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Contributions of Agroforestry Research and Development to Livelihood of Smallholder Farmers in Southern Africa: 2. Fruit, Medicinal, Fuelwood and Fodder Tree Systems

[1]F.K. Akinnifesi, [1]G. Sileshi, [1]O.C. Ajayi, [2]P.W. Chirwa, [3]F.R. Kwesiga and [4]R. Harawa
[1]World Agroforestry Center, Chitedze Agricultural Research Station, P.O. Box 30798, Lilongwe, Malawi
[2]Stellenbosch University, Private Bag X1, 7602 Matieland, South Africa
[3]Département Agriculture et Agro-Industrie (OSAN), Banque Africaine De Developement, Agence de Relocalisation Temporaire BP 323, 1002 Tunis Belvedere, Tunisie
[4]UNDP Millennium Villages Project, P.O. Box 841, Zomba, Malawi

Abstract: Integration of trees on farms provides opportunities for improving diversification and range of livelihood portfolios for smallholder farming households in southern Africa. This study synthesizes 2 decades of research and development on agroforestry interventions in southern Africa. In addition to important horticultural fruits such as mangoes and citrus, indigenous fruit trees such as *Uapaca kirkiana*, *Ziziphus mauritiana*, *Adansonia digitata* and *Sclerocarya birrea* are widely preferred by farmers and traded in the southern Africa region. Domestication of these fruit tree species has advanced and superior clones with multiple-traits have been identified, tested and disseminated to farmers. Through application of vegetative propagation techniques, the time taken for fruiting of these miombo species has been reduced substantially. More than 12.000 farmers have been trained in nursery establishment and over 6000 farmers are involved in on-farm testing of indigenous fruit trees in the field and homesteads in the five countries. The introduction of fast-growing legumes on farms has improved production of fuel wood, fodder, timber and other products and services. In Tanzania alone, over 27.500 farmers have planted fodder trees in the last 6 years. Financial analysis carried out on fodder, rotational woodlots and fruit trees indicated that these agroforestry enterprises were profitable and exhibited positive financial ratios. The provision of quality germplasm, awareness creation and training, in addition to policy interventions are critical considerations for widespread adoption of these technological options.

Key words: High-value trees, homegardens, livestock, miombo woodland

INTRODUCTION

Southern African countries are faced with challenges of increasing deforestation and degradation of natural resources. The rapid increase in population has led to heavy deforestation to meet the requirements of fuel wood, building materials and clearing for agricultural land (Geist, 1999). As a result of the dwindling access to forest products, an increasingly higher proportion of households are finding it necessary to explore options to plant trees for supplying household requirements. Indigenous and exotic tree species that provide various products and services are either planted in homegardens, orchards, woodlots or managed on crop lands.

The homegarden is a traditional agroforestry system involving various tree species and sub-subsistence crops, sometimes combined with cash crops cultivated around homesteads (Kang and Akinnifesi, 2000). Homegardens are low-input systems that are ecologically adapted and planted with complementary species, shade tolerant herbs, shrubs and trees of varying canopies sometimes growing to heights above 20 m (Kang and Akinnifesi, 2000).

A well known example is the *Chagga* homegarden system in northern Tanzania (Fernandes *et al.*, 1984). Chagga grow numerous species of trees and shrubs in home gardens, most of which are forest species (Hemp, 2006). The system is characterized by their multilayered vegetation structure which is similar to a tropical montane forest with trees, shrubs, lianas, epiphytes and herbs (Fernandes *et al.*, 1984). Vertically, several distinct zones can be distinguished in the home gardens. In terms of canopy depth, the lowest zone (0-1 m) consists of food crops like

Corresponding Author: F.K. Akinnifesi, World Agroforestry Center, Chitedze Agricultural Research Station, P.O. Box 30798, Lilongwe, Malawi

taro, beans and fodder herbs and grasses. Included in this zone is the regeneration of the overstorey trees and shrubs. The next zone (1-2.5 m) is mainly coffee, with a few young trees, shrubs and medicinal plants. Next is the banana canopy (2.5-5 m) with some fruit and fodder trees. Above the banana layer, vertical zonation is less distinct with a diffuse zone (5-20 m) of the preferred fuel and fodder species and another zone (15-30 m+) of the valuable timber trees and other fodder and fuelwood species (Fernandes *et al*., 1984). The majority of the plant species serves as food for household and agricultural purposes, for medical applications, as drugs and for magic purposes (Hemp, 1999). Fuelwood production in these home gardens is estimated at 1-2 m^3/year (1.5-3 m^3/ha/year). Assuming a minimum consumption of 1 m^3 per adult/year and if each family requires 4-6 m^3/year, a home garden supplies 25-33% of the household fuelwood requirements (Fernandes *et al*., 1984). Although the Chagga homegarden has been a stable system, it has recently come under pressure from rapid population growth, diminishing land resources and changes in dietary habits (Fernandes *et al*., 1984; Hemp, 2006).

For centuries farmers have also retained a low density of trees in parklands, especially in the semi-arid areas in order to improve the yield of understorey crops (Kang and Akinnifesi, 2000). In southern Africa, traditionally farmers grow crops under scattered trees of different species including fruit trees such as baobab (*Adansonia digitata* L (Bombacaceae)) and mango (*Mangifera indica* Blume (Anacardiaceae)). Farmers also selectively retain wild fruit trees when clearing the land for agriculture (Campbell, 1987; Packham, 1993). For example, in southern Tanzania, farmers whilst converting woodland to farmland have spared fruit trees such as *Uapaca kirkiana* Muell Arg (Euphorbiaceae) and *Parinari curatellifolia* Planch ex Benth (Chrysobalanaceae). Over time these have become, along with introduced mango, the only trees left in an otherwise intensively cultivated area (Knight, 1974). A survey conducted in Tanzania shows that indigenous fruit trees are found on 71% of farmers' fields (Ramadhani *et al*., 1998).

