Impact of Natural Resource Management Technologies on Small-scale Farmers: Case of Fertilizer Tree Fallows in Zambia

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1 Introduction

In the past decade, there have been growing concerns regarding information gap on the demonstrable impacts that investments of the CGIAR system in natural resource management technologies have had on farmers and the environment. In response, the Standing Panel on Impact Assessment of the CGIAR (SPIA) commissioned case studies in selected CGIAR centers aimed at evaluating and documenting the impacts of natural resource management technologies and other interventions that have been developed by CGIAR centers. This work presents a special case study of natural resource management technology- fertilizer tree fallows – the development of which was led by the World Agroforestry Centre (ICRAF). The study describes the technology, provides historical information on its development and evaluates its impact on improving the lives of farmers (especially resource-poor and small-scale farmers) and their landscapes.

2. Research which led to the technological innovation.

2.1 Constraint addressed by fertilizer tree fallows in Zambia

One of the greatest biophysical constraints to increasing agricultural productivity in Africa is the low fertility of the soils (Bekunda et al. 1997; Sanchez 1999). Smaling et al. (1997) estimate that soils in sub-Saharan Africa are being depleted at annual rates of 22 kg/ha for nitrogen, 2.5 kg/ha for phosphorus, and 15 kg/ha for potassium. The degradation of soils is caused by two related factors: (i) breakdown of the traditional production systems resulting from shortening of fallow periods due to population pressure and (ii) low adoption of sustainable resource management strategies (Kwesiga et al. 1999). The need to improve soil fertility management in the continent has become a very important issue in the development policy agenda (Scoones and Toulmin 1999; NEPAD 2003) because of the strong linkage between soil fertility and food insecurity on one hand and implications on the economic well being of the population on the other. To mitigate declining soil fertility, farmers in many areas have traditionally left their land in fallow periodically, i.e., they allowed the land to regenerate after several seasons under fallow. However, given the relative fixed quantity of available cultivable land, as the population increases, fallow periods became shorter and in some cases, farmers were cultivating marginal areas. These led to lower crop yields and declines in food security for the households in most countries in the sub-saharan Africa.

After political independence, the agricultural strategy in Zambia in particular and many countries of southern Africa in general focused on increasing maize production through broad interventions in input and output markets. These include generous subsidies on fertilizer, easy access to agricultural credit, and a range of government-supported institutions and depots located in rural areas to supply farm inputs and assure the purchase of maize output from farmers. The introduction of structural adjustment program, removal of farm inputs subsidies, collapse of agricultural credit programs and para-state marketing system in the late 1980s and early 1990s marked a major turning point in farmers' socioeconomic environment and their capacity to afford chemical fertilizers. Private sector operators did not fill the gap in the fertilizer and credit markets as was originally assumed by the structural adjustment program. African farmers pay the highest fertilizer prices in the world, whether in US dollars or in grain equivalents (Conway and Toenniessen 2003) especially in the landlocked southern African countries. On the other hand, while fertilizer prices were increasing, the producer price of maize was fixed or increased at a lower rate than that of fertilizer. These among other factors led to drastic reduction in fertilizer use among small scale farmers and reduced farm incomes (Place et al 2001, Sanchez et al., 1997). Given that farmers have been accustomed to using fertilizer, they were left with a huge need for soil-fertility improving practices which they could not afford.

In response to the challenges enumerated above, the World Agroforestry Centre (ICRAF) initiated research on sustainable soil fertility management options that are suitable for resource-poor farmers to replenish soil fertility within the shortest possible time and reverse the negative trend. Fertilizer tree fallows allow farmers to produce nutrients through land and labor rather than cash, which they lack.

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2.2 Description of fertilizer tree fallows and identification of technology intervention

Fertilizer tree fallows were not practiced by farmers until after the arrival of ICRAF in southern Africa. The development of fertilizer tree fallows in southern Africa began with diagnostic and design surveys (Ngugi, 1988) and ethno-botanical surveys in the late 1980s which revealed a breakdown of traditional strategies to sustain production of food. At the beginning, ICRAF contemplated and carried out initial research on alley cropping and biomass transfer systems, but they were discontinued because they were too labour intensive and did not perform well technically (Ong 1994, Akyeampong et al 1995). The quest for a new approach to respond to soil fertility problems led to research on fertilizer tree fallows. This option involves planting fast growing plant species that are (usually) nitrogen-fixing, produce easily decomposable biomass, compatible with cereal crops in rotation and are adapted to the climatic and soil conditions of the miombo woodland ecology of southern Africa (Kwesiga and Coe 1994).

The earliest experiments on fertilizer tree fallows began with an indigenous nitrogen-fixing plant, *Sesbania sesban* above

The strategy uses leguminous fallows to accumulate N in the biomass and recycle it into the soil, to act as a break crop to smother weeds, and to improve soil physical and chemical properties. The development of the technology is based on the fact that while nitrogen was identified to be the most limiting macro nutrient in the soil, it is known to be highly abundant in the atmosphere. The hypothesis is that through the use of fast growing, N_2-fixing leguminous trees, fertilizer tree fallows systems would provide nitrogen for the subsequent crop, increase soil organic matter and improve soil physical conditions (Kwesiga et al 1999). The trees increase the availability of nitrogen (N) through atmospheric fixation of N_2. It must be noted that the notion "fertilizer trees" does not imply that the trees provide *all* the major nutrients: they are capable of fixing only N which is the most limiting. The two other macro nutrients phosphorus (P) and potassium (K), which are required by crops, were not as critically limiting levels as N and posed comparatively less serious constraints to agricultural production when research on fertilizer tree fallows began in Zambia. Fertilizer tree fallows do recycle some P and K from soil depths to their leaves, but the two nutrients must be sourced externally if they are depleted from the soil.

The cycle of fertilizer tree fallows begins when plant species are established as a pure stand or intercropped with food crops and they are allowed later to grow for one or two more years. The tree fallows are cut between 12 and 36 months after planting and the foliar biomass is incorporated into the soil during land preparation. The biomass of fertilizer tree fallows easily decomposes and makes nutrients available for subsequent crops (usually maize) that are planted to take advantage of the improved soil fertility and residual effect of the same for two to three years. The complete cycle of fertilizer tree fallows thus is a fallow phase of one or two years followed by a cropping phase of 2-3 years. The major plant species used are *Sesbania sesban, Tephrosia vogelli, Tephrosia candida* and *Cajanus cajan.* To avoid the potential risks of developing a technology based on a narrow plant genetic base, a range of other species, some that can re-sprout ("coppice") after they are cut, has been introduced. Technical details on fertilizer tree fallows have been described elsewhere (Chirwa et al 2003, Kwesiga et al 1999, Kwesiga and Coe 1994 and Mafongoya et al 2003).

A *Tephrosia candida* fertilizer tree fallows field

The development of fertilizer tree fallows can be categorized into two

Gliricidia sepium field- a coppicing fertilizer tree fallows and one of the new innovations to fertilizer tree fallows technology.

broad phases: Phase 1 begins in 1986, when ICRAF and NARS researchers conducted diagnostic surveys to identify farmers' problems and assess whether agroforestry practices could help them and were of interest to them. This followed upon a period of shrinking farm size and natural fallowing, declining soil fertility, and reduced fertilizer subsidies. The second phase began in 1997/98 when the dissemination of the technology to farmers was initiated and was followed by the current efforts aimed at scaling up/out the practice to several other farmers. In the 2002/2003 season, an estimated 180,000 farmers in southern Africa region were planting fertilizer tree fallows (Zambezi Basin Agroforestry Project Annual report 2003).

2.3 Improvement on the antecedent technology

Research results from on-station and on-farm trials in fertilizer tree fallows fields show significant increase in maize yields following *Sesbania sesban and Tephrosia vogelii* fallows compared with common farmers' practice of continuous maize production without fertilizer. Details are presented in Table 1, but to summarize, the yield increases from fertilizer tree fallows range between two and four times those from continuous maize without nutrient inputs.In addition to maize yield increases, 10, 15 and 21 tons per hectare of fuel wood was harvested after 1, 2 and 3 years of Sesbania sesban fallow respectively (Kwesiga and Coe, 1994). Financial analysis showed that fertilizer tree fallows systems were profitable with positive net benefits per unit land cultivated and favourable financial ratios (Place *et al.,* 2002, Franzel et al 2002, Ajayi et al 2004).

