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Impact of Soil Fertility Replenishment Agroforestry Technology Adoption on the Livelihoods and Food Security of Smallholder Farmers in Central and Southern Malawi

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1. Introduction

The expanding information on agroforestry research and development around the globe shows that agroforestry is being promoted and implemented as a means to improve agricultural production for smallholder farmers with limited labor, financial, and land capital (Ajayi et al., 2007). In Africa, and particularly southern Africa, the main constraint to agricultural productivity is soil nutrient deficiency (Scoones & Toulmin, 1999; Sanchez *et al.*, 1997). For this reason, agroforestry research in the region has focused on soil fertility replenishment (SFR) technologies over the years and the adoption and scaling-up of these practices is the main thrust of the ongoing on farm research (Akinnifesi *et al.*, 2008; Akinnifesi et al, 2010). SFR encompasses a range of agroforestry practices aimed at increasing crop productivity through growing trees (usually nitrogen-fixing), popularized as *fertilizer tree* systems, directly on agricultural land. Fertiliser tree systems involve soil fertility replenishment through on-farm management of nitrogen-fixing trees (Akinnifesi et al 2010; Mafongoya et al., 2006). Fertiliser tree systems capitalise on biological N fixation by legumes to capture atmospheric N and make it available to crops. Most importantly, is the growing of trees in intimate association with crops in space or time to benefit from complementarity of resource use (Akinnifesi et al., 2010; Gathumbi et al., 2002). The different fertiliser tree systems that have been developed and promoted in southern Africa (see Akinnifesi et al, 2008; 2010) over the last two decades are briefly discussed below. The type of soil fertility replenishment (SFR) or fertilizer tree system appropriate for a particular setting is determined by a battery of ecological and social factors.

1.1 Intercropping

Intercropping is the simultaneous cultivation of two or more crops on the same field; usually, involving maize as the main crop in southern Africa and other agronomic crops as risk crops. In agroforestry based intercropping systems, species such as pigeon pea (*Cajanus cajan*), *Tephrosia vogelii, Faidherbia albida, Leucaena leucocephala,* and *Gliricidia sepium* are prominent. *Gliricidia* is a coppicing legume native to Central America with a foliage nitrogen content of up to 4% (Kwesiga *et al.*, 2003). It is currently being used in the intercropping technologies throughout southern Africa (Böhringer, 2001; Chirwa et al. 2003). In the intercropping system, *Gliricidia* is planted along with the maize crop. The trees are pruned at crop planting and again at first weeding and the pruned biomass is incorporated into the soil. The advantage of this system is that, because of its coppicing ability, the trees can be maintained for 15 to 20 years (Akinnifesi *et al.*, 2007), eliminating the need to plant each year, as is the case in the relay cropping system. However, it takes 2 to 3 seasons of intercropping before there is a significant positive response in maize yield (Böhringer, 2001; Chirwa *et al.*, 2003) and the technology is labor intensive because of the required pruning (Kwesiga *et al.*, 2003).

The benefits of intercropping on maize yields have proved to be highly substantial. Akinnifesi *et al.* (2006) reported soil fertility levels in *Gliricidia/*maize systems to be significantly greater than sole maize. In the second cropping season, maize yields in the intercropping plots were twice that of sole maize plots. Additionally, maize yields in the intercropping systems maintained an average of 3.8 MT ha^{-1} over a ten year period, compared to an average 1.2 MT ha^{-1} in the sole maize plots (Akinnifesi *et al.*, 2006). Results from Makoka Research Station in southern Malawi showed that by the fourth year, maize yields in the intercropping system were double those of the controls (sole maize) (Kwesiga *et al.*, 2003). Table 1, adapted from Kwesiga *et al.* (2003), illustrates the potential yield benefits of the intercropping technology.

Recommended fertilizer (%)	1992-1993		1993-1994		1994-1995		1995-1996		1996-1997	
	SM	G/M	SM	G/M	SM	G/M	SM	G/M	SM	G/M
	MT ha^{-1}									
0	2.0	1.60	1.20	2.50	1.10	2.10	1.07	4.72	0.56	3.28
25	3.4	3.10	1.60	3.00	2.20	2.90	3.49	6.34	2.11	4.23
50	4.2	4.00	2.40	3.20	2.40	2.90	4.23	6.70	1.89	4.39

SM=sole maize, G/M= Gliricida/maize intercropping recommended fertilizer rates: 96 kg N and 40 kg P ha^{-1}.

Source: Kwesiga, *et al.*, 2003

Table 1. Maize grain yields from a Gliricidia/maize intercropping system with different levels of fertilizer from 1992 to 1997 at Makoka, Malawi.

1.2 Relay cropping

Relay cropping is a system whereby nitrogen-fixing trees, shrubs, or legumes such as *Sesbania sesban, Tephrosia vogelii, S. macrantha, Crotalaria spp.,* or perennial pigeon pea (*Cajanus cajan*), are grown as annuals and planted 3 to 5 weeks after the food crop. Staggering, or relaying, the agroforestry species and crop plantings reduces competition (Akinnifesi *et al.*, 2007; Kwesiga *et al.*, 2003). The agroforestry species are allowed to grow and develop beyond the main crop harvest. At the beginning of the, second season they are felled and the woody stems are collected for use as fuel while the remaining biomass is incorporated into the soil as green manure. Early reports reviewed by Snapp *et al.*, (1998) indicated that after 10 months of growth, *Sesbania* produced 30 to 60 kg N ha^{-1} and 2 to 3 MT ha^{-1} of leafy biomass, plus valuable fuelwood from the stems. In southern Malawi, Phiri *et al*., (1999) found a significant influence of *Sesbania* relay cropping on maize yields at various landscape positions. In another study, tree biomass production averaged 1 to 2.5 MT ha^{-1} for *T. vogelii,* and 1.8 to 4.0 MT ha^{-1} for *S. sesban* and a corresponding average maize grain yield of 2 MT ha^{-1} (Kwesiga *et al.,* 2003). Relay cropping is suitable for areas of high population density and small farm sizes because it does not require farmers to sacrifice land to fallow. The drawback of this system is that the trees are felled and must therefore be re-planted each year. Furthermore, the technology relies on late-season rainfall in order for the trees to become fully established (Böhringer, 2001).

