0.47	0.7	–	–	2.81	1.3	2.53	0.07	0.25
Zinc	–	0.27	–	–	0.56	0.01	–	–	5.19	1.68	3.84	0.08	0.34
Manganese	–	–	–	–	–	–	–	–	–	–	–	–	–
Phosphorous	–	40.1	–	–	156	11.0	–	–	808	74.3	869	20.2	27.1
Vitamins content (mg 100 g^{-1})													
Thiamin	–	0.03	–	–	–	0.03	–	–	0.42	0.42	0.26	0.03	0.05
Riboflavin	–	0.06	–	–	0.10	–	–	–	–	0.13	0.22	0.06	0.42
Nicotinic acid	–	0.53	–	–	4.62	0.27	–	–	0.42	1.78	0.27	0.27	0.96
Vitamin C	–	50.3	–	–	19.70	194	–	–	–	27	Traces	6.7	10.7

(continued)

Table 3.10 (continued)

Species	*Vangueria infausta*				*Diospyros mespiliformis*	*Parinari curatellifolia*		*Pappea capensis*	*Ficus sycomorus*	*Bauhinia thonningii*	*Garcinia livingstonei*	*Guibourtia coleosperma*	*Ochna pulchra*
Component %	Fresh fruit	Peels	pulp	kernel	Fig (fruit)	Fresh fruit	Nut	Nut	Fig (fruit)	Seed	Fresh fruit	Seed	Fresh fruit
Moisture	64.4	26.9	–	10.8	82.7	64.6	2.6	1.9	82.7	82.7	83.9	9.1	63.2
Ash	1.4	4.3	2.8	2.0	1.1	1.5	2.7	2.3	1.1	1.1	0.4	1.9	0.9
Protein	1.4	2.7	0.4	21.0	1.4	1.6	28.7	26.3	1.4	1.4	0.80	14.3	6.3
Fat	0.1	0.3	4.3	37.6	0.5	0.5	58.0	65.1	0.5	0.5	0.30	8.0	7.5
Fibre	4.7	8.6	83.9	21.4	4.3	2.9	4.3	2.6	4.3	4.3	0.70	4.4	1.5
Carbohydrates	25.0	79.0	–	7.7	10.0	28.9	3.7	1.0	10.0	10.0	13.90	62.3	20.6
Energy (KJ/100 g)	498		–	–	210	533	2737	2919	210	210	258	1589	735
Minerals content (mg 100 g^{-1})													
Calcium	24.9	–	–	–	96.0	1.3	182	59.3	72.6	72.6	4.79	323	34.1
Magnesium	39.1	–	–	–	23.4	46.0	416	400	43.1	43.1	12.10	163	45.9
Iron	1.07	–	–	–	1.03	0.86	5.54	4.73	1.73	1.73	0.28	4.69	1.0
Sodium	28.1	–	–	–	13.7	4.63	4.39	6.08	5.70	5.70	6.92	20.3	1.74
Potassium	521	–	–	–	417	411	470	470	347	347	134	390	232
Copper	0.25	–	–	–	0.11	0.51	1.95	1.56	0.16	0.16	0.07	0.87	2.65
Zinc	0.24	–	–	–	0.21	0.1	3.06	3.73	0.38	0.38	0.19	2.7	1.85
Manganese	1.06	–	–	–	–	–	–	–	–	–	–	–	–
Phosphorous	36.6	–	–	–	27.8	26.6	466	411	33.4	33.4	20.30	198	74.6
Vitamins content (mg 100 g^{-1})													
Thiamin	0.04	–	–	–	0.01	0.04	0.68	0.71	0.07	0.07	--	–	0.04
Riboflavin	0.03	–	–	–	0.04	0.07	0.0	0.19	0.03	0.03	0.05	–	0.08
Nicotinic acid	0.61	–	–	–	0.24	1.28	–	3.79	1.41	1.41	0.40	–	0.90
Vitamin C	4.7	–	–	–	24.6	70.9	–	–	7.3	7.3	5.40	–	–