The mango-maize system known as 'mango-savanna' is common in Malawi, Zambia and Zimbabwe (Musvoto and Campbell, 1995). Baobab is particularly an important tree for its pods and leaves as sources of food, fodder, oil and firewood. Substantial benefits are realized from these practices as resource-use by trees and associated crop components rarely overlap (Weil and Mughogho, 1993). Shackleton (2004) reported that 30% of households have planted *Sclerocarya birrea* Hochst (Anacardiaceae) in their homesteads in Bushbuckridge, South Africa. Similarly in Mozambique *S. birrea* is reported to make up bulk of trees left standing on the farms (Mangu, 1999). Traditional communities use *S. birrea* fruits to produce alcoholic beverages and the bark extract for the treatment of diseases such as malaria, dysentery, diarrhoea and rheumatism. The value *S. birrea* in religious and spiritual ceremonies is also widely documented. In some communities in Mozambique, *S. birrea* is considered as a sacred tree and it is never cut when clearing forests. If the traditional values given by local communities could be appropriately placed in the context of *in-situ* conservation, important results would be achieved. *S. birrea* is planted for commercial utilization and export quality liquor is produced in Botswana and South Africa. Trees species that fix nitrogen such as *Faidherbia albida* A Chev (Fabaceae) are also tended on farmland to improve soil fertility, supply fuelwood and browse for animals.

The widespread clearing of the miombo endangers the wealth of the plant genetic resources it contains and the lives of the people who depend on it. Introduction and management of tree species into the farming system is now recognised as a strategy for *ex-situ* conservation and utilisation of valuable plant species. Increasing demand for products and services has also warranted a re-introduction of trees and shrubs into existing croplands and grazing areas and their systematic management to obtain fuelwood, fodder, poles and timber and to address land degradation problems (Otsyina *et al*., 2004; Ramadhani *et al*., 2002).

Past research and extension efforts have been biased towards cultivation of the exotic species and neglected indigenous. This is probable because indigenous species have not been subjected to positive agricultural or forestry policy (Campbell, 1987). Agroforestry has been recognized as one of the strategies to introduce indigenous and exotic trees into cropping systems and impact on livelihoods of smallholder farmers in sub-Saharan Africa (Garrity, 2004; Kwesiga *et al*., 2003). For about two decades, the World Agroforestry Centre (ICRAF) and its partner institutions have been spearheading research and development activities on tree portfolios for production of edible fruits, fodder, timber, fuel wood and other products and services. Notable is ICRAF's indigenous tree domestication program in southern Africa, which has made significant strides in the research and development on miombo fruits.

The objective of this review is to: synthesize achievement in research and development of agroforestry practices aimed at providing fruits, medicines, fuel wood, timber and fodder for improving the livelihood of households in southern Africa and identify knowledge gaps and research needs. Such reviews are especially important as they will facilitate information flow and improved understanding for scaling up decisions on proven technologies.

AGROFORESTRY FOR PRODUCTION OF FRUITS AND MEDICINALS

The crop production capacity in the region is being pushed to its limit, resulting in over-cultivation of fragile soils and loss of soil quality. Periodic droughts aggravate the situation, but even in years of favourable rainfall, most farm families cannot produce enough food to feed themselves. Three major prospects remain untapped in the region: the opportunity for growing exotic and adapted fruit trees for home consumption and market, the potential to cultivate and improve indigenous fruit trees and the unexplored potential of medicinal trees in the region to address the rampant health problems. In the following sections we will briefly highlight some research efforts towards realization of these opportunities.

Fruit trees: Indigenous fruits from the miombo woodlands are central to the livelihoods of both rural and urban dwellers in Southern Africa, especially during periods of famine and food scarcity (Campbell, 1987; Campbell *et al.*, 1997; Mithofer and Waibel, 2003; Mithofer *et al.*, 2006). The Miombo woodlands contain over 200 tree species that bear edible fruits (Malembo *et al.*, 1998; Ham *et al.*, 2005). The fruits of many miombo trees are rich in minerals and vitamins, sold for cash income and constitute important food sources during famines and/or emergencies (Kwesiga *et al.*, 2000; Saka *et al.*, 2006; Mithofer *et al.*, 2006). Since indigenous fruit trees bear fruits in different seasons and even in drought years (Mateke *et al.*, 1995; Kwesiga and Mwanza, 1995), they are an important part of the diet.

Some species such as *S. birrea* and *Strychnos* sp. (Loganiaceae) form a staple food during the hunger periods in the agricultural cycle (Mangu, 1999). For instance, over 70% of the people in southern Africa eat *S. birrea* fruit, which is a seasonal staple in local diets. The pulp contains 4-8 times as much vitamin C per unit volume compared with orange juice. It is argued that without this valuable contribution many children who are most vulnerable and the chief consumers would be affected by dietary deficiencies (Makombe, 1993). Indigenous fruits have also shown to contribute about 42% of the natural food basket in southern Africa (Campbell *et al.*, 1997). In a survey conducted in Malawi, Zambia and Mozambique show that 60-85% of the households lacked food during critical hunger period of the year (Akinnifesi *et al.*, 2004; 2006). Between 26 and 50% of the households surveyed confirmed to have reduced vulnerability by collecting fruits from the miombo woodlands (Akinnifesi *et al.*, 2006). The return from collecting fruits in Zimbabwe was two to four times higher than returns from regular farming (Mithofer *et al.*, 2006).