1.3 Improved fallow

Traditionally, farmers practiced rotational cultivation and allowed agricultural plots to lie in fallow for several years in order to replenish soil nutrients (Kanyama-Phiri *et al*., 2000; Snapp *et al*., 1998). With increasing populations and decreasing land holdings, many smallholder farmers can no longer afford to remove land from cultivation. For this reason, improved fallow technology has emerged as a promising alternative to traditional fallows. In an improved fallow, fast-growing, nitrogen fixing species such as *Sesbania sesban* , *Tephrosia vogelii, Gliricidia sepium,* and *Leucaena leucocephala* are grown for 2 to 3 years in the fallow plot after which, they are felled. The leaf matter can then be incorporated into the soil as green manure, and the woody stems can be used for fuel wood or construction materials. Farmers have also intensified this practice by intercropping during the first year of tree growth (Böhringer, 2001). Improved fallows are being used extensively in Eastern Zambia (Ajayi & Kwesiga, 2003; Ajayi *et al*., 2003) as well as in parts of Malawi, Kenya, Zimbabwe, and Tanzania (Kwesiga *et al*., 2003; Place *et al*., 2003). Improved fallows are perhaps the most widely adopted SFR practice in southern Africa. Kwesiga *et al.* (2003) estimated that by 1998 over 14 000 farmers were experimenting with improved fallows in eastern Zambia, and that by 2006 a total of 400 000 farmers in southern Africa would be using the technology. In trials at Chipata, Zambia, maize yields increased from 2.0 MT ha^{-1} in an un-fallowed plot to 5.6 MT ha^{-1} after a 2 year *S. sesban* fallow (Kwesiga *et al*., 2003). The same study also reported yield increases of 191% after a 2 year *T. vogelii* fallow and a 155% yield increase following a 2 year fallow with *C. cajan* (Kwesiga *et al*., 2003). Despite the shorter fallow period, compared to traditional fallows, the success of improved fallow technology depends, in part, on the farmer's ability to remove land from crop production for a period of 2 to 3 years. In places where landholdings are small, fallows may not be a viable option for farmers. Other constraints include water availability, especially during tree establishment, and pests in the case of *Sesbania* (Böhringer, 2001). For this reason, intercropping and relay cropping have become the dominant SFR practices in central and southern Malawi (Kwesiga *et al*., 2003; Thangata & Alavalapati, 2003).

1.4 Biomass transfer

In the biomass transfer technology, green manure is mulched and/or incorporated into agricultural soils. Biomass transfer is common in Zimbabwe, Tanzania, western Kenya, and northern Zambia where green biomass is grown in *dambos* (shallow, seasonally waterlogged wetlands) or on sloping land and areas that are unsuitable for agricultural production and where labor is not a limiting factor (Kwesiga *et al*., 2003; Place *et al*., 2003). The technology is labor intensive as the mulch must be collected, transported to the agricultural field, and then incorporated into the soils. The amount and cost of labor associated with biomass transfer is the major limiting factor to the technology (Kuntashula *et al.*, 2004). The advantage of this technology is that it allows for continuous cultivation as the incorporated green manure provides sustained soil nutrient replenishment (Place *et al.*, 2003). Typically, *Tithonia diversifolia, Leucaena leucocephala, Senna spectabilis, Gliricidia sepium,* and *Tephrosia vogelii* are the most prominent species used in biomass transfer systems (Place *et al.*, 2003). The technology has been reported to increase maize yields by up to 114% (Place *et al.*, 2003). A compilation of independent studies in Malawi showed that green manures increased maize yields by 115.8%, when compared to unfertilized maize (Ajayi *et al.*, 2007). Similarly, Ajayi *et al.* (2007) reported that incorporating 3.4 MT ha^{-1} of dry weight of *Gliricidia* manure produced up to 3 MT ha^{-1} of maize. Aside from the common use in maize production, biomass transfer is an important technology used in dambo cultivation of high-value cash crops, such as vegetables (Kwesiga *et al.*, 2003). In addition to soil fertility and increased crop production, agroforestry provides other ecological and economic products and services including, but not limited to: wood production, pest management, and carbon sequestration.

1.5 Wood production for construction and energy

One of the most important products of SFR, to the smallholder farmer, is woody biomass production. Wood, for both fuel and construction, is critical to the livelihoods of rural farmers. An estimated 85% of the rural population in developing countries depends on woodlands and forests to sustain their livelihoods (Dixon *et al.*, 2001). As population pressures and deforestation rates increase, there is an increasing demand for wood, but a decreasing supply. In Tanzania, for example, deforestation rates caused by activities associated with agriculture, illegal harvesting, and expanding settlements have reached 91 000 ha per year (Meghji, 2003). In Malawi, high population pressures have stressed the natural resources base, and especially the forest and woodland resources. The country's wood demand was evaluated to exceed the available supply by one third (Malawi, 2002; MEAD, 2002). Additionally, Malawi's forest cover decreased by 2.5 million ha between 1972 and 1992 and the current rate of deforestation is approximately 2.8% per year (MEAD, 2002). As a result of these trends, those who rely on wood for fuel, construction, and other livelihood activities are spending more time collecting and transporting wood to the detriment of other important household activities. Considering that fertilizer tree systems have been shown to produce up to 10 MT of woody biomass per hectare (Kwesiga & Coe, 1994), it is easy to see that the secondary benefit of wood production by agroforestry trees is an important, positive externality to these technologies. Two important species for wood production include *Sesbania sesban* and *Gliricidia sepium*. *S. sesban* produces a high volume of woody biomass in a short time, making it ideal for fuelwood production (AFT, 2008). In eastern Zambia, a *Sesbania sesban* improved fallow produced over 10 MT ha^{-1} (Kwesiga *et al.*, 1999). Kwesiga & Coe (1994) reported fuelwood harvests of 15 and 21 MT ha^{-1} following 2 and 3 year *Sesbania* fallows, respectively. Furthermore, Franzel *et al.* (2002) reported that a 2-year *Sesbania* fallow resulted in 15 MT of fuelwood. The woody biomass of *Gliricidia sepium* is suitable for both fuel and construction. As fuel, the wood of *G. sepium* burns slowly and with little smoke. Alternatively, the hard, durable wood is termite resistant and is used in fence, home, and tool construction (AFT, 2008). Chirwa *et* *al.,* (2003) reported that *G. sepium,* when grown in an unpruned woodlot, or as an improved fallow, produced 22 MT ha^{-1} yr^{-1} of fuelwood. The same study reported fuelwood production amounts of 1 MT ha^{-1} after a 2 year *Gliricida/*maize intercrop and 3.3 and 5.0 MT ha^{-1} after 3 years of *Gliricida*/maize/pigeon pea and *Gliricidia*/maize intercrop, respectively (Chirwa *et al.*, 2003). A 5 year *Gliricidia* rotational woodlot in Tanzania was found to produce over 30 MT of woody biomass (Kimaro *et al.*, 2007). *Faidherbia albida* and *Leucaena leucocephala* are two other SFR species planted in the southern Africa region that are managed for the dual purpose of soil fertility and woody biomass production (AFT, 2008).