Table 1: Maize grain yield after 2 year *Sesbania sesban* and *Tephrosia vogelii* fallows in farmers' fields in eastern Zambia during 1998-2000

Fallow species	Maize grain yield (tons ha^{-1})			
	Land use system	Year 1	Year 2	Year 3
Sesbania sesban fallows	Sesbania fallow	3.6	2.0	1.6
	Fertilized maize	4.0	4.0	2.2
	Unfertilized maize	0.8	1.2	0.4
	LSD (0.05)	0.7	0.6	1.1
Tephrosia vogelii fallows	Tephrosia fallow	3.1	2.4	1.3
	Fertilized maize	4.2	3.0	2.8
	Unfertilized maize	0.8	0.1	0.5
	LSD (0.05)	0.5	0.6	0.9

Source: Ayuk and Mafongoya (2002)

2.4 Modifications and Adaptation of Fertilizer Tree Fallows

In the development of fertilizer tree fallows, several modifications and adaptations to the technology were made by farmers and these were actively encouraged by researchers. Three types of experimental trials can be identified in the development of the technology (Table 2).

Table 2: Typology of experimental trials of fertilizer tree fallows

Type of trial	Location of trial	Design of trial	Management of trial	Level of farmer modification
Type I	On-station	Researchers	Researchers	None
Type II	Both	Researchers	Farmers	Low
Type III	Farmers' field	Farmers	Farmers	High

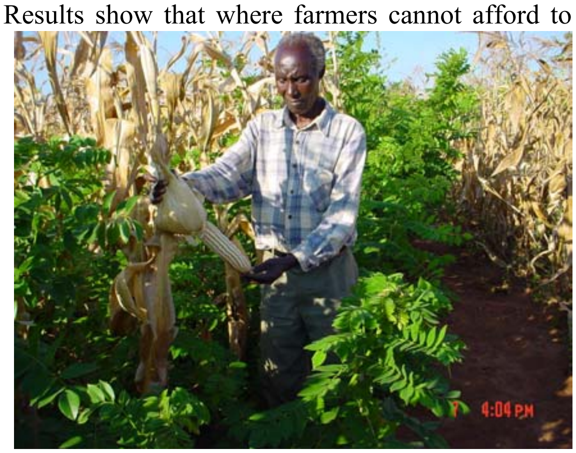
Type III trials is based on constructivists approach- i.e. farmers assess adoption of fertilizer tree fallows as socially constructed process through which they make sense of their experiences and are allowed to freely modify and adapt the technology the way they wanted. Kwesiga et al. (2004) documents key farmer innovations on fertilizer tree fallows presented in Table 3.

Table 3: Farmer innovations and adaptation of fertilizer tree fallow technology

- The use of Sesbania regenerations as planting material for establishing new fallows. This innovation saves farmers' labor for having to establish nurseries during the dry season.
- Testing the effect of fertilizer tree fallows on crops other than maize, such as sunflower, cotton, paprika and groundnuts. In fact no scientific research has been conducted on the effect of fertilizer tree fallows on other crops besides maize and bean.
- Removing of Sesbania tips to stimulate lateral branching and thus biomass production.
- Using rain-fed nurseries as opposed to nurseries in hydromorphic ("*dimba*") gardens during the dry season. These nurseries are preferred because they reduce the labor required for transporting the seedlings and reducing the labor needed for watering
- Planting fertilizer tree fallow species seedlings directly into a bush fallow without preparing the land first. This aims at reducing the cost of land preparation.
- Gapping up their Sesbania fields with seedlings planted one year after the first planting.
- Planting Sesbania at weeding time into parts of fields where maize was performing poorly

Source: Kwesiga et al 2004

Further efforts at modification and generating diverse options of the technology include experiments which were conducted to evaluate the interaction between chemical fertilizers and fertilizer tree fallows. Results show that where farmers cannot afford to apply the recommended full dose of inorganic fertilizer in their field, fertilizer tree fallows produce a synergistic effect as it can be used in combination with lower rates of chemical fertilizers to obtain a more than proportionate yield increase (Kwesiga and Coe 1994, Ayuk and Mafongoya 2002). The synergistic yield increase resulting from the use of fertilizer tree fallows and a small dose of inorganic fertilizer is presented in Table 4 below. Using stochastic dominance approach, results show that over all probability levels, recommended fertilizers offer superior benefits over the fertilizer tree fallow options. However, when ¼ and ½ doses of



A farmer admiring maize cobs in his fertilizer tree fallow field.

recommended fertilizers are added to maize following fertilizer tree fallows, the amended tree-based practices are superior ("dominates") the full recommended fertilizer rate, at higher cumulative probability levels (Figure 2). These results show that at certain levels there is some synergy between mineral fertilizers and improved fallows species such as *Sesbania sesban and Tephrosia vogelii*.

Table 4: Maize yields (ton ha^{-1}) following 2-year *Sesbania sesban* fallows in combination with different dosages of the recommended fertilizer level in eastern Zambia.

Treatment/Year	1996	1997	1998	1999	2000
Sesbania fallow + 50% fertilizer	F	F	3.6	4.4	2.7
Sesbania fallow + 25% fertilizer	F	F	3.6	3.4	2.3
Sesbania fallow + no fertilizer	F	F	3.6	2.0	1.6
Continuous maize + 100% fertilizer	3.0	3.7	4.0	4.0	2.4
Continuous maize + no fertilizer	0.7	0.8	1.0	1.2	0.5

F= fallow phase: trees growing for two years;

Source: Mafongoya (2002)

Compared with the preceding year, maize yield generally fell drastically in 2000 due to drought that occurred in the year. However, fertilizer tree fallows performed better during the drought year compared with continuous cropping methods as average yields fell by 30% in fertilizer tree fallows fields compared with 49% reduction in yield in conventional maize fields. The reduction in the effect of drought is because fertilizer tree fallows increased soil-water storage in the soil profile compared to conventionally-tilled non-fertilized maize system (Phiri et al 2003).

Figure 1. Cumulative distributions of discounted net benefits of full fertilizers vs pure fertilizer tree fallows

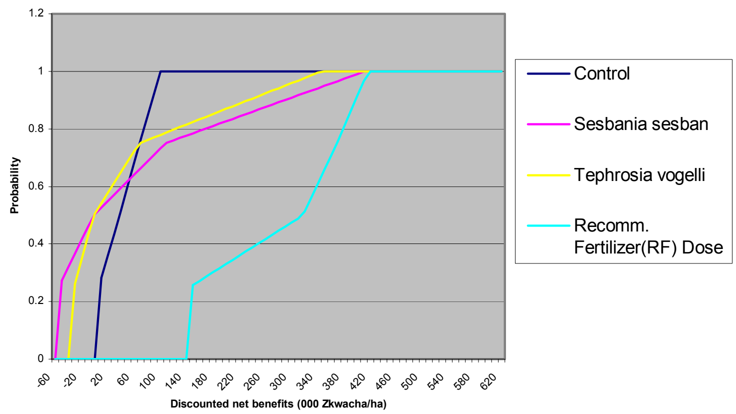
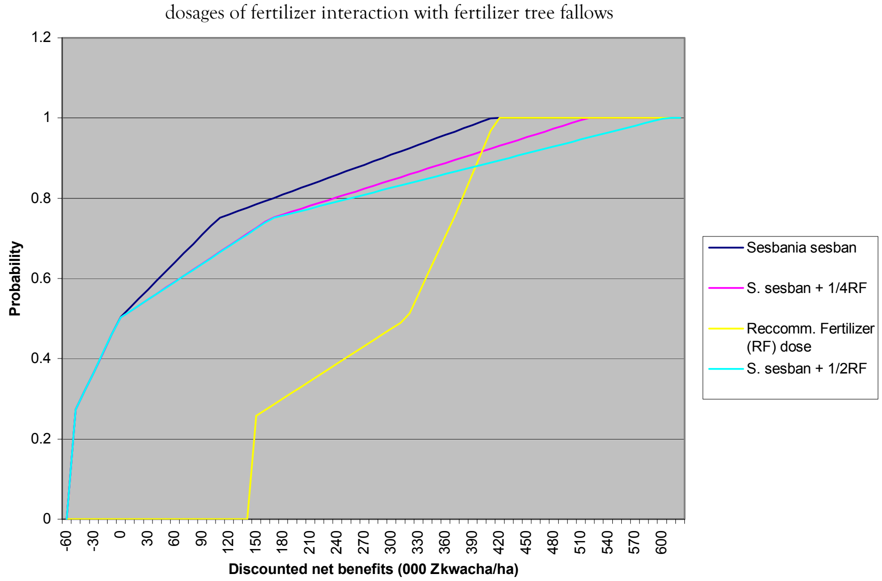


Figure 2: Cumulative distributions of discounted net benefits of full fertilizers vs different dosages of fertilizer interaction with fertilizer tree fallows



Source: Ayuk and Mafongoya (2002)

Recommended fertilizer (RF)=112kg N/ha; 20kg P/ha; 20kg K/ha

Previous studies have found a tentative indication that organic and inorganic fertilizers prove to be complementary. Haggblade et al (2004) for example attribute the complementarity to the contributions of soil organics to improved water and nutrient retention as well as improved microbiological activity, and given the well-established links between inorganic fertilizer and availability of water.