An impact analysis of whole farm in Zimbabwe also showed that indigenous fruit collection, consumption and sale reduce income poverty by 33% (Mithofer *et al.*, 2006). A simulation of income flow of household portfolios using indigenous fruits indicates that the benefits from selling fruits come at critical time when income is generally low and provide nutrition and food when agricultural labour demands are high (Mithofer and Waibel, 2003; Mithofer *et al.*, 2006). Even if fruits are available in the wild, the improvement of IFTs is important because this will create an incentive to their cultivation by farmers (Mithofer and Waibel, 2003).

Efforts have been made to domesticate and improve indigenous fruit trees in southern Africa. The approach used involved 4 basic steps:

- Identification of priority species by farming communities and other users,

Table 1: Consumer preferences in Malawi and Zimbabwe

Site	Market survey Southern Malawi (n=315)†		Market survey central region (n = na)		Household survey Malawi (n=223) ††		Market survey Zimbabwe (n=)‡	
Rank	*Species*	*Weighted score*†	*Species*	*Weighted score*	*Species*	*Weighted score*	*Species*	*Weighted Score*
1	*Mangifera indica*	*734*	*Citrus sinensis*	*279*	*Mangifera indica*	*678*	*Malus domestica*	*661*
2	*Citrus sinensis*	*656*	*Mangifera indica*	*177*	*Persea americana*	*472*	*Citrus sinensis*	*626*
3	*Malus domestica*	*548*	*Psidium guajava*	*136*	*Citrus sinensis*	*291*	*Uapaca kirkiana*	*537*
4	*Uapaca kirkiana*	*424*	*Musa parasidiaca*	*116*	*Uapaca kirkiana*	*269*	*Mangifera indica*	*531*
5	*Ziziphus mauritiana*	*288*	*Carica papaya*	*115*	*Carica papaya*	*234*	*Ziziphus mauritiana*	*377*
6	*Adansonia digitata*	*281*	*Citrus reticulata*	*105*	*Musa parasidiaca*	*199*	*Azanza garckeana*	*337*
7	*Azanza garckeana*	*220*	*Citrus limon*	*73*	*Psidium guajava*	*198*	*Adansonia digitata*	*278*
8	*Strychnos cocculoides*	*178*	*Uapaca kirkiana*	*51*	*Casmiroa edules*	*198*	*Strychnos cocculoides*	*242*
9	-	-	*Persea americana*	*47*	*Citrus reticulata*	*164*	-	-
10	-	-	*Strychnos cocculoides*	*41*	*Ziziphus mauritiana*	*158*	-	-

†Adapted and recalculated from Mmangisa (2006); ††Mhango and Akinnifesi (unpublished data, 2002); ‡Adapted and recalculated from Ramadhani (2002)

- Participatory selection of "plus" trees and naming them *in situ*.
- Propagation and cultivation of selected trees in fruit orchards.
- Dissemination and adoption. The achievements through the 4 steps have been recently documented by Akinnifesi *et al.* (2006).

Initially, ethno-botanical surveys were carried out in Malawi, Tanzania, Zambia, Zimbabwe and Mozambique (Kwesiga *et al*., 2000). The surveys were aimed at characterizing indigenous multipurpose trees and shrubs with respect to their establishment and management, market opportunities and uses and functions in farmer fields. Systematic region-wide priority setting exercises were also undertaken and *U. kirkiana*, *Strychnos cocculoides* Backer (Loganiaceae), *P. curatellifolia* and *S. birrea* were identified as the regional priority fruit tree species. In addition to these species, country-specific species were also identified. Among the country-specific additions are *Azanza garkeana* Exell and Hillc (Malvaceae) and *Flacourtia indica* Merr (Flacourtiaceae) for Malawi, *Vitex* sp. (Verbenaceae) and *Tamarindus indica* L (Fabaceae) for Tanzania, *Anisophyllea boehmii* Engl (Rhizophoraceae) for Zambia and *A. garkeana* and *Ziziphus* spp (Rhamnaceae) for Zimbabwe (Kadzere *et al*., 1998). Recently updated species priority surveys in Malawi and Zimbabwe indicate dynamics in consumer preferences for both exotic and indigenous fruits (Table 1).

Several follow-up surveys conducted in each country confirmed that indigenous fruit trees are an important resource to rural communities. These fruits are available mainly during the rainy season when crops are not yet ready for harvest and hence contribute significantly to the diets of the rural people. Studies also show that farmers generally do not deliberately plant indigenous fruit trees for the following reasons: Lack of planting materials, lack of knowledge on propagation, nursery and tree husbandry, uncertain markets and low price, unknown nutritional values and the belief that they are abundant in the forests. Farmers' major concerns are the need for improvement of the precocity and fruit quality attributes such as variation in fruit sizes, sweetness for tree like *S. cocculoides* and tree size for most priority species. The survey results also showed that most of the fruits are consumed raw. That means very little processing is done at household level.

Germplasm of various species was collected from Botswana, Malawi, Mozambique, Namibia, Swaziland, Tanzania, Zambia and Zimbabwe in October 1995. More than 10 tones of fruit of various species were collected during the exercise. This facilitated the exchange of 24 provenances of *U. kirkiana* and 40 provenances of *S. birrea* among these eight countries in 1996 (Akinnifesi *et al*., 2004). The trees were established in provenance trials and in the arboretum at Makoka in Malawi. Some of the species have started to produce fruits after 7-10 years of establishment.