1.6 Environmental services

1.6.1 Pest management

Another added benefit to some SFR agroforestry species is a pest management quality. *Striga* (*S. asiatica* and *S. hermonthica*) is a parasitic plant that thrives in nutrient starved soils (Ajayi *et al.*, 2007; Berner *et al.*, 1995; Gacheru & Rao, 2001; Sileshi *et al.*, 2008). It attacks several of the major food crops, including maize, millet, rice, and sorghum. Seedlings attach to the roots of the host plant where they continue to grow underground for four to seven weeks; it is during this period that they cause the most damage (Berner *et al.*¸ 1995). A single *Striga* plant can produce over 50 000 seeds and these seeds can remain viable in the soil for 10 to 14 years (Berner *et al.*, 1995; Gacheru & Rao, 2001). Yield losses of 32% to 50% and 18% to 42% from *Striga* infestations have been reported in on-station trials in Kenya and Tanzania, respectively (Massawe *et al.*, 2001). For smallholder, subsistence farmers, losses can be up to 100% with heavy infestation (Berner *et al.*, 1995; Gacheru & Rao, 2001; Massawe *et al.*, 2001).

High populations have necessitated the use of continuous cultivation. This leads to soil nutrient depletion and has caused an increase in the severity and spread of *Striga* infestations (Gacheru & Rao, 2001). Several agroforestry species have shown potential in combating *Striga.* For example, on moderately-infested sites in western Kenya, *Desmodium distortum, Sesbania sesban, Sesbania cinerascuns, Crotalaria grahamiana,* and *Tephrosia vogelii* fallows were found to decrease *Striga* by 40% to 72% and increase maize yields by 224% to 316% when compared to continuous maize plots (Gacheru & Rao, 2005). Additionally, Kwesiga *et al.* (1999) found less than 6 *Striga* plants 100 m^{-2} following 3 year *Sesbania* fallows in two experiments from Zambia. This is in stark contrast to the 1532 and 195 *Striga* plants 100 m^{-2} found in two experiments of continuously cultivated and unfertilized maize (Kwesiga *et al.*, 1999).

Tephrosia vogelii has also been found to be effective as both a repellant and insecticide against *Callosobruchus maculates*, the main pest infecting stored cowpea. In a laboratory study conducted by Boeke *et al.* (2004), beetles exposed to tubes treated with *T. vogelii* powder laid fewer eggs in the first 24 hour period than beetles in the control. The *T. vogelii* powder was also found to reduce the parent beetle lifespan (Boeke *et al.*, 2004). Another study reported that the juice of *T. vogelii* was effective in managing maize stem borer (*Chilo partellus*) populations in southern Tanzania and northern Zambia (Abate *et al.*, 2000). Similarly, in Uganda, the presence of *T. vogelii* plants in sweet potato fields was reported to protect the potatoes from mole and rat damage (Abate *et al.*, 2000). The dry, crushed *Tephrosia vogelii* leaves are also documented to be effective against lice, fleas, tics, and as a molluscicide (AFT, 2008).

1.6.2 Carbon sequestration

The Kyoto Protocol recognizes agroforestry as a greenhouse gas mitigation strategy and allows industrialized nations to purchase carbon credits from developing countries (Orlando *et al.*, 2002). In this context, agroforestry not only plays a part in mitigating the effects of global climate change through carbon sequestration (Ajayi *et al.*, 2007; Ajayi & Matakala, 2006), but also has the potential to contribute to farmer incomes through the sale of carbon credits (Takimoto *et al.*, 2008). Several initiatives have recently been developed to support and encourage farmers who adopt land use practices that render environmental services (Ajayi *et al.*, 2007). While there is increasing interest in the global warming mitigation potential of agroforestry, research has lagged behind in quantifying this potential for various systems (Albrecht & Kandji, 2003; Makumba *et al.*, 2007). While the volume of research on agroforestry and climate regulation is limited, there have been a few studies that reveal the carbon sequestration potential for some systems. For example, a *Gliricidia*/maize intercropping system in Malawi was found to sequester between 123 and 149 MT of C ha^{-1} in the first 0 to 200 cm of soil through a combination of root turnover and pruning application (Ajayi *et al.*, 2007; Makumba *et al.*, 2007). In a separate report, Montagnini & Nair (2004) estimated that the potential carbon sequestration for smallholder agroforestry systems in the tropics range from 1.5 to 3.5 MT ha^{-1} of C yr^{-1}. Albrecht & Kandji (2003) have calculated the carbon sequestration potential to be between 12 and 228 MT ha^{-1} for similar systems. Between fuel and pole wood production, pesticide qualities, and climate regulation, it is clear that agroforestry offers benefits beyond improved soil characteristics and crop yields. Table 2, adapted from Ajayi *et al.* (2007), highlights some of the private and social benefits of SFR technologies.