Species	*Ximenia americana*	*Ximenia caffra*	*Annona senegalensis*	*Ziziphus mauritiana*	*Ziziphus mucronata*	*Grewia retinervis*	*Grewia villosa*	*Grewia schinzii*	*Grewia flava*	*Grewia avellana*	*Grewia bicolor*
Component %	Fresh fruit	Fresh fruit	Pulp	Fresh fruit	Fresh fruit	Flesh + peel	Flesh + peel	Flesh +peel	whole fruit	Flesh + peel	Flesh + peel
Moisture	64.8	77.4	77.2	24.4	56.4	6.9	70.0	69.6	74.7	18.3	13.2
Ash	1.9	1.3	1.2	2.2	3.2	3.2	2.0	21	1.0	3.2	5.9
Protein	2.8	1.9	1.7	3.2	3.8	4.9	3.3	2.4	1.8	7.0	10.3
Fat	0.8	1.5	1.5	0.6	0.5	0.3	0.2	0.6	0.08	0.7	0.1
Fibre	1.2	0.9	3.9	2.4	2.1	15.9	1.9	1.8	1.6	28.2	13.5
Carbohydrates	28.5	17.0	14.5	60.9	34.4	68.8	22.6	23.5	20.8	42.1	67.0
Energy (KJ/100 g)	556	374	329	1198	659	1250	443	458	383	851	1302
Minerals content (mg 100 g^{-1})											
Calcium	7.58	8.17	41.1	157	129	150	–	–	62.4	150	268
Magnesium	31.1	19.0	83.8	38.5	58.3	173	34.6	63.9	61.1	112	317
Iron	1.27	0.49	0.74	0.73	0.95	3.8	0.9	0.9	1.08	1.78	5.92
Sodium	3.33	1.25	1.31	4.01	5.05	18.40	3.80	2.10	2.59	3.76	12.4
Potassium	718	558	465	1078	726	768	224	197	275	1050	1707
Copper	0.28	0.17	0.21	0.32	0.86	0.34	–	0.5	0.25	3.91	1.29
Zinc	0.68	0.29	0.26	0.39	0.52	1.11	–	–	0.47	2.84	2.59
Manganese	–	–	–	–	–	–	–	–	–	–	–
Phosphorous	34.2	35.4	375	101.0	51.4	54	41.0	41.8	51.3	91.8	181
Vitamins content (mg 100 g^{-1})											
Thiamin	–	0.03	–	0.05	0.06	0.03	–	0.03	0.03	0.17	0.20
Riboflavin	–	0.02	0.14	0.08	0.05	0.04	–	0.23	0.07	0.15	0.25
Nicotinic acid	–	68.2	0.82	1.96	0.71	1.61	–	–	0.62	1.28	3.47
Vitamin C	69.7	0.48	18.2	–	42.6	–	–	–	29.4	6.5	9.3

species are important sources of vitamin C. Examples include *Sclerocarya birrea*, *Parinari curatellifolia*, *Ximenia americana* and *Ziziphus mucronata*.

As discussed above, it is clear that adopting agroforestry models of cultivation, a smallholder can sustain the productivity of his fields and can produce edible fruits, vegetables, nuts, grains, rhizomes and tubers, forages, flowers, medicinal plants, other non-timber forest products, livestock products, honey, fuelwood for cooking, thatching material and other minor products of routine use on the same piece of land. Agroforestry technologies such as improved fallows (in western Kenya, southern Malawi and eastern Zambia) and alley cropping in moist regions and high lands have proved that degraded soils due to deforestation can be restored along with increasing productivity of farm as well as pasture lands. This all is interlinked with food security of the region. Even in the regions like southern Africa where agroforestry innovations are not well known, the role of indigenous fruit trees in food security and nutrition supplement in diet (as discussed earlier) has been well recognised. These results clearly indicate that agroforestry can play a vital role in the food security and accomplishing nutrient requirement to a greater extent in the developing world particularly in tropical Africa.

3.5 Community Agroforestry and Gender-Related Issues

With the escalating worldwide interest in agroforestry and true planting activities during the past couple of decades, several other terms like *community forestry*, *farm forestry* and *social forestry* have emerged. In these activities, the people's participation in tree planting need not associate with agricultural crops and/or animals as in agroforestry, but with social objective, these have equal importance in production. Thus, community agroforestry may be considered a practice using trees and their produce for livelihood of rural masses particularly in countries of southern Africa where indigenous fruits are commonly used by the rural communities for their livelihood. A community on communal/common land undertakes agroforestry tree planting or deliberately retaining of trees, with direct participation of local people or by processing the tree products locally. Collection of marula (*Sclerocarya birrea*) and manketti (*Schinziophyton rautanenii*) fruits and their processing for alcohol and other products for livelihood in southern Africa are classical examples of community involvement. Thus, all these labels jointly may be dealt as community agroforestry because these directly or indirectly refer to growing and using trees to provide food, fuel, medicine, fodder, building material (including grass for thatching in association with trees) and cash income. Akinnifesi et al. (2008c) have included socio-economic aspects of community plantations in Africa.