Table 2: Relative tree growth and indicative fruiting of Uapaca kirkiana trees at Makoka orchard from grafted, marcotted and seedling stocks, at four years after establishment (Akinnifesi, unpublished data)

Parameter stock	Marcotted	Grafted	Seedling
Tree height (m)	2.4±0.11	2.0±0.13	2.7±0.14
Bole height (m)	0.39±0.04	0.35±0.04	0.46±0.64
Root collar diameter (cm)	8.50±0.32	9.14±0.35	10.3±0.36
Crown depth (m)	2.0±0.13	0.35±0.04	2.4±0.76
Crown spread (m)	2.7±0.14	2.3±0.13	2.4±0.16
Number of primary branch	17.2±1.33	15.8±0.95	15.3±2.
Number of secondary	25.0±2.6	19.9±2.6	15.3±2.
Number of tertiary	15.0±2.97	10.3±2.91	5.6±1.32
Minimum number of fruits	2.	3.	0
Maximum number of fruits	414	127	0
Mean number of fruits	78	52.	0

After superior individual tree were identified from natural stands, using participatory approaches (Akinnifesi *et al*., 2006), vegetative propagation was initiated and to release genotypes with desirable qualities. Vegetative propagation allowed the domesticator to rapidly multiply, test, select from and use the large genetic diversity in wild tree species. It is now evident that the miombo species are amenable to grafting and to some extent air-layering. A significant improvement in graft take of over 70% has been recorded for most species including *U. kirkiana*, *A. digitata*, *Vanguaria infausta* Burch (Rubiaceae), *S. birrea*, *Ziziphus mauritiana* Lamk (Rhamnaceae). This compared favourably with graft intake in exotic species, such as mango, which attain over 90% intake (Akinnifesi *et al*., 2006). Both grafting and air-layering set during November-December gave the best results.

Precocity in these species also compared well with mangoes when grafted. Table 2 shows tree growth and fruiting of *U. kirkiana* trees established from seedling, grafted stock and airlayering in the orchard at Makoka in Malawi. Tree established from grafted stock fruited within 2-3 years after establishment, but seedling stock did not fruit, even after five years. In adjacent provenance trials, trees raised from seedling have not fruited after 10 years (Akinnifesi *et al*., 2004, 2006). Similarly, at Veld products research in Botswana, it has been shown that grafting can reduce the precocity of *S. birrea* from eight to 10 years in the wild to 4 to 5 years in grafted plants (Taylor *et al*., 1996). A *U. kirkiana* clonal orchard at Makoka also fruited at two years after establishment, but fruiting only becomes stable in the third year. Research now explores tissue culture techniques to detect the problem of early incompatibility between rootstock and scion and for developing mass-multiplication protocols (Mng'omba *et al*., 2007).

Currently over 6000 farmers in the four countries are involved in on-farm testing of indigenous fruit trees in the field and homesteads. In southern Malawi, 70% of farmers are willing to pay for seedlings (Akinnifesi *et al*., 2006). More than 12,000 farmers were trained in nursery establishment and at least 5000 individual farmers are managing their own nurseries in five countries.

In partnership with various institutions, ICRAF has developed strategies for product development and commercialization of indigenous fruits. Feasibility assessments on fruit enterprises conducted in Malawi, Zambia, Zimbabwe and Tanzania showed a profit margin of 15-28% and provided women groups with a 40% of the market share and an average internal rate of return of 34% (Joardaan *et al*., 2007).

Medicinal plants: It has been estimated that more than 80% of the rural dwellers in sub-Saharan Africa depend on medicinal plants for most of their health needs (Garrity, 2004). The market in raw materials for medicinal or therapeutic plants and products in southern Africa is estimated at USD 150 million per year. Between 5 and 10 tonnes are exported annually and 50 to 100 thousand tonnes are consumed locally (Diederichs, 2006). The informal trade of medicinal plants and products in southern Africa is dominated by about four to five hundred thousand traditional healers that dispense medicines and herbal remedies to up to 100 million consumers (Diederichs, 2006; Mander and Breton, 2006). The market consists of two generalised systems:

- A primarily informal market system focusing exclusively on traditional medicines and herbs and
- A more formal market system that includes herbal remedies, phytomedicines and cosmetics.

A study conducted at three major markets in southern and central Malawi on the use, availability, supply and demand appraisal of medicinal plants (Thangatha, 2004) shows that of the 490 medicinal herb products sold, 66% were harvested directly by healers and 33% bought by them from other harvesters. *Prunus africana* Kalkm (Rosaceae), a medicinal tree native to Africa is widely harvested in Central Africa and also becoming important in southern Africa. Because of unsustainable harvesting methods and economic pressures, *P. africana* is now threatened (Cunningham *et al*., 2002). The pharmaceutical products derived from *P. africana* are now worth more than $220 million annually and commercial harvesting of over 4000 metric tonnes of bark has been reported recently and will likely increase to 12,000 metric tonnes per annum (Simons and Leakey, 2004). A kilogram of *P. africana* seeds fetches $25 providing avenues for rural income generation. Germplasm collection and testing had been initiated in Tanzania (Swai, unpublished) while tree propagation and cultivation of medicinal trees, especially *P. Africana* has been reported in Cameroon (Cunningham *et al*., 2002).