	Private	Social
Benefit	Yield increase	Carbon sequestration
	Stakes for tobacco curing	Suppresses noxious weeds
	Improved fuel wood availability	Improved soil structure, reduced erosion and run-off
	Fodder	Promotes biodiversity
	Bio-pesticide	Potential for community income diversity
	Suppresses weeds	
	Improved soil structure, reduced erosion and run-off	
	Diversification of farm production (cash crops)	

Source: Adapted from Ajayi, et al., (2007)

Table 2. Benefits of SFR Technologies

2. Case study of SFR technology in central and southern Malawi

There are a variety of agroforestry technology options that are being researched, tested, and adopted throughout the world. The type of SFR technology that is acceptable, appropriate, and sustainable to a particular setting is determined by a battery of ecological (climate, soil and terrain characteristics) and societal factors such as available land and labor and institutional support and regulations. As a result of the various ecological and social boundaries in the study area, the respondents in this study used a combination of one or more of the following SFR technologies: intercropping, relay cropping, improved fallow, and biomass transfer. This case study's main objective was to investigate the link between SFR adoption and poverty reduction in farming households of central and southern Malawi by assessing food security, asset status, and household activities and income. Specific objectives were as follows: (i) evaluate changes in food security resulting from increased yields associated with SFR adoption; (ii) determine if there is a cause-and-effect relationship between SFR adoption and household assets as an indication of improved wealth and (iii) determine if SFR adoption has allowed households to diversify their activities and income.

2.1 Study areas

Forty-eight percent of the land area in Malawi is under cultivation. However, only 32% of this is classified as suitable land for rain fed agriculture (Malawi, 2002). Agricultural land increased from 3 million ha to 4.5 million ha between 1976 and 1990 while the average land holding size decreased from 1.53 ha in 1968/1969 to 0.8 ha in 2000 (Malawi, 2002). In order to achieve its various goals and objectives, the Ministry of Agriculture established a National Rural Development Programme that divides the country into various management units. There are eight Agricultural Development Divisions (ADD) within the country and each ADD is divided into several Rural Development Project (RDP) areas. The RDPs are further divided into Extension Planning Areas (EPA) and then finally into smaller Sections. The study was conducted in Rural Development Programmes in two districts of Malawi, Kasungu (S 13°2′0″, E 33°29′0″) in the central region and Machinga (S14° 58′ 00″, E35° 31′ 00″) in the southern region (Fig 1a). Within the Kasungu RDP the Chipala EPA was chosen and interviews were carried out in three different Sections. In Machinga ADD, interviews were conducted in Mikhole Section within Nanyumba EPA (Figure 1b).

2.1.1 Farming activities and food production

The primary source of food in Kasungu is from local crop production, with availability being lowest between January and February. Apart from tobacco (*Nicotiana tabacum*) the cash crop, maize (*Zea mays*) is the most important food crop and is cultivated by an estimated 95.9% of the population of Kasungu District (Malawi National Statistical Office, 2005). Groundnuts (*Arachis hypogaea*), rice (*Oryza sativa*), pulses and, to a lesser extent cassava (*Manihot esculenta*) are also important crops with 55.3%, 48%, 41% and 12.3% of the population cultivating these crops respectively (Malawi National Statistical Office, 2005). In Machinga, most households are subsistence farmers whose main crops are maize, cassava, and rice (MVAC, 2005). Almost 98% of households in Machinga cultivate maize, 67.7% grow pulses, 38.6% grow groundnuts, 42.1% cultivate rice, and 26.6% cultivate cassava (Malawi National Statistical Office, 2005). Traditionally, households engage in a multiple cropping of maize/pulse farming system (Msuku *et al.*, s.d.). Relay planting, the inclusion of N-fixing legumes, and incorporation of crop residues into the soil are common soil fertility management practices (Msuku *et al.*, s.d.). Most farmers cannot afford inorganic fertilizers: consequently, only about 20% of households use fertilizers, pesticides, or improved seed (Msuku *et al.*, s.d.). While most plots are intercropped, tobacco is grown in pure stands (Msuku *et al.*, s.d.). Tobacco is an important cash crop for those who cultivate it, but it is grown by only about 22% of the population (Malawi National Statistical Office, 2005).

Fig. 1.a. Map of location of Kasungu and Machinga Agricultural Development Division