2.5 Contribution to the development of innovation in Zambia.

The World Agroforestry Centre (ICRAF) initiated research on various agroforestry-based soil fertility management options that can be used on their own or in combination with other soil replenishing options. This was done in close collaboration with national research and development in the Southern Africa Agroforestry Research Network. ICRAF established on-farm research not only to assess biophysical and economic responses under farmer management, but also to expose the technology to agricultural extension officers and to assess how farmers used and modified the technology. The on-farm research approach taken was first to establish good relationships with the extension staff, and through them to the farmers. ICRAF and partners spent much time exposing the technology to the government extension officers (camp officers) in their target villages, where each camp extension officer is responsible for about 200 farm families. Camp officers were thus the main facilitators at the grassroots level. Based on initial training of camp officers with village discussion groups, villages near a farmer training center (FTC) were selected for technology demonstration and experimentation purposes. ICRAF also organized "agricultural field days" when farmers, extension staff, and development agencies were invited to the research station or to on-farm trials to see and discuss the progress on research and technologies being developed. Given the high profitability of fertilizer tree fallows compared with continuous maize without fertilizer (Franzel et al. 2002, Ajayi et al 2003) and awareness by policy makers about potential impacts, ICRAF begun efforts to scale up/out the information about the technology and knowledge on seed systems to reach more farming communities. The scaling up effort is coordinated through the Adaptive Research and Development Network (ARDN) – comprising ICRAF, government research and extension, farmer organizations, and NGOs. In many of the partner organizations, fertilizer tree fallows (and agroforestry in general) is one component among several other programs that they are involved with. The ARDN framework enhances collaboration and exchange of germplasm and information among the many different types of organizations. It also ensures that the demise of any organization will not affect the overall progress in the development of options and the spread of the practice among farmers.

2.6 How innovation reached farmers and create benefits

In addition to increasing crop yields, fertilizer tree fallows provide benefits to farmers in terms of reduced crop production risk from drought, increased fuel wood and other byproducts, such as insecticides made from *Tephrosia vogelii* leaves. The main environmental benefits at farm level are improved soil physical properties, such as better infiltration and aggregate soil stability, which reduce soil erosion and enhance the ability of the soil to store water. Fallows can also provide wider environmental services such as biodiversity conservation through reduced pressure on woodlands for fuel wood and carbon sequestration. These are discussed in section 5.

Table 5: Historical milestones of the development of fertilizer tree fallows and out-reaching in southern Africa

Period	Key milestones
1989	Diagnostic & Design ➢ Assess key constraints to agricultural productivity and food production ➢ Soil fertility problems highlighted as one of the principal constraints
Early 1990s	On station trials ➢ Controlled experimentation on the use of fast growing nitrogen-fixing tree species to replenish soil fertility within 2-3 years
Mid 1990s	➢ Beginning of on-farm trials and farmer adaptation/modification of the technology
1998 and later	Scaling up & wider dissemination among farmers

Modified from Kwesiga et al 2004

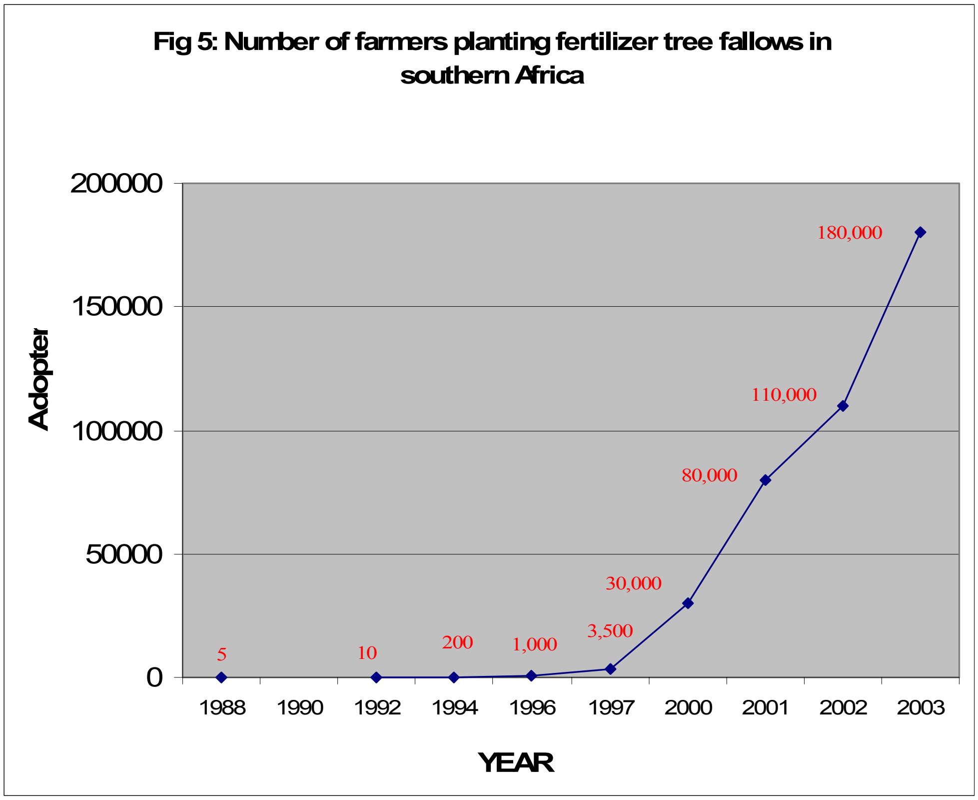
3 Adoption and beneficiaries of fertilizer tree fallows

3.1 Adoption of fertilizer tree fallows

Because fertilizer tree fallows are a new technology, and its dissemination on a large scale to farmers took place more recently, there has been inadequate time for many farmers to have implemented more than one cycle. Those that have planted for a second time (on a reasonable size of land) might be called adopters while those still in a first cycle might best be called users. In practice, much of the socioeconomic research has not carefully distinguished between these two types. In fact, early research took place before there were any true adopters. Later research (i.e. after 2000) looked both at patterns among first time planters and among those planting repeatedly. To be consistent with common terminology, we have opted to use the terms "use" and "users" though we realize that in many cases, this reflects bonafide adoption. These terms reflect the complexity of farmer decisions regarding "adoption" of agroforestry technologies compared with those for traditional annual crops (Scherr and Müller 1991, Mercer 2004*).*

3.2.1 Level and Trend of Use of Fertilizer Trees

In the early period of the development of fertilizer tree fallows, researchers and farmers placed emphasis on technology generation, modification and adaptation. From less than a hundred adopters in the early nineties, the number of farmers who have planted the fertilizer trees has been increasing steadily since the late 1990s and especially from the year 2000 onwards. There has been a spillover of the establishment of fertilizer tree fallow fields beyond the initial geographical region (eastern Zambia) where the technology was initiated. Several hundreds of farmers across the border in Malawi had also planted in the 1995-98 period, largely as a result of farmer-to-farmer exchange visits between Zambian, Malawian and Mozambican farmers. As at 2002/2003 season, the number of farmers who have established at least one fertilizer tree fallow field throughout the southern Africa region is estimated at 180,000 (Zambezi Basin Agroforestry Project Annual report 2003). This figure includes farmers that have been reached directly by ICRAF and indirectly through collaborating partner institutions and farmer-to-farmer exchange programs (Table 5).



Source: ZBAP Annual report 2003

In addition to an increase in the number of farmers planting fertilizer tree fallows, the average size of fields cultivated by farmers has followed an upward trend. From an average field size of 0.07 ha in 1997, the average size of fertilizer tree fallow fields have increased to 0.20 hectare in 2003. However, the distribution of the field size varies widely ranging from 0.01 ha to 0.78 ha per farmer.