ICRAF's research on medicinal trees in Africa dates back to the early 1990s, starting from ethnobotanical surveys in Malawi, Zambia and Tanzania (Kwesiga *et al*., 2000). Over 300 tree species were reported as used for treatment of more than 100 human diseases. In Tanzania, Dery *et al*. (1999) identified the following top ten priority species: *Securidaca longependunculata* Fresen (Polygalaceae), *Zanha africana* (Sapindaceae), *Senna abbreviate* (Caesalpinoides), *Entada abyssinica* Steud (Mimosoidae), *Turaea fischeri (Meliaceae), Albizia anthelmintica* Brongn (Mimosoidae), *Entandrophragma bussei* (Meliaceae), *Combretum seyheri* (Combretaceae), *Zanthoxylum chalybeum* Engl (Rutaceae) and *Terminalia sericea* Burch ex DC (Combretaceae). Further reviews by the same authors have indicated that these species are widely used in southern Africa. Similarly, many of the 20 top priority indigenous fruit trees identified in southern Africa also have medicinal uses (Maghembe *et al*., 1998).

The National Herbarium of Malawi has identified *Pterocarpus angolensis* DC (Fabaceae), *Erythrophleum suaveolensis* Brenan (Fabaceae) and *Psorospermum febrifugum* (Cluceaceae) as the most used medicinal tree species in Malawi (Nyirenda, unpublished report). *Warburgia salutaris* Chiov (Canellaceae) is known for its antibacterial and antifungal medicinal properties, for curing several diseases (Simons, unpublished). Local communities have exploited the leaves for treating several ailments, such as constipation, toothache, cold and cough, fever, pains, measles and malaria.

Germplasm collection and testing of some of these species had been initiated in Tanzania (Swai, unpublished) while tree propagation and cultivation of medicinal trees, especially *P. Africana* has been reported in Cameroon (Cunningham *et al*., 2002). As the rate of growth for most of the species is slow, a deliberate domestication policy should be promoted especially for the most important species as has been the case in South Africa (Crouch and Symonds, 2006; Diederichs, 2006).

AGROFORESTRY FOR FUEL WOOD PRODUCTION

Trees grown in rotational woodlots, contour strips, fallows or scattered on crop land can produce large

Table 3: Potential annual harvestable fuel produced by trees planted in 1oodlots, coppicing fallows and non-coppicing fallows

Country	Site	Tree species	Tree age (years)	Quantity (t ha/Yra)	References
Tanzania	Mganga	*Acacia crassicarpa*	5	22.4	Otsyina,1999
	Kiwango	*Acacia crassicarpa*	4	24.0	Otsyina, 1999
	Dotto	*Acacia crassicarpa*	4	19.5	Otsyina, 1999
	Sanania	*Acacia crassicarpa*	4	21.0	Otsyina, 1999
	Shinyanga	*Acacia nilotica*	7	1.20	Nyadzi *et al.*, 2003
	Shinyanga	*Acacia polycantha*	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	9.70	Ngugi, 2002
	Chipata	*Sesbania sesban*	3	8.00	Ngugi, 2002
	Chipata	*Gliricidia sepium*	3	7.00	Ngugi, 2002

quantities of fuel wood. Woodlots are one of the promising agroforestry options that can be used to address the problems of deforestation and shortage of wood energy in southern Africa. 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).

Since 1990s, an improved agroforestry practice known as the rotational woodlot has been developed. Its primary purpose is to increase fuel wood production, but as a secondary benefit, it also doubles as a soil fertility improvement strategy (Kwesiga *et al.*, 2003). The rotational woodlot involves growing of trees and crops in three phases:

- An initial tree establishment phase in which trees are intercropped with annual food crop(s), usually maize;
- A tree fallow phase in which cropping is discontinued because of canopy closure and increased shading;
- A cropping phase after felling the trees and harvest of wood (Ramadhani, 2002; 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. Trees benefit from land preparation and weed management primarily for the annual crops. During the two to three years of fallow phase, the trees could be managed as the traditional '*ngitili* system' in Tanzania where designated areas are enclosed for natural regeneration of vegetation for livestock sustenance (Otsyina *et al.*, 2004) or as fodder banks (Nyadzi *et al.*, 2003). In the third phase, after harvesting trees, crops can be grown between tree stumps to exploit accumulated nutrients in the litter fall, leaves and branches. The coppiced shoots may be pruned to reduced competition during this second cropping phase and incorporated in the soil or taken out as fodder. However, the coppiced shoots may be allowed to grow for another cycle of the tree fallow phase (Nyadzi *et al.*, 2003).

Suitable trees species have been screened for this system and those identified as suitable for the miombo eco-zone of southern Africa include: *Acacia crassicarpa* A Cunn ex Benth, *Acacia leptocarpa* A Cunn ex Benth, *Acacia auriculiformis* A Cunn ex Benth and *Acacia julifera* Benth (Fabaceae). Some of these species can provide substantial amounts of fuelwood. In Shinyanga, Tanzania, four-year old *Acacia polyacantha* Wild and *Leucaena leucocephala* De Wit (Fabaceae) woodlots yielded 71 to 81 t/ha of wood (Banzi *et al.*, 2004). On-farm assessments in Tabora, Tanzania estimate that *A. crassicarpa* woodlots produced high quantity of fuelwood ranging between 77 t/ha within seven years (Nyadzi *et al.*, 2003) and 100 tha within 6 years (Ramadhani *et al.*, 2002). These amounts of wood yields are enough to meet the fuelwood consumption of one 8-member family for 12-15 years, at 2 kg per person per day (Nyadzi *et al.*, 2003). Studies from Tanzania (Huang *et al.*, 2002; Ramadhani *et al.*, 2002) suggest that pressures on the natural forests and woodlands can be reduced through using fast-growing trees in rotational woodlots. The wood quality in terms of storage and calorific values need further assessments.