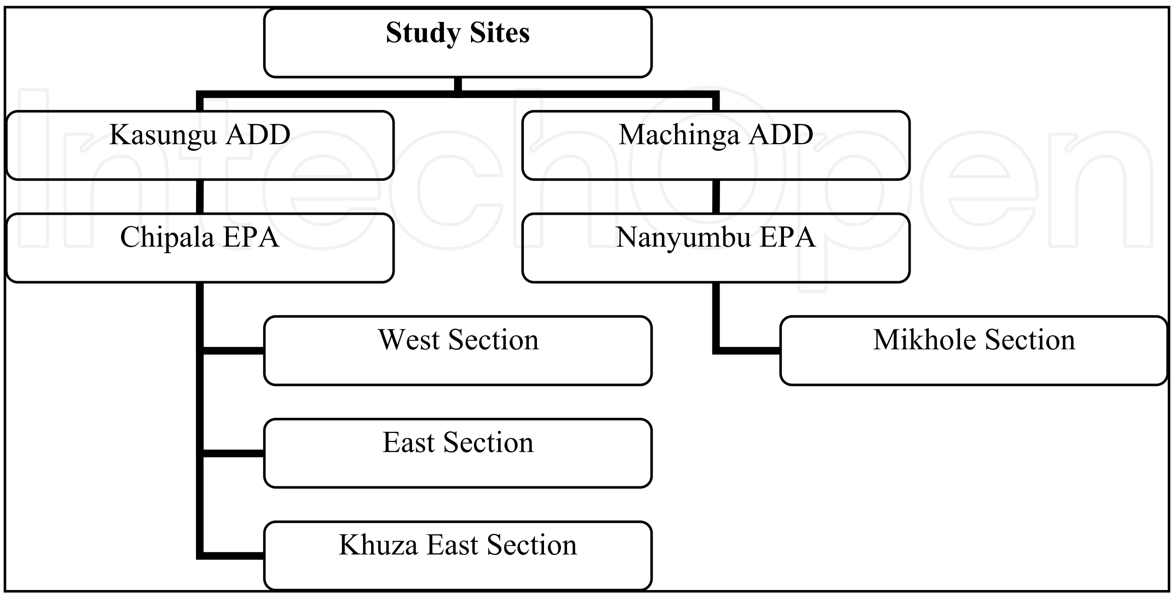

Fig. 1.b. Detailed subsection of the study sites

2.1.2 Wealth and income

According to the Malawi Baseline Livelihood Profiles (MVAC, 2005), wealth in the Kasungu region is heavily reliant on access to food and credit. Households with access to credit are more likely to have a larger land holding from which they can cultivate and harvest a higher crop yield. These households may also be able to purchase livestock such as cattle which can be used for meat, milk, farming, or sold for cash in times of stress. Overall, those considered "better-off" cultivate twice as much land, may own as many as 10 head of cattle, and/or own twice as many goats and chickens as those considered "poor" (MVAC, 2005). Crop sales are the primary source of income in the region, with tobacco constituting 65% to 85% of the average household income (MVAC, 2005). Approximately 64% of the population of Kasungu District grows tobacco (Malawi National Statistical Office, 2005). It is the most important cash crop in the region with an estimated 45% of the yearly tobacco sales in the country coming from Kasungu ADD, and 60% of this comes from Kasungu RDP (Mwasikakata, 2003). Among the poor, cash and in kind wages from *ganyu*[1] work are the second most important source of income, while for those households considered to be either middle or better-off, food crops and livestock sales are the secondary sources of income (MVAC, 2005). The average landholding size throughout the region is 0.4 ha (Msuku *et al.*, s.d.; MVAC, 2005). Households who, according to the Malawi Baseline Livelihood Profiles, are considered "poor" own between 0.4 ha and 1.0 ha, while for those deemed to be better-off, land holdings average between 1.2 ha and 2.4 ha (MVAC, 2005). Despite low soil fertility and market access problems, crop sales are the most important source of income in Machinga. Crops such as groundnuts (*Arachis hypogaea*), sweet potatoes (*Ipomoea batats*), and soya beans (*Glycine max*) are sold mainly in the local markets (MVAC, 2005). Other major income sources include labor and firewood sale. Even after household production and in kind payments, poor households still face a 33% food deficit. According to the Malawi Integrated Household Survey of 2005, Machinga District has a 73.7% poverty rate and only 36.7% of the population has an adequate food supply. The sandy soils, poor infrastructure, and high population density, make poverty relief and hunger alleviation especially challenging.

2.2 Methodology

The sites, communities, and individual households were selected using purposive sampling strategies (Babbie and Mouton 2001) based on information provided by the project staff and local extension officers. In total, 131 household interviews were conducted, 65 from Kasungu and 66 from Machinga. Farmers were selected on the basis of length of SFR and/or agroforestry technology use; having been adopters of the fertilizer tree technologies for at least 5 years.

2.2.1 Data analysis

Household characteristics such as number of household members and landholding size were summarized using descriptive statistics. Frequency tables and descriptive statistics were used to identify and evaluate trends in the agroforestry technology use, crop production, shocks, assets, and income. Sign and Signed Rank Non-parametric (also called

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[1] Ganyu refers to casual labor or piecework and is paid for with either cash or in kind upon completion of the job

Wilcoxon Matched Pairs test) analysis was used to test for a change in the crop yield and asset variables between pre- and post-adoption (Clewer and Scarisbrick 2006). The test for equality of proportions was used to examine the probability of an increase in income amount, number and type of income sources, and maize yields as a result of the technologies adoption. Chi-square analysis test was used to determine if there was an influence of the addition of agroforestry related activities on both the amount and number of income sources

3. Results and discussion

3.1 The relationship between the adoption of SFR technologies and food security

The majority of respondents (65%) reported an increase in maize yield due to SFR use with an average total yield increase of 381.5 kg in Kasungu and 241.7 kg in Machinga (Table 3). The difference between sites was likely due to the fact that respondents in Machinga cultivate much smaller areas. The results confirm what the existing literature has already established, that integrated soil fertility technologies do cause a significant increase in crop production (Ajayi *et al*., 2007; Akinnifesi *et al.,* 2006; Kwesiga *et al.,* 2003; Phiri *et al*., 1999). Some of the studies have even shown increases of over 100% (Ajayi *et al*., 2007; Phiri *et al.* 1999; Place *et al*., 2003) for various agroforestry technologies. However, the respondents only provided information about the amount of yield increase with no reference to any baseline information pertaining to yields per hectare and so the reported increases cannot be extrapolated to kg per hectare; making it difficult to directly compare the production at the two sites. It should also be mentioned that no data was collected on the use of inorganic fertilizers among the respondents. At the time of interview, the government fertilizer subsidy program supplied 100 kg of inorganic fertilizer to approximate 50% of the smallholder farming sector (Malawi Ministry of Agriculture and Food Security, 2008) and it is likely that some of the respondents in this study were recipients of these subsidies. The use of both organic and inorganic fertilizer options are complementary and will contribute to increasing crop yields.

Crop	Kasungu	Machinga
Maize*	381.5 (192.4)	241.7 (126)
Cassava*	188.2 (92.75)	50
Vegetables	34.1 (28.60)	17.1 (6.98)

* Indicates that differences between sites are significant at $p<0.05$

Table 3. Mean increases (kg) (and SD) of crops in Kasungu and Machinga districts

The other two crops that also showed significant increases in yield since adoption of SFR technologies were cassava and vegetables (Table 3). Respondents at both sites grew vegetables for consumption and sale. However, the sale of vegetables was a much more common source of income in Kasungu than in Machinga (Table 4). The use of biomass transfer in dambo (wetlands) cultivation of high value cash crops such as vegetables has been shown to provide a potential net profit of US$700 to US$1000 per hectare (Ajayi *et al*., 2006). Ajayi and Matakala (2006) reported that in Zambia the use of *Leucaena* biomass in cabbage cultivation resulted in a net profit of US$5 469 per hectare. It is likely that, when compared to Machinga, the larger land holdings in Kasungu has allowed the more prevalent use of biomass transfer, and resulted in the production of larger quantities of cash crops (vegetables) which has also contributed to a more diversified income portfolio.