Gender issues, to a greater extent, influence agroforestry innovations in many African countries. African rural women by custom intend to produce the food crops in many societies, while men are interested to produce the cash crops. As food producers, women farmers are the key to reversing the crisis and increasing domestic production, but they lack power inside their own households. Food security analysists correctly argue that development strategies need to reach African smallholders to be effective, but they ignore the fact that the constraints facing women smallholders may be an important part of the problem. Gladwin et al. (2004) mentioned that 45% of the smallholders responsible for Zimbabwe's second Green Revolution (1980–1986) where women, and the women smallholders were responsible for adoption of hybrid maize in Malawi. Some ethnographic and policy researches (Rocheleau 1995) suggest that women have more limiting factors to adoption than men and an interaction between gender-related property relations and resource uses, users' groups, landscapes and ecosystem in western Kenya (a region where agroforestry had been practised since the 1600s). Scherr (1995) found that gender differences in agroforestry practices are still quite significant. In one study, men had 50% more trees on their farms and almost 30% higher tree density as compared to women farmers. Men tended to plant trees in cropland, while women's farms had more trees used primarily for fuelwood. Men also have dominance in decision-making at household level. This power differential between men and women lays the formation for gender bias from household-level decisions to policy-level decisions. Peterson (1999), however, reported from eastern Zambia that women do adopt improved fallow technologies because they understand their soils are depleted and they cannot afford to acquire the number of fertilisers required for their crops. In nursery raising, collection of non-timber forest products and taking value-addition trainings, women play very important and significant role in tropical African regions, hence contributing to poverty elevation and adopting agroforestry land use systems.

Kiptot and Franzel (2011), based on 104 studies conducted in different regions based on gender issues in agroforestry, emphasised that women who despite farming remain disadvantaged in the agricultural sector due to cultural, socioeconomic and sociological factors. Such factors include ownership and access to resources, land tenure systems, access to education and extension services, among many others. Women's participation is very high in enterprises that are considered to be women's domain, such as indigenous fruit and vegetable products and processing. In the *Vitellaria paradoxa* (shea)-growing region of Benin, 90% of women are involved in collecting nuts/fruits of the *shea* tree, while in Cameroon, women and children are also the main collectors of the leaves of *Gnetum africanum* which is used as a vegetable. In Zambia and western Kenya, no significant differences were found between proportions of men and women practising improved fallows. However, there were more women than men using improved fallows and biomass transfer in western Kenya and using fodder shrubs in central Kenya.

Although women are actively involved in agroforestry for fodder production, in application of woodlot technology and soil fertility improvement, their level of participation is low comparative to men. Female heads of households planted only half as many shrubs/trees as men. The lesser involvement reflects women's lack of resources, particularly land and labour, their heavy workload and perhaps also their greater aversion to risk. In initial agroforestry management issues such as hoeing and watering, women manage well. Another interesting feature was observed that the men are usually interested in trees for commercial purposes while women are more inclined to tree products for subsistence use such as firewood, soil fertility improvement, fodder and fruits. This is reflected in the tree attributes that women prefer. In Malawi, women in female-headed households considered trees that grow fast as their first choice, followed by trees with good burning qualities and that produce a lot of charcoal. In turn, men ranked trees that grow straight as their first choice, an indication that timber is their number one priority. As far as marketing of agroforestry products is considered, women are usually confined to the small retail trade, while men dominate the wholesale trade. Women traders also receive lower marketing margins than men. This is attributed to the fact that men usually have more stock than women, because they have access to more capital. Only 20% of the participants in the major market information systems of Kenya and Malawi are women maybe due to the reason that their literacy level is lower than men's. These disadvantages mean that women fail to benefit equitably from the growing national and international markets.

Policy interventions, especially in extension, are essential to empower women in this sector. In order to promote gender equity in agroforestry and to ensure that women benefit fully, Kiptot and Franzel (2012) and Kiptot et al. (2014) recommended various policy, technological and institutional interventions which include (1) facilitating women to form and strengthen associations, (2) assisting women to improve productivity and marketing of products considered to be in women's domain and (3) improving women's access to information by training more women extension staff, holding separate meetings for women farmers and ensuring that women are fully represented in all activities. Further, using fertiliser tree systems, they can minimise the input costs towards fertilisers.