Farmers use the fuelwood from rotational woodlots to cure tobacco instead of wood from the forests which is usually bought, thereby making savings. Ramadhani *et al.* (2002) estimated that 8,500 ha of forest lands will be saved in Tabora region of Tanzania alone every year, if all tobacco farmers adopted rotational woodlots. In addition, farmers benefit from rotational woodlots through increased crop yields. Identifying species with high N-fixation, fast growth, coppicing ability and high water use efficiency is crucial for the performance and extent of benefits that farmers get from woodlots (Table 3).

AGROFORESTRY FOR FODDER PRODUCTION

Improving livestock productivity is an option for coping with the fragile and precarious nature of the food security situation within the smallholder sector in southern African region. However, the inability of farmers to provide adequate feeds for their dairy animals

Table 4: Milk yield by Friesian cows fed dried leaves of multipurpose shrubs or cottonseed meal as protein supplements

Supplement	Milk yield (kg/d)
Acacia angustissima	11.6
Calliandra calothyrsus	8.6
Cjanus cajan	12.8
Lucaena leucocephala	14.4
Cotton seed meal	15.6

Source: Hove

throughout the year to maintain high levels of milk production remains one of the greatest constraints. Farmers face major problems of fodder shortage especially during the dry season when most pastures have dried up. This is a major constraint to milk production in smallholder dairy farming systems (Chakoma *et al*., 2004).

Domestic animals often roam freely in many parts of Africa and are able to capture their food intake from various sources. Dry tropical Africa is endowed with indigenous fodder tree and shrubs which are an important feed source for livestock. For example, the pods of *F. albida* serve as excellent source of animal feed. However, details of browse production and nutritive value were lacking for most of the species identified (Dicko and Sikena, 1992. The availability of conventional sources of forage and fodder to farm animals is becoming less and the quality is generally low in terms of palatability and food-value. Tree-based fodder banks have been identified as one of the potential sources of quality feeds to ease the constraints of animal feeding. Fodder banks involve purposefully planting trees or shrubs that can be used for controlled browsing or fed to animals in an enclosure in a cut-and carry fashion.

Although farmers prefer indigenous species (Roothaert and Franzel, 2001) in some arts of Africa, there has been more research on exotic tree species. This is because the exotic species have shown fast growth and high feed quality. Several multi-purpose protein rich browse trees evaluated for fodder banks in southern Africa during the last 15 years, have shown potential to overcome these problems, especially when they are grown in fodder banks. The promising browse species were members of the family Fabacea including *Leucaena leucocephala* De Wit (Fabaceae), *Leucaena pallida* Britton and Rose, *Leucaena diversifolia* Benth, *Calliandra calothyrsus* Meisser, *Acacia angustissima* Kuntze and *Gliricidia sepium* H B and K (Hove *et al*., 2003; Kwesiga *et al*., 2003). The quality of fodder is generally high (Hove *et al*., 2003). The potentials for resource-poor smallholder farmers to increase milk yields (Table 4) and reduce cost of feed for their livestock through tree-based fodder technology has been well documented in a recent study in Zimbabwe (Jera and Ajayi, 2007). Most of these species are also used for soil fertility improvement and fodder production.

Fodder bank technologies are targeted toward providing feed for dairy cow production, small ruminant (sheep and goats) and draught-oxen animals. Many hundreds of farmers in Tanzania and Zimbabwe have dairy cattle and have established fodder banks (Chakoma *et al*., 2004). For example, over 205,523 farmers have been reported to have planted fodder trees in Eastern Africa and 27,500 reported for Tanzania, 81,645 for Kenya, 82,369 for Uganda and 13,990 for Rwanda (Franzel *et al*., 2005). These involved 224 organizations promoting fodder shrubs in the region. However, the possibility of double-counting in estimates can not be completely ruled out, but the results show that the number of farmers embracing the technology is increasing.

PROFITABILITY AND RETURNS TO INVESTMENT

Profitability of the various agroforestry practices has been analysed by various workers and the results show that they are profitable relative to conventional production practices where trees are not grown (Franzel, 2004; Ajayi, 2006; Mithoefer and Waibel, 2003; Place *et al*., 2002). Agroforestry practices are financially profitable when compared with conventional farmers' practices due to either higher crop yield or reduced inputs cost or both. The profitability of agroforestry practices increases when environmental "products" and services produced by these practices are taken into account (Ajayi and Matakala, 2006).

Fruit tree systems: Mithofer and Waibel (2003) analysed the profitability collecting indigenous fruits in rural Zimbabwe. According to that study, the gross margin for *U. kirkiana* ranged from USD 14-50 depending on the geographical location in the country.. Collection of indigenous fruit trees contributes between 5.5 and 6.5% of total household income. The returns to labour of collecting indigenous fruit tree products from communal forest areas is equivalent to USD 13.31 per day (Mithoefer and Waibel, 2003). Compared with a labour wage rate of less than one US dollar per day in Zimbabwe, this figure represents very high returns on investment. Relative to the returns to labour obtained from planting non-domesticated trees (USD 1.3 per day), investment in fruit tree collection enterprise is ten times higher.