3.1.2 The "take off" of use of fertilizer trees

One of the major reasons for the success recorded in the fertilizer trees over comparable technological options is the active encouragement for a constructivist approach taken in the development of the technology, i.e. farmers were encouraged to try the technology, then modify and re-adapt it based on their experiences and desires in a repeated iterative cycle. Compared with preceding periods, a significant increase in the number of farmers establishing fertilizer tree fallows was recorded from the late 1990s. Several factors contributed to the "take off" of fertilizer tree fallows in the late 1990s compared with preceding periods. These include:

- Devaluation of the national currency following structural adjustment program (SAP) weakened the purchasing power of the local currency resulting in the cost of imported chemical fertilizer to be increasingly prohibitive for small scale farmers.
- In addition to the increases in the cost of fertilizers, farmers also faced increasing occurrences of late delivery of the inputs due to poor maintenance of rural feeder road infrastructures and markets facilities compared to the government-subsidy era.
- Collapse of agricultural finance banks (e.g LIMA and Cooperative Banks) that provided farmers with soft loans to purchase chemical fertilizers.
- At later stages, several institutions that were interested in promoting natural resource management options provided added impetus in spreading the innovations among farmers. Such institutions include the World Vision Integrated Agroforestry Project in Zambia (ZIAP), Eastern Province Development Women Association (EPDWA), TARGET Project in Zambia, Soil Conservation and Agroforestry Extension (SCAFE) in Zambia and Malawi Agroforestry and Extension (MAFE), USAID-funded TARGET agroforestry training Project, and new interests in agroforestry technology by organizations such as PLAN international and KEPA (a Finnish development organization). In partnership with ICRAF, these institutions assisted in reaching a nucleus of farmers through direct training and provision of initial seed to farmers. These contributed to "kick start" the spread of the technology mainly through a farmer- to- farmer exchange process. These organizations focused more on the dissemination of information on the technology, but the research and refinement of the technology was championed by ICRAF.
- .Increasing emphasis by ICRAF on development programs aimed at accelerating the scaling up/out of the use of fertilizer tree fallows among farmers. This strategic focus

was institutionalized in ICRAF's organizational structure through the formal creation of a Development Division in ICRAF.

- Fertilizer tree fallows are knowledge-intensive technology. This requires a time lag for farmers to acquire necessary information and the confidence about the new innovation. As a result, initial training and development efforts did not translate to immediate adoption response by farmers. In recent years, farmers appear to have overcome the initial inertia as indicated by the significant increase in the number of users.
- The emerging trend of the involvement of private sector organizations and individual entrepreneurs in the provision of support services and inputs for fertilizer tree fallows. These include:
    - Tobacco companies who are training their contract farmers on the use of poles from fertilizer tree species to make sheds for curing tobacco to avoid further deforestation associated with tobacco curing operations.
    - The time limit given by the government and international buyers to tobacco companies within which companies are expected to comply with more environment-friendly operations and to demonstrate commitments to reduce deforestation. This has led some tobacco companies to initiate "cash-for-trees" programs aimed at paying farmers to plant trees including agroforestry species.
    - Individual entrepreneurs (at present, these are exclusively rich men and others who have retired from formal employment) who are establishing large hectares of seed orchards to meet rising demand for fertilizer tree fallow seeds (especially *Gliricidia sepium*) for sale to farmers.

3.2 Factors driving Use and Adoption of Fertilizer Tree Fallows

Our studies regarding farmer use and adoption of fertilizer tree fallows have centered primarily on two major issues: (i) the factors that drive the use/adoption of fertilizer tree fallows among the farming communities and, (ii) gaining insights into the categories of farmers who use/adopt (or do not adopt) the technology. Table 6 presents selected studies that have been carried out to fill this gap. Many used descriptive statistics but two relied on multivariate econometrics (see table). Ajayi et al (2003) synthesized the studies on the adoption of fertilizer tree fallows in Zambia to highlight the main lessons learnt and identify generic issues that have emerged from the studies, and draws implications of the findings for policy and scaling up of fertilizer tree fallow technology in the region.

Table 6: Description of selected adoption studies and summary of factors affecting farmers' decisions to plant fertilizer tree fallows in eastern Zambia.

Study (and number of households involved)	Wealth	Age	Sex	Education	Labor / Household size	Farm size	Uncultivated land	Use of fertilizer	Off-farm income	Oxen owner-ship	Village exposure to improved fallows
Factors affecting decision to plant fertilizer tree fallows for the first time											
Franzel, S. 1999 (157 households)			N		N						
Phiri et al. 2004 (218 households)	+		N								+
Kuntashula et al. 2002 (218 households)	+	N		N		+	N		N	+	
Ajayi et al. 2001 (305 households)			N		+,N	N		+			
Peterson et al. 1999 (320 households)	+					+				+	
Factors affecting decision to continue to plant											
Keil 2001 (Tobit analysis of 100 households)	+/-	N	N	N	+	+					
Place et al. 2002 (Logit analysis of 101 households)		+	N	N	N	N					+

Legend: +: increases planting of fertilizer trees -: decreases planting of fertilizer trees

N: no effect on planting of fertilizer trees +/-: can increase or decrease planting

Blank means the variable was not included in the specific study.

Source: Ajayi et al (2003)

The synthesis noted that adoption of fertilizer tree fallows is a continuous process in which farmers can be conceptualized to occupy a position along a continuum in the adoption path. The synthesis indicates that farmers' decision to adopt fertilizer tree fallows is not a direct relationship based exclusively on some technological characteristics, but is influenced by a matrix of several hierarchies of factors. The factors can be categorized into broad groups: (i) institutional and policy factors especially fertilizer subsidies and land tenure issues, (ii) spatial and geographical factors like accessibility to markets and location of a village/farmer within or outside the intervention zones of Projects that are promoting agroforestry technologies and (iii) household-specific variables (e.g. wealth status, gender, household size).

3.2.1 Fertilizer subsidies and government policies

The cross-cutting issues that have wider impact on farmers' decision to adopt fertilizer tree fallows are subsidies on fertilizer and land tenure. The Zambia government introduced fertilizer subsidies in 1971-72. Initially subsidies were 30 percent of landed cost, but averaged 60 percent by 1982. Maize, the staple food and a politically strategic crop in the country is the primary beneficiary of these subsidies accounting for 90% of the total subsidized fertilizers (Howard and Mungoma, 1996). As important as the direct subsidies, the expansion of a network of government-supported cooperative depots during the early 1970s made inputs more accessible to farmers in remote areas thus increasing fertilizer use from 20,000 tons of nutrient in the early 1970s to 85,000 in the mid-1980s. The expansion of the cooperative depot system also made it possible for smallholder farmers to obtain subsidized fertilizer through government inputs loan programs (Howard and Mungoma, 1996). As a result, fertilizer use was common among farmers in Eastern and other parts of Zambia during the 1980's but the removal of subsidies and collapse of the para-state marketing system in the late 1980s and early 1990s had dramatic negative effects: the ratio between the price of nitrogen and the price of maize increased from 3.1 in 1986/87 to 11.3 in 1995/96 and, fertilizer use in Zambia declined by 70%. The breakdown in subsidies and credit programs and the subsequent reduction in fertilizer use marked a key turning point in farmers' socioeconomic environment. Farmers had "tasted fertilizer," but after the breakdown in support systems promoting its use, they were left with a huge need for soil-fertility improving practices (Kwesiga et al 2004). This previous appreciation for the benefits of soil nutrients contributed to the interest and uptake of the fertilizer tree fallow technology. It has to be noted that fertilizer trees are one option within a range of several others that can provide nutrients or otherwise contribute to soil health. Given that subsidies make fertilizer prices artificially lower and more profitable for users, it is expected to have implications for the adoption of different soil fertility replenishing options. As a result, subsidies on fertilizer do have some effects on the demand for and the adoption of agroforestry-based soil fertility management technologies (Place and Dewees 1999). Where mineral fertilizer is highly subsidized, it is less likely that farmers will readily adopt agroforestry as an option for supplying nitrogen. Recent financial analysis of fertilizer tree fallows (Ajayi *et al* 2004, Franzel 2004) show that fertilizer subsidies and other key non-household specific factors affect the profitability and potential adoptability of fertilizer tree fallows relative to other soil fertility management options even when technical relationships (e.g. yield coefficients) between inputs and outputs remain constant. Most households do not have direct control over the major factors that determine profitability and potential adoptability of soil technologies and as result, enhanced adoption of fertilizer tree fallows need to be facilitated by appropriate and conducive policies and institutional framework at the local and national levels.