3.6 Research Opportunities and Policy Issues

3.6.1 Research Opportunities

Agroforestry systems are complex in nature in which one component of a system has influence on the performance of the other components as well as the system as a whole. As discussed earlier under different agroforestry systems, the impacts of trees, shrubs, mulch, manure and litter on soil amelioration in terms of increasing organic carbon and availability of nutrients are well documented. The major types of positive or complementary interactions at the tree-crop interface are those relating to microclimate amelioration and nutrient balance. Microclimate amelioration involving soil moisture and soil temperature relations and microbiological advantages result primarily from the use of woody perennials for shade, as alley crops, for fruits or minor products or as live supports, live fences or windbreaks. Temperature, humidity and movement of air, as well as temperature and moisture of the soil, directly affect photosynthesis, transpiration, microbial activities in soil and the energy balance of the associated crops, the net effect of which may translate in increased yield. The increased productivity can easily be transformed into animal productivity with high nutritional and monetary value. The productivity of silvopastoral system (including animals) can be further increased through the transfer of manure as a fertiliser source and shade as a factor for increasing animal productivity. The magnitude of interactive effects between trees and other components of agroforestry systems depends on the characteristics of species, their planting density and spatial arrangement and above all the management of trees and crops. Other common management operation such as fertilisers, application of mulch and manure, cut-and-carry fodder systems and rotation or confinement of the animals can also be employed.

As discussed in text, agroforestry systems provide an opportunity for modifying nutrient cycling through management, which results in more efficient use of soil nutrients whether added externally or made available through natural processes. For example, the trees may mine uptake of nutrients from deeper soil horizon and made available to associate crops through litter fall, and symbiotic nitrogen fixation can be enhanced through tree-species selection and admixture. Another major management tool is the possibility of reducing nutrient loss through soil conservation and to manage water resources in a watershed particularly through suitable agroforestry practices. For example, vegetative barriers (forage grasses and woody perennials) across the slope are quite effective in soil and water conservation on a sloping land. Trees also play the important role of biodrainage in waterlogged situations, and alley crops help in checking runoff on highlands in high-rainfall areas and maintaining crop residues on soil surface for retaining soil moisture.

Agroforestry not only assures the sustainable production but also helps in biodiversity conservation. In developing countries of Africa, for the requirements of fuelwood, fodder, timber and thatching material for ever-increasing population, the pressure on natural forests is immense leading to deforestation. The anticipated magnitude of species loss has drawn worldwide attention, fuelling attempts to rapidly assess and conserve biodiversity. The strategy to conserve biodiversity includes establishment of protected area network and corridors with emphasis on appropriate levels of management; reduction of anthropogenic pressure on natural population by cultivating them elsewhere (including in agroforestry systems); programmes of augmentation, reintroduction and introduction of target taxa; and in situ techniques such as establishing botanical and zoological gardens and banks of pollen, seed, tissue culture, DNA, etc. Agroforestry can play vital role in conserving biodiversity in the following ways: (1) relieving direct pressure on natural forests; (2) direct cultivating of rare species (e.g. rare medicinal plants) in agroforestry systems as crop; (3) number of species automatically will increase under agroforestry system (particularly in multi-tiered homegardens) as compared to sole agriculture; and (4) the microbial population will be manyfold richer under good moisture, better water-harvesting processes, application of mulch, litter and mulch degradation and introduction of leguminous N-fixing trees. Recently, studies have shown that greater plant species diversity leads to greater productivity in plant communities, higher nutrient retention in ecosystems and greater ecosystem stability. The functioning of terrestrial ecosystems depends on soil biodiversity as many of the plant interactions take place belowground. Microbial communities inhabiting soil mediate key processes that control system nutrient cycling.