Crop	Kasungu		Machinga	
	%	Mean Rank (SD)	%	Mean Rank (SD)
Groundnuts	86.2	2.11 (1.22)	92.4	1.54 (0.79)
Cassava	64.6	2.95 (1.46)	30.3	3.05 (1.05)
Potato	56.9	3.59 (1.36)	25.8	3.47 (0.94)
Maize	52.3	2.76 (1.07)	3.0	2.0 (0)
Vegetables	46.2	3.07 (1.55)	7.6	2.2 (1.3)
Tobacco	43.1	1.50 (0.88)	50.1	1.82 (1.07)
Cotton	18.5	2.25 (1.48)	3.0	5.0 (0)
Pulses	15.4	3.90 (1.10)	45.5	3.13 (1.67)
Millett	4.6	3.33 (2.52)	0	-
Rice	0	-	65.2	2.60 (1.00)
Sorghum	0	-	10.6	3.57 (1.13)

A rank of 1 is considered the most important

Table 4. Percent (%) of respondents cultivating, and mean ranking of, cash crops in Kasungu and Machinga districts

3.2 SFR technology adoption and the impact on household assets

Table 5 shows the ownership of assets at the two study sites. Ownership of bed mats, bicycles, radios, goats, and chickens increased significantly ($p<0.05$) between pre- and post-SFR adoption. The results show that the majority of respondents (85% to 100%) attributed an increase in asset ownership to SFR use. Assets increased both in number (purchasing additional chickens, for example) and in diversity (for example, purchasing a first radio). However, it was not possible to determine if asset status was directly correlated to the number of years since adoption. This would have required taking asset inventories at regular intervals, e.g. annually, over time. It is therefore impossible to determine if there is a relationship between assets and years of SFR use. It can however, be said that there is a significant change in asset status between pre- and post-adoption. Studies from Ellis *et al.* (2003) and the Malawi Baseline Livelihood Profiles (MVAC, 2005), found that changes in livestock ownership may indicate a change in wealth. Through wealth-ranking exercises in Zomba and Dedza districts of Malawi, Ellis *et al.* (2003) found that households considered to be “well-off” owned, among other things: 5 or more cattle, 3 to 5 goats, and at least one bicycle. Similarly, using livestock ownership as one indicator of wealth, the Malawi Baseline Livelihood Profiles (MVAC, 2005) reported that in Kasungu district those considered poor owned zero to 5 goats or chickens, those in the middle wealth bracket owned zero to 3 cattle and up to 6 goats and chickens, and those considered better-off owned 3 to 10 cattle and 5 to 10 goats and/or chickens. The same study reported that for Machinga district, households classified as poor owned 4 to 6 chickens, those in the middle owned 1 to 4 goats and/or 4 to 6 chickens, and the better-off households owned up to 15 goats and 15 or more chickens.

3.3 SFR adoption and diversity of income among households

3.3.1 Seasonal income generating activities

Crop sales were the most common and most important sources of income at both sites (Table 6). This is consistent with the Malawi Baseline Livelihood Profiles (MVAC, 2005) which reported that crop sale is the largest source of income in both the Kasungu / Lilongwe Plain and Phalombe Plain and Lake Chilwa Basin (which includes the Machinga site) areas. The majority of crop sales occur between the months of May and September (Figure 2). This is expected since these are the months during which most agronomic crops are harvested

Asset	Kasungu (n=65)	Machinga (n=66)	Total (n=131)
Iron Roof	9.2	6.1	7.6
Radio*	61.5	39.4	-
Bicycle	46.2	53	49.6
Bank Account*	18.5	0	-
Bed Mats	100	100	100
Goats	27.7	28.8	28.2
Chickens	64.6	48.5	56.5
Cattle	1.5	0	0.7
Other	32.3	7.6	19.8

* Indicates a significant difference (Fisher's exact p-value<0.05) between the sites and means could not be pooled

Table 5. Percent of respondents reporting asset ownership

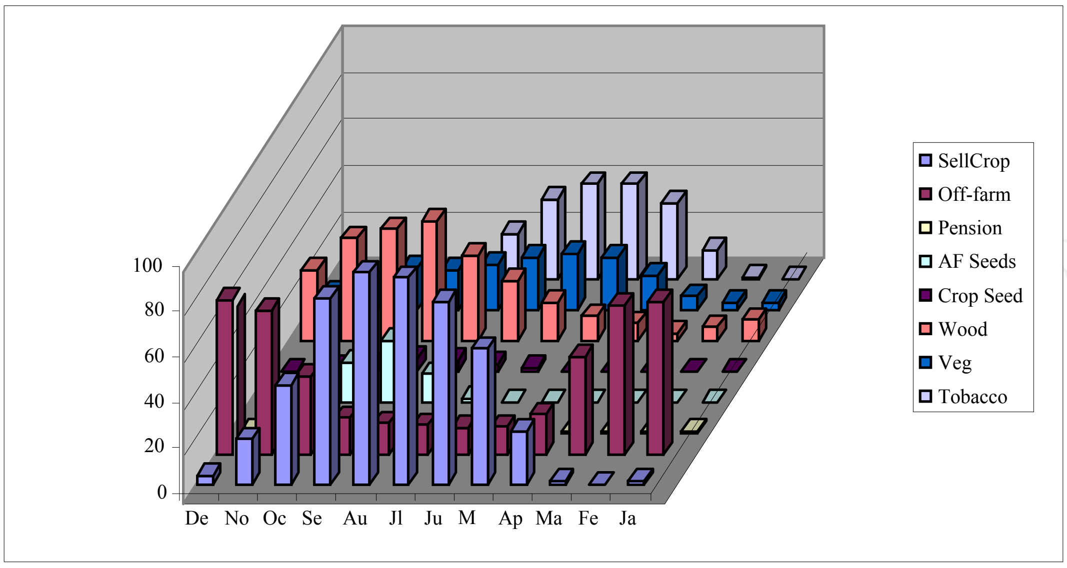

Fig. 2. Income sources by month for the whole sample

The study found off-farm wages to be especially important sources of income between November and March (Figure 2), coinciding with the annual food shortages and hunger periods experienced by many subsistence farmers. These months are also times of high labor demand as it is during these months that land preparation, land clearing, ridging, and vegetables are harvested (MVAC, 2005). Farmers are therefore faced with the dilemma of hiring out labor for payment or working on their own plots. If household labor resources are constrained, the loss of an active household member to off-farm labor may be to the detriment of household land preparation and subsequent crop production (Place *et al.*, 2007). However, the additional income (either cash or in-kind) from off-farm labor may be more critical to meeting the household's immediate needs.