3.2.2 Institutions and property rights

Property rights and customary practices of setting bush fires and free grazing affect the adoption of fertilizer tree fallows in Zambia. A recent study (Ajayi and Kwesiga 2003) shows that the pattern of distribution of benefits (or costs) of fertilizer tree fallows among various sectors of a community are important factors that enhance (or inhibit) the widespread use of the technology. The study also finds that privatizing of seasonal commons is an important issue in the efforts to scale-up the technology in Zambia. A comprehensive study on the influence of land tenure on the adoption of tree resource management and agricultural investment in southern Africa region (Malawi) is documented in Place *et al* (2001). The major method of land acquisition is inheritance followed by allocation by a chief or headman. Generally, these methods offer long-term rights to households in the sense that they may retain rights over the land so long as they continue cultivation, and may also bequeath the land to descendents. A key distinction, however, is between matrilineal and patrilineal inheritance systems. Studies have found that there is less investment in tree planting in matrilineal systems where husbands live in their wives' villages with insecure long-term rights to land.

3.2.3 Spatial location factors

Community level variables, residence of household in pilot agroforestry dissemination villages and the location of the camp of a farmer significantly affected the continued adoption of fertilizer tree fallows These factors have similar impacts on all types of households within the communities. The most important was whether the household resided in one of the pilot villages having access to greater attention and technical advice from agroforestry institution (Place et al 2002). To provide greater insights into the spatial dimension of the adoption of fertilizer tree fallows, a detailed multi-disciplinary spatial adoption study has been initiated to map out the geographical location of adopters of fertilizer tree fallows, determine the spatial trend of distribution of the adopters and the underlying reasons for such distribution.

Preliminary results from the study (on-going) suggest that the presence of agroforestry-supporting institutions (because they provide information and visual demonstration of potential benefits), capacity and commitment of government agricultural extension services to fertilizer tree fallows in a given location and, access to road and markets- are important factors driving the adoption of fertilizer tree fallow technologies. The influence of access to roads and markets may be because the profitability of a technology (and hence its potential adoptability by farmers), determined largely by the cost of production and value of output, is dependent on the access to roads, markets and other spatial factors. It may also reflect the interests of organizations involved in scaling up of the technology. When finalized, the study will provide more insight into the spatial pattern of adoption beyond the information that have been provided by conventional adoption studies that are based exclusively on household surveys.

3.2.4 Household and individual factors

In addition to the above, several individual household-specific factors that influence farmers' decision to establish fertilizer tree fallows including the following:

Training and Awareness: given that fertilizer tree fallows is relatively more knowledge-intensive, this is one of the most important factors driving the adoption of the technology. Farmers who plant fertilizer tree fallows are mainly those who have heard of or witnessed (in fellow farmers' fields or on demonstration plots) the role of trees to improve soils. Others are farmers who are aware that their soils are poor but cannot afford fertilizer and have access to information on the potential of trees to replenish the fertility of their soils. Many adopters comprise those who have been formally trained by organizations that support agroforestry, or informal knowledge-sharing by fellow farmers who have adopted earlier and through farmer exchange visits.

Wealth status: There is some evidence that wealth level and planting fertilizer tree fallows are positively related (log linear model, $p < .08$). Whereas 53% of the well-off farmers planted fallows, 40% of the fairly well off, 22% of the poor and 16% of the very poor group of farmers planted fertilizer fallows (Phiri et al. 2004). However, the proportion of farmers who continue to plant fertilizer tree fallows (i.e. adopters) after their first planting did not appear to vary by wealth status. The fairly well-off were the most likely to continue, followed by the poor, the very poor, and then the most well-off in that order (Kiel 2001). The lower likelihood of the well-off to continue planting fertilizer tree fallows is probably associated with their ability to use a range of soil fertility measures, such as manure and fertilizer that are not available to other farmers.

Labor inputs: There is no conclusive evidence that fertilizer tree fallows require a higher quantity of labor inputs compared with traditional soil management practices. Over a five-year period, farmers used 11% less labor on fertilizer tree plot than on unfertilized maize because of reduced labour when the fallows are present (Franzel et al 2002). Another labour issue concerns the timing of labour for fertilizer tree fallows and that it may coincide with other critical field activities. The popular notion of "labor constraints" associated with fertilizer tree fallows may have stemmed from the fact that the introduction of the technology into the farming system obliges farmers to provide *additional* labor inputs within a short period, over and above the normal labor inputs required in conventional crop fields (Ajayi et al 2004). Lack of availability of labor does not necessarily prevent farmers from establishing fertilizer tree fallows (because average area planted is small) but it may pose an important limitation to the area that a farmer allocates to the technology (Place 2002).

Gender: The existing power relations between men and women generally influence the adoption of new agricultural technologies in most African communities and agroforestry is no exception. The gender difference is manifested in terms of decision making, land tenural rights and access to productive resources. However, apart from these gender differences, fertilizer tree fallows in themselves appear to have similar chances to be use and to benefit both men and women.. Several studies (Ajayi et al 2001, Franzel et al 1999, Keil 2001, Gladwin et al., 2002, Phiri et al 2004) found no significant differences between the proportions of women and men planting fertilizer tree fallows. However, in certain cases however, some married women are constrained from establishing improved fallow fields until they obtain consent of their husbands (Peterson 1999).

Affordability of fertilizer: farmers are motivated to plant fertilizer tree fallows because of the high price of fertilizer and lack of access to cash to purchase it. Some farmers who can afford fertilizer presently still plant fertilizer tree fallows as a “back up” measure because they are not sure that they will be able to continue to afford fertilizer in the near future given the history of drastic changes in fertilizer prices (Peterson 1999, Ajayi et al 2001). Farm-level data also shows that once started, most farmers continue to plant fertilizer tree fallows. Keil (2001) noted that 71% of a sample of farmers who planted fertilizer tree fallows in 1996/97 continued to plant them over the next three seasons.

Size of available land owned: Availability of land and size of land holding were positively associated with the establishment of fertilizer tree fallow plots. This is because farmers who have larger uncultivated land could afford to put some part of their fields to fallow compared to farmers who are less land abundant (Place et al, 2002). This limitation led to the introduction of coppicing tree fallow system that remains intercropped with annual crops after the initial establishment of the trees in the field. This has proven attractive in the densely populated areas such as southern Malawi.

Farmers' groups: Farmers who belong to cooperatives or farmers' clubs have higher probabilities of trying improved fallows (Kuntashula et al 2002, Ajayi et al 2001). One of the reasons is that the cooperative groups facilitate easier access to information and training opportunities for their members. Also, for species that require a nursery stage before establishment in the field, groups are useful for managing nurseries (Bohringer and Ayuk, 2002).

3.2.5 Time preferences and characteristics of fertilizer tree fallow technology

Since the effects of conservation agriculture including fertilizer tree fallows may occur through time, adoption of the technology depend on the time preferences and risk aversion of households. Some farmers do not plant fertilizer tree fallows because they are not willing to wait for two years before realizing the benefits of the technology (Peterson 1999), especially if they perceive their initial investment in terms of land and labor to be significant. Such investment horizons are inhibited by poverty because households are often unable to exchange current needs for future gains. Poor households generally have higher discounting factor for future benefits which implies that when making choices of technologies, they tend to sacrifice long term benefits for immediate ones. Taking cognizance of this and as part of the constructivists approach in the continuous modification of the technology, efforts are being made to mitigate this constraint by reducing the "waiting period" generally to one year as follows: First, farmers now intercrop trees with maize in the first year of fallow phase such that the true fallow period occurs only in the second year. Second, new provenances of fallow species (e.g. *Tephrosia candida*) which have vigorous vegetative growth and are able to accumulate good biomass within one year are being introduced into the system.

3.2.6 Farmers' knowledge and perception of soil fertility options

While fertilizer tree fallows have residual fertility effects in the soil over multiple years, farmers mentioned that they need to apply mineral fertilizers repeatedly each year and they have to be procured them through cash or on credit (which often leads to indebtedness). In addition to high cost, the interest of farmers in fertilizer tree fallows is reinforced by the perception that fertilizers spoil the soil (Place et al 2003) or that they burn crops (Ajayi *et al* forthcoming, Peterson et al. 1999). Most farmers desire and like to use mineral fertilizers, the perception that fertilizers "spoil the soil" is linked to acidification and lowering of soil PH from repeated application of the input. Due to wider promotion programs and increased farmer awareness on agroforestry over the years, farmers are appreciating the importance of fertilizer tree fallows beyond just replenishing the fertility of their soils, e.g. provision of fodder for livestock and as source of fuelwood.