As is evident from several studies discussed earlier in this paper, tree plantations and silvopastoral systems improve soil organic matter and availability of nutrients. The soil microbial biomass is a labile fraction of soil organic matter and plays a crucial role in maintenance of soil fertility and availability of plant nutrients. Addition of organic matter favoured rich micro-biodiversity of soil and nitrogen mineralisation in a silvopastoral system on degraded soil. The microbial biomass carbon increased due to increase in the carbon content in the soil-plant system. Nitrogen mineralisation rates were found greater in silvopastoral system compared to only grass system, and the soil organic matter was linearly related to microbial biomass carbon, soil N and nitrogen mineralisation rates. The role of key functional groups of soil fauna such as termites and earthworms has been analysed in nutrient cycling, organic matter decomposition and formation of soil structure in different types of ecosystems, and the belowground plant dynamics (including litter decomposition) regulate the composition and functional role of soil organisms. Plant diversity and litter quality regulate diversity of soil organisms, community dynamics and soil microbial biomass. Thus, agroforestry is a tool for sustainable production and biodiversity (including of microbial) conservation.

The rapid increase in atmospheric concentration of CO_2 and other greenhouse gases since the onset of the industrial revolution in 1850 is attributed to change in the soil and biotic C pool. Soils of the tropics, constituting a major part of the soil C pool, have contributed considerably to the anthropogenic increase in atmospheric CO_2 pool resulting to global warming. During the last two decades, mean temperature of African continent has risen more as compared to the global temperature. Results of several experiments have shown rapid decline in soil organic carbon (SOC) content when natural ecosystems in the tropics are converted to arable and pastoral land use (Lal 2000). In one experiment, SOC content of the surface horizon from 1.7 to 2.0% under native vegetation declined to 0.8–1.0% within 10 years of cultivation (Lal 1997). Restoration of degraded soils is an important strategy of increasing SOC content and sequestering C within the terrestrial ecosystems. Relevant soil restoration measures include those which facilitate establishment of any vegetative cover that adds a large quantity of biomass into the soil. These include establishing trees, growing cover crops and raising multi-storeyed homegardens. Establishment of woody perennials can lead to soil restoration and enhancement of SOC pool. The rate of C sequestration through restoration of degraded soils may range from 200 kg ha^{-1} $year^{-1}$ to 2500 kg ha^{-1} $year^{-1}$ depending on the management and the potential of pool depletion (Lal 2000). In one study, it was found that under *Acacia nilotica*- and *Populus deltoides*-based agroforestry systems, the SOC contents were 48% higher than sole crop cultivation. Afforestation and agroforestry have tremendous potential for C sequestration not only in aboveground C biomass but also in root C biomass in deeper soil depths. Reforestation of about 19 million ha of most degraded lands with suitable trees and grasses/crops may sequester about 1 Pg C (Dagar and Swarup 2003). Thus, well-managed agroforestry systems particularly on degraded lands have tremendous potential of C sequestration in dry regions.

3.6.2 Policy Issues

Soil fertility depletion in smallholders' farms is one of the fundamental causes of declining per capita food production in Africa, and it has implications for food insecurity in many parts of the continent. Past efforts focused primarily on promoting wide-scale use of subsidised mineral fertilisers in southern Africa, but the increased cost of fertilisers has dramatically reduced the use of fertilisers. Planted tree fallows (improved fallows) have demonstrated great biophysical potential for improving soil fertility on smallholder's farms, but efforts to scale up their adoption to more farming households are constrained by lack of permanent ownership rights over land, incidences of bush fires and browsing of tree biomass by livestock. To resolve these institutional bottlenecks, some traditional authorities in Zambia enacted bylaws to prohibit these incursions. Ajayi and Kwesiga (2003) and Ajayi et al. (2003) conducted studies on implications of local policies and institutions on the adoption of improved fallows and indicated that the effectiveness of bylaws is influenced by many factors such as ambiguous interpretation of the bylaws, relying exclusively on moral persuasion to enforce the bylaws, lack of well-defined responsibilities and conflict of economic interest among different stakeholders within the communities. The patterns of distribution of benefits of an agricultural technology among various sectors of a community may be important factor that affects widespread adoption of a technology. They also stated that the policy dialogue among community members, increased awareness and diversification of options appear to be the way forward to improve the effectiveness of the bylaws. The farmers must be educated about diversification of agricultural options. For example, for increasing soil fertility, one should avoid the species palatable to animals, and livestock farmers should be encouraged to plant fodder species to feed their animals, thereby reducing the competition for improved fallow species during the dry season. The diversification options also include the use of live fences that not only prevent animals from intruding but also provide extra fruit or income to farmers. Madhura et al. (2003) while studying the potential for adoption of *Sesbania sesban*-improved fallows in Zimbabwe concluded that households with larger farm sizes with more family members working full time on farm and having draft power and access to cattle manure were in better position to adopt the technology.