Using real options approach, Mithoefer and Waibel (2003) analyzed the outcome of investment decisions for tree planting in Zimbabwe to determine whether waiting to invest in tree planting has a value for investment. They found that the economic rationale for individual farmer investment in indigenous fruit tree planting is affected mainly by the precocity of trees and cost of collecting fruits from the communal forests. At current scenarios,

Table 5: Financial analysis ($US/ha) of rotational woodlots in Tabora district, Tanzania

	Rotational woodlo			Maize fallow	
Benefits	Year 1	Year 2	Year 3	Year 1	Year 2
Net benefit	-37.17	9.51	713.48	40.16	40.16
Workdays	0.11	0.10	0.27	0.09	0.09
Net benefits to labour	0.96	44.14	806.62	73.10	73.10
Net benefits to labour/workday	0.02	0.755	0.09	1.31	1.31
Net present value	388.52			61.36	
Discounted work days	0.31			0.14	
Discounted net benefit to labour	498.25			111.68	
Discounted net benefit and labour	2.67			1.31	

Adapted from Franzel (2004)

farmers can be expected to invest in planting indigenous fruit trees if trees begin to produce fruits at 2 years of age and the fruit yield increases ten folds. Alternatively, individual farmer investment can be expected if trees fruit within two years and the cost of collecting fruits from communal forests increase about three folds (e.g. if abundance of trees decreased sharply or is already present in areas, which have experienced higher rates of deforestation in the past).

Fodder tree systems: Fodder from trees can be used as a supplement to animal diet or as a substitute of animal dairy meal. Financial analysis conducted on fodder shows that the latter option is more profitable for dairy farmers (Franzel, 2004). At a discount rate of 20%, the net present value of fodder bank technology is estimated at US$260 in a field where biomass from 500 *Calliandra* species is used to supplement the feeds of animals (Franzel, 2004). When fodder is used to substitute dairy meal, the net present value increased to US$413. In terms of farmers' annual income, this represents an increase ranging between US$79 and US$125 per cow per year depending on whether the fodder was used as a supplement or substitute to animal feed (Franzel, 2004). Compared with longer term agroforestry technologies such as indigenous fruit trees, fodder bank has a very short payback period of about two years only. This is primarily because the initial investment costs to establish trees are modest, estimated at about US$14 for 1000 trees. Sensitivity analysis shows that the net worth of fodder bank figures are stable, with the enterprise remaining profitable after a decrease in milk price of up to 30% (Franzel, 2004).

Rotational woodlots: The financial analysis carried out in Tanzania shows that over a cycle of five-year period, rotational woodlots are more profitable than conventional maize fallow system (Table 5). The discounted net worth (NPV) is estimated at US$388 per hectare which is 6 times higher than the net benefits estimated for conventional maize fallow systems (Franzel, 2004). Sensitivity analysis shows that the financial estimates is very stable across a wide range of changes in important parameters, as rotational woodlots consistently maintained their superior financial performance over conventional maize systems even when maize prices and labour cost, for example, changes up to 50% (Ramadhani *et al.*, 2002). Returns to labour are even more relevant than returns to land, because labour is much more limiting resource than land. In terms of returns to investment, the discounted net returns per day for rotational woodlots is estimated at US$ 2.67, which is much higher than the labour wage rate prevailing in rural Tanzania and well above the daily one dollar per day consumption poverty line. Comparatively, the net returns per day for conventional maize fallow are estimated at US$ 1.31 (Franzel, 2004; Ramahdani *et al.*, 2002). The high financial profitability of rotational woodlots is however accompanied by a higher initial investment costs and a longer pay off period of five years before the woodlots could completely pay off its initial investment costs.

Fuel wood is particularly useful to tobacco farmers and the environment. The adoption of rotational woodlots in Tabora District alone can conserve 8,675 ha of forests per year, or 0.8% of total wooded area in the district. An important advantage of the woodlots is that they allow farmers to substitute land and labour for cash, which is their most scarce resource. Tobacco farmers can obtain wood for curing only by purchasing it, whereas with the rotational woodlots, they can use their land and labour to produce it, using little if any cash in the process. The labour required for harvesting the wood is considerable but it can be spread over a long period during the farmers' slack season.

POTENTIALS AND CONSTRAINTS TO ADOPTION

Potentials: In the preceding discussion we established the importance of agroforestry from agricultural, environmental and social perspectives. As a result, several efforts are being made to enhance the uptake of agroforestry among farmers by encouraging them to evaluate its performance in their fields (Kwesiga *et al.*, 2003), assess farmer's perception of and feedback regarding the technologies (Ajayi, 2007) and by exploring various approaches for disseminating the technologies to farm communities.

There is a high potential of adoption of several agroforestry technologies. There is a niche for fodder bank technologies and potential for its adoption due to the inability of smallholder farmers to provide adequate feeds for their dairy animals to maintain high levels of milk production remains one of the greatest constraints to improving livestock productivity. For example, in addition to improving the nutrition and income of rural households, fodder bank technology provides other benefits to farmers such as firewood, serving as live fences and assisting to reduce soil erosion. Farmer adoption of fodder bank tends to increase with the herd size of dairy cattle. More dairy cows implies more supplements especially in the dry season when natural grazing is not enough to meet the food and nutrition requirements for increased milk supply. In general, the probability of farmer adoption of fodder bank increases for farmers who had more resources at their disposal is more likely to invest in the technology.

Studies on the adoption of fodder bank in Zimbabwe showed that dairy herd size, land holding size, membership of dairy association and agro-ecological potential are the key factors influencing farmers' decision to adopt the technology (Jera and Ajayi, 2007). Age, sex, household size and educational level of farmers played lesser role to influence adoption. Male and female farmers were equally likely to adopt fodder bank if given similar opportunities and incentives.

Market research shows that indigenous fruit trees are widely traded in the region (Ramadhani *et al*., 2002). Major problems include lack of knowledge and skills on value addition and post harvest handling of Agroforestry Tree Products (AFTPs), limited income generating opportunities, poorly developed markets and lack of formal pricing systems. Several studies indicate that rural communities can increase their incomes by utilizing and marketing tree products from forests and horticultural tree crops grown on-farm (Campbell *et al*., 2002; Akinnifesi *et al*., 2006; Schreckenberg *et al*., 2006).