Tobacco sale in Kasungu was the most highly ranked cash crop (Table 6) although it was not as common an income source as would have been expected based on the literature. The MVAC report (2005) also identified tobacco as the most important cash crop in Kasungu district, accounting for 65-85% of the income across all wealth groups. The high ranking of tobacco in the present study supports the results from Mwasikakata's (2003) study which found nearly 45% of the yearly tobacco sales in Malawi come from Kasungu ADD, and 60% of this comes from Kasungu RDP (Mwasikakata, 2003).

	Machinga (n=66)		Kasungu (n=65)		Whole Sample (n=131)	
Income Source	%	Average Rank (SD)	%	Average Rank (SD)	%	Average Rank (SD)
Sell Crops	95.5	1.51 (0.76)	89.2	2.60 (1.38)	92.4	2.03 (1.22)
Off-farm wages	71.2	1.87 (0.85)	90.7	2.56 (1.59)	81	2.25 (1.35)
Sell Wood	33.3	2.77 (0.61)	72.3	3.43 (1.49)	52.6	3.22 (1.32)
Sell AF seeds	6.1	2.75 (0.50)	80.0	3.48 (1.49)	42.7	3.43 (1.45)
Tobacco	44.0	2.10 (1.01)	40.0	3.08 (2.12)	42	2.56 (1.69)
Sell Vegetables	12.1	3.13 (1.25)	47.7	3.58 (1.43)	29.7	3.49 (1.39)
Sell Maize	3	2.50 (0.71)	52.3	2.94 (1.32)	27.5	2.92 (1.29)
Sell crop seeds	0		10.7	5.00 (1.83)	5.3	5.00 (1.83)
Other	0		3.1	2.00 (0.00)	1.5	2.00 (0.00)
Pension#	0		1.5	2.00	0.76	2.00
Sell Other#	0		1.5	6.00	0.76	6.00

Rank of 1 indicates most important source of income
#Indicates only one household reported this sources of income

Table 6. Percent of respondents reporting and average ranking of various income sources

3.3.2 Income diversity as a result of SFR adoption

With agroforestry adoption come other income generating opportunities. For example, wood from the agroforestry species can be sold for fuel or construction materials; seeds can be collected and sold; and if increased crop yields produce a surplus, those crops can also be sold (see Table 6). It was therefore hypothesized that SFR use would promote the diversification of income generating activities (IGAs). Responses from Machinga showed that there was no significant diversification of income sources. While a few households did report an increase in the number of income sources, the majority said the number had remained the same. The results from Kasungu, however, showed a significant number of respondents reporting an increase in the number of household income sources. Since Kasungu respondents were cultivating larger plots, and more respondents used improved fallows and biomass transfer than in Machinga, they may have more income generating resources available to them. For example, the use of improved fallows requires more land than relay cropping and the resulting woody biomass yield will be greater in a plot that is dedicated to an improved fallow than in a plot where woody growth shares the same space as food crops. Therefore, the resulting volume of saleable wood will be greater from an improved fallow than from a relay cropping system.

3.4 The impact of SFR adoption on household vulnerability and coping strategies

Vulnerability is the potential to be adversely affected by an event or change and is a robust function of the interaction between and among natural or environmental variability, socio-economic processes, and policy (Eriksen *et al.*, 2005).The vulnerability context refers to external shocks, trends, and seasonality over which people have little or no control (DFID, 1999). While some changes to these external forces can have a positive influence in reducing vulnerability, many interactions among external shocks, trends, and seasonal processes provide a positive feedback into increased vulnerability. In this study, while some households demonstrated a positive change in income, crop yield, and assets, this does not appear to have been significant enough to allow for any substantial reduction in vulnerability, except for perhaps a shorter annual hunger period, the significance of which should not be ignored. It is difficult to separate the effects of hunger, illness, labor shortage, and crop loss as the presence of one can directly affect another. Case studies from an investigation of SFR livelihood impacts conducted by Place *et al.* (2007) in western Kenya revealed that shocks and coping strategies were key causes of poverty. Therefore, this study looked for any changes in the household's ability to cope with shocks as an indication of increased security and decreased vulnerability. Hunger is by far the most prevalent shock or crisis facing smallholder farmers, as illustrated by the fact that all of the respondents in this study were still vulnerable to several months of food insecurity each year. It was hypothesized that if SFR adoption had enabled households to increase crop production and diversify their livelihoods, then they would also have been able to invest in various adaptation and coping strategies that would mitigate the adverse effects of any shock or crisis that arose. Despite the gains in food security, brought about by a significant increase in crop yields, a marked decrease in hunger periods (Figure 3), and in some cases a more diversified income portfolio and asset inventory, there is still an obvious lag in household security, the ability to absorb and cope with shocks, and overall improved welfare.

When households live on the margin of survival, livelihood strategies focus more on addressing immediate needs and surviving shocks than progressing out of poverty (Eriksen *et al.*, 2005). The results revealed that where households were able to increase their income, the added income was reinvested into activities that support the household's immediate needs (Table 7), rather than investing in any form of insurance. In a study of household budgets in western Kenya, David (1997) found that up to 87% of all household expenditure went towards purchasing food and non-food necessities, while only 7% went towards farm inputs such as hired labor, fertilizer, and seed. This study agrees with David's (1997) conclusion that resource-poor farmers have little or no savings and households give priority to investments which yield short-term returns.

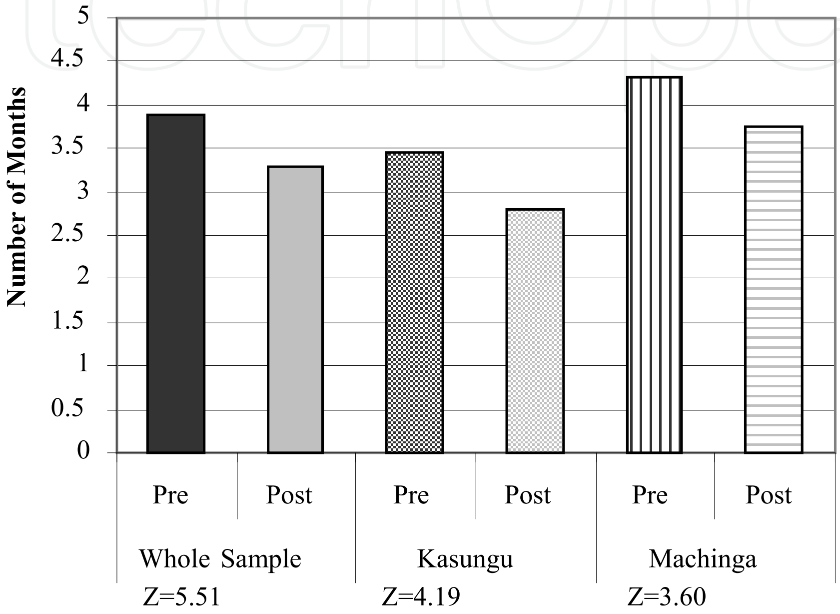

Fig. 3. Average number of hunger months before (Pre) and after (Post) SFR adoption. All differences are significant at p<0.05