In southern Africa, fruit from many indigenous fruit trees like marula (*Sclerocarya birrea*), *Uapaca kirkiana*, *Parinari curatellifolia* and *Strychnos cocculoides* are collected for household consumption and to generate income. Attempts are being made for their domestication, but the technologies for their propagation at large scale have not fully developed. This should be given priority in all national policies. A number of technical areas still require scientific investigations. Research must be directed to provide the information needed to develop strategies to respond to the projected trends in demand and opportunities for agroforestry in Africa. The following strategies and opportunities have been discussed by Kwesiga et al. (2003) and Akinnifesi et al. (2008b) for success of agroforestry in Africa:

1. Improving marketing and processing of agroforestry products in demand for urban and rural markets.
2. Diversification of agroforestry products and by-products such as high-values trees, indigenous and exotic fruit trees, medicinal plants, fodder for livestock and organic vegetable production. This will help small producers to develop their own processing and marketing channels (cottage industries).
3. Development and promotion of substitutes and supplements for costly imported inputs like inorganic fertilisers (e.g. growing protein-rich folders and nitrogen-fixing trees).
4. Options for mitigating the continuous degradation of the environment and loss of biodiversity (e.g. C sequestration through afforestation and agroforestry options).
5. International issues like mitigating global warming.
6. Development and implementation of strategies for large-scale dissemination of agroforestry technologies at the local level.
7. Training and capacity building in agroforestry among all major stakeholders.
8. Co-operation and partnerships with a broad range of actors.

Besides the above strategies and opportunities, the following points may also be added:

9. Legislation for stopping intentional and non-intentional burning of forests. For example, in the Kwango region (Namibia), community people have a notion that better thatch grass will be regenerated after burning of the old, and in the process, they burn the forest. In such instances, the forest guards should be strengthened and empowered through meaningful legislation.
10. Research efforts should be enhanced to domesticate the indigenous forest trees on degraded and bare lands and on pasturelands so that the pressure on natural forests may be reduced. For fuelwood and fodder, block plantations/fodder banks of suitable species may be raised on degraded lands.
11. Pasture should be improved by seeding with legumes during rainy season, and leguminous trees should be preferred for introduction on fallow lands.
12. Research gaps should be identified, and more research projects should be sanctioned to develop techniques of tree propagation and improvement. Indigenous fruit tree improvement programme should be further strengthened.
13. Fruit transformation training should be extended to rural women so that they can increase the income of their household.
14. Women would be made equal partners in decision-making policies.
15. Strengthening of extension programme so that the techniques developed should reach to the needy poor farmers.

16. Promotion of African/regional co-operation through technology and germplasm exchange, study tours and field visits, demonstrations of on-farm research, information exchange, trade and marketing of agroforestry products.
17. Financial supports form international organisations like the FAO and World Bank to generate technologies in the fields of indigenous fruit transformation, nutrition analysis of potential fruits and income generation potential of indigenous fruit, medicinal, fodder and timber species and their genetic improvement.

There are some constraints to wider adoption of agroforestry techniques in African countries, which need to be addressed by the planners, politicians, researchers and extension workers. Some of the constraints and issues are briefed here:

1. One intrinsic change lies in the long-term nature of the benefits to be derived from most agroforestry practices. Similar experience is found with most natural resource management practices. Farmer must be able to withstand initial years of low or negative profitability in order to reap longer-term economic profits. Access to credit, reliable tree seed supply and improved access to agricultural markets offering adequate prices would minimise this constraint (Kwesiga et al. 2003).
2. Another significant source of limitation is institutional—It lies with national agricultural extension services, which need to be greatly strengthened by offering more education and training to their personnel and resources.
3. Easy access to natural resources (forests) is another interesting issue. Most of the community people have access to thatching grasses, fruits and other forest produces; therefore, they do not take pains for domestication of indigenous fruit trees on their own farm. They must be educated and trained in the field of domestication and fruit transformation so that habit of income generation through fruit products on their own farm is inculcated in them.
4. Lack of improved germplasm—Very little efforts have been made in genetic improvement of indigenous fruit tree species and techniques of tissue culture, and tree improvement should get the priority so that plenty of good quality of germplasm may be available for propagation of preferred tree species.
5. Some second-generation issues are emerging such as growing incidences of pest and disease, water requirement for crops and fruit trees, reduced investment in agricultural sector, lack of availability of fertilisers and pesticides due to their cost and related policy shifts such as removal of agricultural subsidies (Kwesiga et al. 2003).
6. Poor infrastructure of marketing.
7. Traditional ways of processing of fruit products—Most of the farmers (mainly women) process their fruit products like extraction of juice and making of alcoholic drinks in their traditional way. They need extensive training in fruit transformation so that they can prepare commercial juice and jam. They must be made partners in commercial exploitation such as preparation of alcoholic drinks from wild fruits and nuts.