4 Impact of fertilizer tree fallows

4.1 Inventory of Costs and Benefits from fertilizer tree fallows

4.1.1 Benefits from fertilizer tree fallows.

The main benefit from fertilizer tree fallows is the increased yields of crops that follow the fallows. In addition to increasing crop yields, fertilizer tree fallows provide benefits to farmers in terms of reduced risk from drought, increased fuel wood and other byproducts, such as insecticides made from *Tephrosia vogelii* leaves. The main environmental benefits are improved soil physical properties, such as better infiltration and aggregate soil stability, which reduce soil erosion and enhance the ability of the soil to store water (see section 5.0). Sesbania fallows were also found to greatly reduce the occurrence of *striga* weeds, which generally thrive under conditions of low soil fertility (Kwesiga et al. 1999). Tree fallows may also help reduce pressure on woodlands for fuel wood energy. However, rigorous field studies are needed to test this hypothesized linkage between planting trees on farms and deforestation reduction. These are listed in Table 7.

In addition to increased average benefits, fertilizer tree fallows may also reduce the effects of drought. In the event of drought (a common phenomenon in southern Africa) leading to crop failure, Franzel and Scherr (2002) identified four ways in which fertilizer tree fallows can help mitigate risk for small scale farmers. These include:

a. Farmers who use inorganic fertilizer would lose investment in fertilizer estimated at US$ 154 ha^{-1} whereas a farmer who planted fertilizer tree fallows would lose investment in planting and maintaining the trees estimated at only US$ 90 ha^{-1} (which is mainly labour costs).
b. The benefits of improved fallow are likely to be spread over a three-year period whereas those of nitrogen fertilizer take place in a single year. Thus in the above case where a farmer's crop fails in the first post-fallow season, there is likely to be a substantial response the following year.
c. Fertilizer tree fallows improve the soil structure and organic matter content of the soil, thus enhancing the soil's ability to retain moisture during drought years.
d. Those who use inorganic fertilizer may not be able to purchase the chemical even if they have the cash, as it sometimes arrives too late in the season to have any effect.

Table 7: Summary of the types of benefits and costs of fertilizer tree fallows

	Individual	**Public**
Cost	• Land • Labor • Agroforestry seeds • Water for nursery • Pest (some fertilizer tree species only) • Working equipments • Field operations in fertilizer tree fallows coincide with those of traditional cash crops (groundnut and cotton) • Risk of uncontrolled fire outbreak	• Incidence of Mesoplatys beetle pest (restricted to specific species only) • Limit the possibility of free grazing during dry season • Risk of uncontrolled fire outbreak
Benefit	• Yield increase • Higher price premium for farm production • Increase in maize stover (helps livestock) • Stakes for tobacco curing • Fuel wood- available in field, and so reduces time spend searching for wood • Helps in fish farming- *Gliricidia sepium* is fed to fishes • Fodder for livestock • Improved opportunity to grow high value vegetables-garlic and onion • Used as biopesticides (*Tephrosia vogelii*) • Suppresses the growth of noxious weeds • Improved soil infiltration and reduced runoff • Potential to mitigate the effects of drought spells during maize season • Much more available to all farmers- availability is not dependent on political connection or social standing • Reduction of risks of maize production • Provision of shade against the sun • Diversification of production (e.g. mushrooms) • Additional income from sale of agroforestry tree seeds • Serves as wind breaks •	• Carbon sequestration • Suppression of noxious weeds • Improved soil infiltration and reduced runoff on the slopes • Potential to mitigate the effects of drought spells during maize season • Enhanced biodiversity • Diversification of income opportunities in the community • Serves as wind breaks

Source: Ajayi (forthcoming)

4.1.2 Costs of fertilizer tree fallows

The chief costs of improved fallows to farmers are the cost of taking land out of cultivation (as indicated in table 8, this value is rather low because maize yields without inputs are low) and the cost of labour. Labour use over the entire fallow rotation compares with that under continuous maize production, but farmers still perceive labour investments in the establishment and cutting of fallows, as well as the nursery labour time where necessary. Over a five year cycle of fertilizer tree fallows, the total labor inputs for continuously cultivated maize field (without fertilizer) is 462 manday equivalent per hectare, 532 mandays in maize production (with fertilizer) while it ranges between 434 and 521 mandays for different species of fertilizer tree fallows.

In addition to these investment costs, the development and promotion of fertilizer tree fallows resulted in several unintended problems. These costs include the increased incidence of pests such as *Mesoplatys* beetles and nemotodes. Thus far, their damage has been limited mainly to the fallow trees and not on other plants. Other social and institutional problems are the reduced grazing areas and lower tolerance of bush fires as farmers protect their fallow fields. In some cases, these incidents cause unintended social problems resulting from a conflict of economic interests among different sections of the community. Details of an in-depth study on this issue have been documented in Ajayi and Kwesiga (2003) and Ajayi (2001). Collaborative efforts by traditional chiefs, village headmen, farmers and research & development organizations and policy dialogues between the different stakeholders have resulted in various approaches to try and find ways of dealing with the problem of livestock browsing and fire. Some of these problems have been successfully addressed (Ajayi and Kwesiga 2003).

4.2 Economic impacts

The results from the trials above were very promising from a biological point of view. However, while the bio-physical feasibility of improved fallow species to replenish soil fertility has been well established, the labor inputs implications and comparative economic performance and impact of the technology on farms may not follow suit. Questions have been asked regarding how labor input requirements for fallows compare with the respective yields obtained from the systems. In particular, labor input is one of the most important agricultural resources in small-scale farms in southern Africa as many of the farmers use little or no external resource inputs. Moreover, in view of the HIV/AIDS pandemic and its potential impact on the quantity (and quality) of household labor supply, more than ever before the labor input implications of agricultural technologies in general and soil fertility management options in particular is an important criterion in farmers' decision-making regarding the appropriateness of agricultural technologies. Issues on the profitability of fertilizer tree fallows compared to other land use and production systems have also been raised. A detailed study was carried out to respond to these concerns.

Using primary data collected from farmers' fields on weekly basis throughout the 2002/2003 agricultural season in Zambia, the financial impacts of five soil fertility management options were evaluated: (i) Sesbania sesban fallow, (ii) Gliricidia sepium fallow, (iii) Tephrosia vogelii fallow, (iv) Continuous cropping with fertilizer and (v) Continuous cropping without fertilizer. For fertilizer tree fallows, farmers were selected so as to represent different phases of the 5-year cycle, i.e. two years of fallow establishment and three years of cropping. The results presented in Table 8 show that agroforestry-based soil management options are more profitable than current farmers' practices but less profitable than full fertilizer application. One of the primary reasons for this is because the government subsidized chemical fertilizer at a rate of 50% of the market price in Zambia and Malawi. In terms of returns to labour, the differences between fully fertilized maize and the fertilizer tree fallow systems shrink. The return to a labour day is $3.20 for fertilized maize and $2.50, $2.40, and $1.90 for the three fallow species tested. By comparison, the returns to labour for the unfertilized maize system was only $1.10, while the daily agricultural wage is around $0.50.

Table 8: Profitability of maize production per hectare using tree fallows and *subsidized* fertilizer options over a five-year cycle in Zambia

Production sub-system	**Description of land use system**	**NPV** (Zambian Kwacha)	**NPV** (US $)	**BCR**
Continuous, NO Fertilizer	Continuous maize for 5 years	584,755	130	2.01
Continuous + Fertilizer (subsidized at 50%)	Continuous maize for 5 years	2,243,341	499	2.65
Continuous + Fertilizer (at non-subsidized market price)	Continuous maize for 5 years	1,570,500	349	1.77
Gliricidia sepium	2 years of *Gliricidia* fallow followed by 3 years of crop	1,211,416	269	2.91
Sesbania sesban	2 years of *Sesbania* fallow followed by 3 years of crop	1,390,535	309	3.13
Tephrosia vogelli	2 years of *Tephrosia* fallow followed by 3 years of crop	1,048,901	233	2.77

- Market price for fertilizer include a 50% subsidy by the government
- Figures are on one hectare basis, using prevailing costs & prices and an annual discount rate of 30%

Source: Ajayi et al 2004

Different price and other policy scenarios affect the financial attractiveness and potential adoptability of maize production systems even when technical/agronomic relationships between inputs and outputs remain the same. For example, if the subsidy on fertilizer is removed in the analysis, the difference in the financial profitability between chemical fertilizers and fertilizer tree fallows is greatly reduced as shown in the third row of Table 8.