Allocation	Kasungu (n=48)	Machinga (n=30)	Whole Sample (n=78)
Savings	16.7	6.7	12.8
Pay Debts	93.8	96.7	94.8
Purchase Household Items	100	100	100
Purchase Food	97.9	100	98.7
Purchase Agricultural Supplies	97.9	96.7	97.4
Medical Fees	47.9	53.3	50
School Fees*	35.4	13.3	-

Values are the percent of "yes" responses from those who reported an increase in income.
* Indicates a significant difference (Fisher's exact p-value<0.05) between the sites and means could not be pooled

Table 7. Percent of respondents reporting various allocations of additional income

Households allocated income to the purchase of household items, agricultural supplies, and food. These items have an immediate and direct effect on the wellbeing and security of household members. Investing additional income or resources into savings, non-essential assets, or school fees are investments that have long-term implications to the household's well-being, but may be at the expense of immediate needs. It was not expected that households in this study would have become fully food self-sufficient, but rather that they would have been able to spend less money to meet immediate needs and be able to put more income towards non-essential investments, such as savings, or school fees. The results show that households who had seen an increase in income are able to allocate income to a variety of areas, though they still rely heavily on purchasing food and non-food necessities. A full economic analysis at the household level would be necessary to determine if households have realized any significant financial relief since SFR adoption. The use of various coping strategies provides another indication of a household's vulnerability. Ideally, households would have some form of insurance or "safety net" to rely on in difficult times. In the absence of formal security measures however, households are likely to sell productive assets, reallocate time to increase income, or a previously non-working member may enter in the labor market (Jacoby & Skoufias, 1997; Skoufias, 2003) in response to unexpected challenges. It is not surprising then that in this study, households at both sites relied heavily on selling assets, crops, and labor as a response strategy. When households choose to sell their physical assets or crops as a coping mechanism in response to a shock, they may be able to mitigate the immediate effects of the crisis, but to the detriment of future stability. This observation is supported by Skoufias (2003) who observed that poor households may be forced to use coping strategies that ultimately prevent movement out of poverty.

4. Conclusion

This case study has confirmed that agroforestry, and specifically integrated soil fertility replenishment technologies have the ability to increase crop production and provide additional income. This acknowledgement points to the conclusion that farmers have an understanding of the importance of soil fertility and the currently low soil nutritional status. Other studies have also found that even in the absence of knowledge about the chemical or structural properties of soils, farmers are keenly aware of, and have noticed detrimental changes in various aspects of their local environments such as rainfall patterns, and soil performance over time and soil analysis consistently supports farmer perceptions of soil fertility (Desbiez *et al.*, 2004; Mairura *et al.*, 2007; Murage *et al.*, 2000; Thomas *et al.*, 2007).

Hunger months have decreased, and in many cases, income has increased. However, the respondents in the two study areas still live on the margins of survival. This study revealed that while food security is paramount to sustaining the livelihoods of smallholder farmers, livelihood security and poverty reduction depend on more than increased food production. SFR technologies are fulfilling their primary role as a means to food security, but their adoption does not lead to significant livelihood improvements. Achieving lasting impacts requires that initiatives take an integrated approach and address not only household food production, but the multifaceted dynamics of social institutions, markets/economy, and policy. However, it is apparent that despite the repeated confirmation of the challenges associated with land, labor, seed and training, little has been done to find solutions to these issues.

While agroforestry alone cannot completely bring households out of poverty, it can play a significant role by improving food security and providing additional income opportunities. Livelihood improvements will depend on several factors. First, market inefficiencies must be remedied and economic barriers must be broken down. Second, the challenges identified by the respondents, especially access to resources and training, need to be addressed in a participatory way that promotes education and empowerment. As these two issues are tackled, households will become better equipped to manage the complexities that arise from SFR adoption and livelihood diversification, such as managing crop surplus and additional income.

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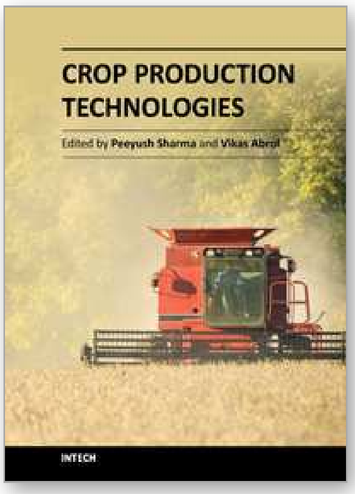

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Crop production depends on the successful implementation of the soil, water, and nutrient management technologies. Food production by the year 2020 needs to be increased by 50 percent more than the present levels to satisfy the needs of around 8 billion people. Much of the increase would have to come from intensification of agricultural production. Importance of wise usage of water, nutrient management, and tillage in the agricultural sector for sustaining agricultural growth and slowing down environmental degradation calls for urgent attention of researchers, planners, and policy makers. Crop models enable researchers to promptly speculate on the long-term consequences of changes in agricultural practices. In addition, cropping systems, under different conditions, are making it possible to identify the adaptations required to respond to changes. This book adopts an interdisciplinary approach and contributes to this new vision. Leading authors analyze topics related to crop production technologies. The efforts have been made to keep the language as simple as possible, keeping in mind the readers of different language origins. The emphasis has been on general descriptions and principles of each topic, technical details, original research work, and modeling aspects. However, the comprehensive journal references in each area should enable the reader to pursue further studies of special interest. The subject has been presented through fifteen chapters to clearly specify different topics for convenience of the readers.

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