8. Capacity building—People need training at all levels (planners, foresters, extension workers, researchers and community people) for economic feasibility of agroforestry products.
9. Institutional and international collaborations—At times, one institute is not familiar about the work carried out in another. At national and regional levels, there must be inter-institutional collaboration particularly in processing and value-addition aspects. If need be, international collaborations are also needed to get knowledge and training in different fields especially in food-processing aspects.

Recognising the lessons learned that there are four critical conditions that encourage agroforestry, it should be beneficial to farmers and other land users, there must be security of land tenure, intersectoral coordination is essential and good governance of natural resources is crucial, FAO (2013) concluded that the guidelines provide ten tracks for policy action:

1. Spread the word—Raise awareness of the benefits of agroforestry systems to both individual farmers and global society.
2. Revise the context—Appraise and reform unfavourable regulations and legal restrictions.
3. Secure the land—Clarify land use policy goals and regulations.
4. Create a new approach—Elaborate new agricultural policies that take into account the role of trees in rural development.
5. Organise and synergise—Organise intersectoral coordination for better policy coherence and synergies.
6. Provide incentives—Create a clear context for payments for environmental services.
7. Develop markets—Strengthen farmers' access to markets for tree products.
8. Communicate the know-how—Enhance stakeholder information.
9. Include the stakeholder—Formulate or strengthen policy based on local people's needs and rights.
10. Govern wisely—Engage in good governance of rural activities.

It is expected that the actions outlined above will contribute to the formulation of coherent, interactive and proactive public policies that support the development of appropriate agroforestry systems in Africa.

3.7 Conclusions

Due to fast-growing population, many regions in tropical Africa are presently facing shortage of food, fodder and fuelwood. Deforestation, declining soil fertility and soil erosion are the crucial indicators of land degradation. Most of the dry regions experience food shortage due to low crop yields in the nutrient-depleted soils. There lies problem of cattle health due to scarcity of fodder especially during the dry season. Due to increase in cost of inputs, smalholders are not in a position to afford the application of fertilisers in their crop fields. Continuous cultivation has inevitably replaced shifting cultivation and the bush fallow systems, which were traditionally practised to rebuild soil fertility in the savanna of eastern and southern Africa.

In the area of soil fertility management, the focus must be on growing woody perennials in situ or on the transfer of biomass from one part of the farm to another. Improved fallow systems as alternatives to the traditional fallow practices have been developed using either coppicing tree species (e.g. *Gliricidia sepium*) which are grown in permanent association with crops or non-coppicing species (e.g. *Sesbania sesban*, *Tephrosia* species), which are grown in rotation with crops. Growing fertiliser trees in association with crops, particularly in rain-fed ecologies, has helped in increasing crop yield significantly, improving the soil and conserving soil moisture. In recent times, much emphasis has been placed on domestication of indigenous fruit trees and their value addition, and significant progress has been made in identification, raising nursery and plantations, processing, value addition and marketing of suitable fruit trees.

In the humid and subhumid areas of West Africa, alley cropping has been found ideal for sustainable production of crops and soil and moisture conservation. Other agroforestry options include domestication and processing of indigenous fruits to enhance family nutrition and income and fodder banks for supplementary feeding of dairy cattle. Low income at initial stage, resource management know-how, institutional limitations, lack of training of different stakeholders, irrational access to natural resources, casual approach to domestication programmes, lack of improved germplasm and technology like tissue culture for multiplication of germplasm, lack of irrigation facilities, poor infrastructure of marketing, removal of agricultural subsides, traditional ways of processing of fruit products and non-implementation of forest legislation are some constraints and issues of agroforestry adaptation. In addition, a number of technical areas still require scientific investigations. The widespread adoption of agroforestry technologies, supported by continued participatory research and dissemination, has the potential to achieve the goals of poverty alleviation, food security and environmental protection including C sequestration in wider regions of Africa. In the scenario of climate change, agroforestry-based smart agriculture is the most suitable option for sustaining yield, improving soil and mitigating climate change.

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