4.3 Estimate of economic benefits to farmers using the fertilizer tree fallows system

4.3.1 Direct benefits of fertilizer tree fallows to farmers in eastern Zambia

Given the numbers of farmers planting fertilizer tree fallows, it is possible to integrate the information on average size of fallow, average maize yield response, and average wood value (which is just a fraction of the crop value) to produce an overall estimate of the economic benefits to farmers using the system. This information is most accurate for Eastern Province Zambia where the bulk of the analyses have been done. In 2004, the planters of fallows in 2000, 2001, and 2002 will reap some benefits. We estimated the total benefits to be about $1.27 million dollars accruing to approximately 47,000 farmers. In the 2003-04 season, it has been estimated that 77,500 farmers had planted a fallow. Thus by 2005-06, the economic impacts may increase to $1.91 million. If adoption trends continue with consistent yield effects and stable prices, by 2008, we might expect economic impacts in the order of $6.53 million. More rigorous impact assessment work needs to be done to confirm these predictions. On the cost side, ICRAFs accounting systems changed over the years and trying to combine all the costs associated with the development of the fertilizer tree fallow system has proved challenging. Research costs in eastern Zambia, coupled with backstopping support from headquarters, certainly exceeded $500,000 dollars in most years between 1989 and 2004. Thus, it is fair to say that the net benefits from research are only now transforming from the negative to the positive. Indeed, most of the payoffs are expected to occur over the next few years.

4.3.2 Value of N fixed by fertilizer tree fallows in southern Africa region

On a regional scale, the Zambezi Basin Agroforestry Project estimates that a total of 180,000 farmers have established fertilizer tree fallows as of the 2003 season (this would include the coppicing fallow-intercrop system). Average size of fertilizer tree fallows per farmer is 0.20 ha (Ajayi et al 2004). This is equal to 36,000 ha under improved fallows. Field trials in Zambia estimated the amount of nitrogen fixation by fertilizer tree fallows at 150 Kg N per hectare per year. The estimated total monetary value of the N fixed by fertilizer trees in the region is US$ 5.7 million per annum[1]. Depending on distance and

[1] Nitrogen fixation by fertilizer tree fallows estimated at 150 Kg N per hectare per year for a field area of 36,000 hectares, the total N fixed =5,400 tonnes of N or equivalence of 12857 tonnes of

condition of the roads, the cost of transportation of fertilizer bags from the shops in the major town/cities to farmers' village ranges between 10-25% of the purchase cost of fertilizer. In the five countries (Zambia, Malawi, Zimbabwe, Tanzania and Mozambique) of southern Africa agroforestry regional program, the value of N fixed by fertilizer tree fallows in the range of $6.27 to $7.13 million per year in 2003.

4.4. Impacts on social equity

In terms of availability and access, mineral fertilizers are more accessible to richer farmers and those who have more political influence in the society, thus reinforcing already existing power structure. A third of the farmers who used fertilizer in Zambia received fertilizer from government and these farmers were better off, on average, than those farmers who did not receive the subsidized fertilizer (Ministry of Agriculture/Agricultural Consultative Forum/Food Security Research 2002). This is because political patronage influences the selection of farmers who benefit from subsidized fertilizers. Although the subsidized fertilizer loans were expected to be paid back at the end of crop harvest, in some cases, the inputs were de facto distributed free to farmers because the loan recovery was very low. This is partly because tough measures to recover the loans were considered to be socio-politically inexpedient. On the other hand, the availability of fertilizer tree fallows de-emphasizes social power structure and are relatively more accessible to poor farmers and women. By being relevant to small scale and resource-poor farmers, fertilizer tree fallows enhances social equity among the society.

5 Intermediate and Long term Ecosystem impacts

5.1 Changes in soil physical properties

The ability of trees and biomass from trees to maintain or improve soil physical properties has been well documented. Alley-cropping, for example, was proven to improve the soil physical conditions on alfisols (Hullugalle and Kang, 1990). Plots alley-cropped with four hedgerow species showed lower soil bulk density, higher porosity, and

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Urea per year. Price of urea in Zambia =ZKW 105,000 per 50kg bag or $22.34 per bag (At exchange rate US$=ZKW4700) or $447 per tonne of urea.

greater water infiltration rates compared with a no-tree treatment (Mapa and Gunasena, 1995). Tree fallows can improve soil physical properties also due to the addition of large quantities of litter fall, root biomass, root activity, biological activities, and roots leaving macropores in the soil following their decomposition (Rao et al., 1998).

In addition to improved soil fertility, soil aggregation is higher in fertilizer tree fallows fields and this enhances water infiltration and water holding capacity. This ensures that water runoff and soil erosion is reduced relative to continuous maize production system (Phiri et al 2003). As shown in Table 10, *Sesbania* fallow increases the percentage of water-stable aggregates with a diameter greater than 2 mm compared with continuous maize cultivation without fertilizer. Under fertilizer tree fallow, the improvement in soil structure was evident, as reflected by the results from time-to-runoff studies. Through rainfall simulation studies, Nyamadzowo et al. (2004) found that ree fallows of *Sesbania sesban* and *Gliricidia sepium* mixed with Dolichos (an herbaceous legume) increased infiltration rates significantly compared with continuously fertilized maize plots (Nyamadzowo et al. 2004). Tree fallows also significantly reduced soil loss compared to no-tree plots. That fertilizer trees improve soil physical properties is seen from measured increases in infiltration rates, increased infiltration decay coefficients, and reduced runoff and soil losses. However, these benefits are short-lived and decline rapidly during the first year of cropping where non-coppicing fallow species are used. This is consistent with an increase in soil loss in the second year and a decrease in infiltration rates as well. To improve on this, studies have been carried out by mixing (permanent) coppicing fallow species (e.g. *Gliricidia*) with herbaceous legumes (e.g. *Dolichos*) to ensure high infiltration rates and reduced soil loss over two years of cropping (Mafongoya et al., 2005). In agroforestry as in other agriculture, we see repeated advantages of polycropping over use of single species

Table 9: Effects of land use system on some soil physical properties after 8 years of fertilizer tree fallow-crop rotations in Zambia

Land-use system	Average infiltration rate (mm min^{-1})	Average cumulative water intake after 3 hours (mm)	Average water stored in 70 cm root zone at 8 weeks after planting (mm)	Average penetrometer resistance at 40 cm soil depth (Mpa)	Average water stable aggregates >2.00mm (%)
Sesbania sesban	4.4a	210.6ab	235.4a	2.2c	83.3a
Cajanus cajan	5.2a	235.8a	222.7b	2.9b	80.8a
Natural fallow	5.3a	247.9a	209.5c	2.9b	65.7b
Continuous M+F	3.1b	142.0bc	208.8c	3.9a	65.6b
Continuous M-F	2.1c	103.4c	217.3b	3.2b	61.2a
Mean	4.0	187.9	218.7	3.1	71.5
SED	0.5	36.0	7.9	0.2	3.1

Means in a column followed by the same letter or letters are not significantly different at $P \leq 0.05$

Source: Chirwa et al 2004

5.2 Effects on soil nutrient balances

Improved fallows with Sesbania or Tephrosia have been shown to give subsequent maize grain yields of 3 to 4 t/ha without any inorganic fertilizer addition. Palm (1995) showed that organic inputs of various tree legumes applied at 4 t ha^{-1} can supply enough nitrogen for maize grain yields of 4 t ha^{-1}. However, most of these organic inputs could not supply enough phosphorus and potassium to support such maize yields over time. The question for sustainability is: Do improved fallows reduce soil stocks of P and K over time, even while maintaining a positive N balance? To answer this question nutrient balance trials on improved fallow trials were conducted at Msekera Research Station. These plots were maintained under fallow-crop rotations for 8 years.

The nutrient balances considered the nutrients added through leaves and litter fall, which were incorporated after fallows as inputs. The nutrients in maize grain harvested, in maize stover removed, and in fuelwood taken away at end of the fallow period were then considered as nutrient exports. As shown in Table 10, for all the improved fallow species , there was a positive N balance in the two years of cropping after the fallow. Fertilized maize had the highest N balance due to the annual application of 112 kg N ha^{-1} for the past 10 years. Unfertilized maize had lower balances even though maize grain and stover yields were very over time. The tree-based fallows had a positive N balance due to BNF and deep capture of N from depth. These results are consistent with those of Palm (1995) showing that organic inputs can supply enough N to support maize grain yields of 3 to 4 t ha^{-1}. However, we note that in the second year of cropping, the N balance became very small. This is consistent with our earlier results which showed a decline of maize yields in the second year of cropping after two-year fallow. The large amount of N supplied by fallow species could be lost through leaching beyond the rooting depth of maize. Our leaching studies have shown substantial inorganic N at some depths under maize after improved fallows. This implies that if cropping goes beyond three years after fallowing, there will be a negative N balance. Thus the recommendation of two years of fallow followed by two years of cropping is supported by both N balance analyses and maize grain yield trends.