The adoption of tree-based technologies is much more complicated than those for annual crops because it involves several years during which farmers test, adapt and eventually "adopt" them. It is therefore important to delineate a 'testing' phase from 'adoption' phase (Franzel *et al*., 2002) and similarly, it is necessary to identify 'experimenters' from 'adopters' (Adesina *et al*., 2000). In general, the factors which influence farmers' decision regarding agroforestry during the initial "testing" phase may differ from or assume different importance at the adopting" or expansion phase (Ajayi *et al*., 2006). Awareness and household characteristics are important during the testing" phase while over time, institutional factors such as fire and grazing (Ajayi and Kwesiga, 2003) land tenure and related policies assume importance.

Constraints: Despite their potentials, the level of farmer uptake of agroforestry technologies has generally lagged behind the advances that have been made in scientific and technological development of the technologies (Mercer, 2004). This has been the trend globally and southern African is no exception. While agroforestry technologies are financially profitable, widespread adoption of the technologies by a large number of smallholder farmers who could otherwise benefit from the technologies is nonetheless constrained by several challenges, some of which are listed below:

One of the greatest constraints of some agroforestry technologies is the lack of access to quality seeds. Unlike crops and other commodities where established institutions to promote their seeds exist and private sector organizations have been engaged in the multiplication and distribution of appropriate quality of germplasm, there is little or no institutional structure to make the seeds of agroforestry available "off the shelf" to potential users. The absence of the relevant structures to promote agroforestry is partly due to the fact that agroforestry is a "new" technology.

The second major constraint is related to policy issues. Customary practices and institutions regarding control of bush fires and livestock during the dry season and lack of secure land and tree tenure limit the widespread uptake of some agroforestry technologies. Roaming animals browse the trees after planting (Ajayi and Kwesiga, 2003; Place *et al*., 2001). For example, bi-laws and other regulations which prohibit the marketing of indigenous fruits, land and tree tenure affect individual farmer's decision to invest in indigenous fruit tree fields. ICRAF have been working in collaboration with traditional rulers, government officials, community-based organizations, NGOS and national partners to resolve these institutional bottlenecks (Ajayi and Kwesiga, 2003).

Lack of awareness, skills and knowledge is another constraint to adoption. Given the status of agroforestry as a new" technology compared with conventional agricultural practices, farmers require more training to build their skills and confidence in the management of the trees. The costs of providing information greatly decrease over time, but they are critical when helping farmers get started with the practice. Over several years, there have been structural shifts towards "quick fixes" and technologies that render immediate benefits. The opportunity of agroforestry technologies to provide some medium and long term benefits to individuals and the public simultaneously is increasingly being appreciated but still has to be well communicated to more farmers and other stakeholders.

The human capacity, infrastructures and institutional supports for agroforestry are not as well developed as for annual crop technologies. The missing support includes well developed input and output market to enhance access of small-holder farmers to ensure that they get the price premium for their crop produce.

CONCLUSION AND FUTURE DIRECTION

There are many high-value tree crops that can be integrated into farming systems in the semi-arid regions of southern Africa to support livelihoods of rural communities. This study has analysed agroforestry research and development efforts in the last decade in southern Africa. An active program in domestication of indigenous miombo fruit trees species, introduction of exotic and indigenous trees in farming systems for fuel wood, fodder timber and other products has been on-going in Malawi, Mozambique, Tanzania, Zambia and Zimbabwe. Considerable progress has been made in identifying opportunities, formulating and implementing tree domestication strategies and examining the economic and social environment as well as the aspirations and interest of smallholder farmers. It is recognized that economic incentives can be important motivators for their cultivation and adoption.

The scaling up of high-value trees requires germplasm improvement and this will include:

- Development of improved planting materials may result in significant changes in fruit quality, harvesting and regeneration costs. This should be addressed by combining clonal selection with vegetative propagation techniques, tissue culture and genetic breeding approaches to improve yield and quality of trees. To develop both the fresh market and processing fruit qualities, a robust approach is to select both the rootstocks and scions from superior phenotypes in a semi-domesticated environments or in the wild and manage the trees as orchard crops. Selection of early and late fruiting clones would help to extend the period of fruit availability.
- Applying molecular techniques to better understand the genetic factors controlling fruit precocity, dioecy and superior fruit traits in priority indigenous fruit trees (especially, *U. kirkiana* and *S. birrea*) and active ingredients in priority medicinal trees. Such research will aim at creating incentives for growing priority wild fruit and medicinal trees and catalyze their adoption by farmers.
- Management aspects of indigenous fruit tree orchards needs further research. The soil and water requirements, other management practices are different from well known exotics species such as mangoes (Akinnifesi *et al*., 2007) and warrant further studies.
- Recent studies have demonstrated that improved marketing and adding value to agroforestry tree products can increase small-holders' incomes from high value trees. Market interventions should give attention to improved access to market information, product development, identification of new markets, certification and labelling, collective action of rural groups to assemble and market produce and policy reforms to improve conditions under which farmers operate.
- Indigenous fruit trees have not been subjected to agricultural or forest policies. The neglect at policy level has resulted in haphazard conservation strategies and genetic erosion of native fruits and other valuable germplasm from the miombo woodlands, through fire and clear-felling for agricultural land expansion. Policies are needed to achieve successful conservation, selection, multiplication, improvement and management.

Research and development efforts are needed to further harness the wider genetic diversity for quality germplasm of these trees, while improved capacity building and training are needed among stakeholders and farmers. Institutional support and conducive policy environment will speed the gains of high value tree systems.

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