Most of the land use systems showed a positive P balance. This can be attributed to low off take of P in maize grain yield and stover. However, it should be noted that this site had a high phosphorus status already. The trees could have increased P availability through secretion of organic acids and increased mycorrhizal populations in the soil. These issues are under investigation at our site. In general, we have observed positive P balances over eight years. However, this result needs to be tested on-farm where the soils are low in P.

Most land-use systems showed a negative balance for K. For tree-based systems, Sesbania showed a larger negative K balance compared to pigeon pea. This is attributed to the higher fuelwood yield of Sesbania with subsequent higher export of K compared to pigeon pea. The larger negative K balance for fully-fertilized maize is due to higher maize and stover yields which export a lot of potassium (and therefore the current recommended dose of K may not be sustainable). This implies that the K stocks in the soil were very high and that K mining has not reached a point where it negatively affects maize productivity. However in sites with low stocks of K in the soil, maize productivity may become adversely affected.

Table 10: Nutrient budgets for different options in two year non coppicing fallows (0-60cm)

	Nitrogen			Phosphorus			Potassium		
	1998	1999	2002	1998	1999	2002	1998	1999	2002
Cajanus	44	17	84	21	8	33	37	9	27
Sesbania	47	19	110	39	24	32	-20	-25	-20
Fertilized maize	70	54	48	14	12	12	-56	-52	-65
Unfertilized maize	-20	-17	-22	-2	-1	-2	-31	-30	-38

Source: Mafongoya *et al* (2005)

Overall, the tree-based fallows maintained positive N and P balances. However, on low-P-status soils, a negative P balance would be expected. There was a negative K balance with most land-use systems. It can be hypothesized that as the number of farmers and area planted to fertilizer tree fallows increase, the K and P balances would become negative with time. Farmers should be encouraged to obtain N from fertilizer tree fallows and supplement this with a simpler and cheaper fertilizer formulation containing only P and K that will be more affordable for farmers than existing NPK formulations.

5.3 Effect on deforestation of miombo woodlands

Due to the wood obtained from fertilizer tree fallow fields, farmers who establish fertilizer tree fallow fields have some of their fuel and other wood requirements of their households satisfied from their own fields. This may reduce the exploitation of wood from the communally owned miombo forests and thus have the potential to mitigate deforestation. A study was carried out in Eastern Zambia to determine whether this was observed or not (Govere 2002). Of the total amount of firewood consumed (3.1 tons per household), the improved fallows contributed 11% on average. The value of this to the farmer varies according to local fuelwood supply conditions. Close to the miombo woodlands, the price of firewood may be as little as $4 per ton, whereas in wood scarce areas, the price may rise well above $30 per ton. This amount of firewood production didn't necessarily "save" trees in the miombo from being cut. There is conflicting evidence on this from two field sites (see Table 11).

Fuelwood from fertilizer tree fallows reduces the time spent searching for fuel energy by households. On the average, over 3 tons of fuel energy is produced per household that adopts the fertilizer tree fallows technology

Table 11: Source of fuel-wood production per year in eastern Zambia

	Chipata North	Chipata South
Fuel-wood from fallows for adopters (kg)	261	431
Fuel-wood from miombo for adopters (kg)	2919	2915
Fuel-wood from miombo for non adopters (kg)	2943	3385

Source: Govere (2002)

In one district (Chipata South), it does indeed appear that the fallows are contributing firewood that ultimately reduces the amount of fuel energy collected from the "miombo" forests. But that is not the case in the other district where collection amounts are the same despite the additional wood from the fallows. Thus

Stems/ branches of fertilizer tree fallows species are increasingly being used as stakes in curing sheds by tobacco farmers. This has the potential to reduce the degradation of the natural forests.

there are some positive signs that the fallows may be able to reduce pressure on the natural woodlands, but this is not guaranteed; further monitoring will be necessary.

5.4 Effects on carbon sequestration

The debate on carbon and global warming has gained momentum. Of late, there has been increased scientific interest in measuring carbon sequestration in different land use systems to mitigate climate change issues. Agroforestry land use systems have been cited to sequester the most soil C without a lot of scientific evidence. The amount of soil C was measured in in long-term trials involving improved fallows and other land uses.

Table 12: Carbon sequestration in fertilizer tree fallow and woodlot fields

	Non coppicing fallows	Coppicing Fallows	Rotational woodlots
C fixation in biomass t/ha	1.9 – 7.0	3.0 – 8.9	32.6 – 73.9
Intake of C t/ha	1.6 – 3.2	1.4 – 4.2	3.5 – 8.0
Root C input	0.7 – 2.5	1.0 – 3.6	17.6

The results in Table 12 show the different potentials of various fallow types and rotational woodlots (a rotational woodlot is a longer-term fallow of about 5 years, in which the wood product is a major product sought by farmers) to sequester carbon in the above and below ground biomass. The order was woodlots>coppicing fallows>noncoppicing fallows. Among species, *Sesbania sesban, Tephrosia candida and Leucaena collinsii* showed the greatest potential to sequester carbon.

Data on soil carbon showed carbon sequestration varied with soil depth. The soil layer of 60 -100cm stored the largest amount of C. This is critical because this carbon is protected from anthropogenic disturbance such as ploughing and tillage practices. The amount of carbon stored depends on species, soil texture and depth. Rotational woodlots offer the highest potential to sequester carbon both in the soil and above ground biomass. We are conducting studies to test various carbon models and link to carbon credit schemes with smallholder farmers who are adopting agroforestry practices. The role of agroforestry and global warming will be discussed with policy makers to provide technical information for negotiations in various global conventions. Evidence on soil carbon from similar fertilizer tree fallow systems in Kenya shows that the net amount of carbon sequestered (after deducting NO_2 emissions) was on the order of 4 tons per hectare of fallow (lasting one year) using time averaged methods. Current prices of carbon for land managers are between $3 and $8 per ton so the potential for fertilizer tree fallows to increase the incomes of farmers is limited at this point in time.

6 Summary

The case study focus on the development, adoption and impact of fertilizer tree fallows especially on resource-poor farmers in Zambia in particular and the southern Africa region in general. It shows that to make sustainable impact, agricultural technology innovation should be targeted to the real needs of farmers in relevant locations, with an active encouragement of user modification and adaptation of the technology the way it best suits them. The adoption of the technology by farmers is not a not a direct relationship based exclusively on technological characteristics, but is influenced by several broad groups of factors including institutional and policy (especially fertilizer subsidies), spatial and geographical factors and household-specific variables.

Fertilizer tree fallows are more profitable than the traditional practice of continuous maize cultivation without fertilizer but is less profitable compared to fully fertilizer plots especially when the latter is subsidized. In a typical five-year period for fertilizer tree fallows, farmers obtain a net benefit ranging between $230-$300 per hectare of fertilizer fallows plots. This compares with $130 per hectare for continuously cultivated fields without fertilizer and, $349 for fertilized plots (without subsidy) and $500 in fertilized plots (with subsidized fertilizer). The benefit-cost ratio or the returns per unit investment made on fertilizer tree fallows is higher for fertilizer tree fallows ranging between 2.8 - 3.1 compared to 1.77 for non-subsidized fertilizer plots and 2.65 for subsidized fertilizer plots. In Zambia where the daily agricultural wage is around $0.50, the return to labor day is $3.20 for fertilized maize and $2.50, $2.40, and $1.90 for the three fallow species tested. By comparison, the returns to labor for the unfertilized maize system was only $1.10. Different price and other policy scenarios affect the financial attractiveness and potential adoptability of maize production systems even when technical/agronomic relationships between inputs and outputs remain the same.

The study identified different types of costs and benefits of fertilizer tree fallows for the individual adopters and a wide range of environmental services that accrue to the society at large. Some of these have been quantified but a detailed study is required to assign a quantitative value on others. On a larger scale, the value of the nitrogen fixed by fertilizer tree fallows in the five countries participating in the southern Africa regional program is estimated at US$6.3 million to $7.1 million per annum. For natural resource management technologies to make impacts, not only must the technology be right and appropriate, the enabling policy and institutional framework must also be appropriate.

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