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Impact of natural resource management technologies

Fertilizer tree fallows in Zambia

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Abstract

This paper reviews the impact of an improved fallow fertilizer tree system on lives and landscapes in eastern Zambia. It draws on a number of analyses conducted both by the World Agroforestry Centre (ICRAF) staff and by other scientists. The authors describe the diagnosis of problems that led to the use of the fertilizer tree system as an intervention. They also highlight ICRAF's role in promoting fertilizer trees in Zambia. The paper then assesses the factors associated with adoption of the improved fallow system, its biological, economic and environmental impacts at the farm level, and then its wider impact on livelihoods and landscapes in Eastern Province, Zambia.

Keywords

improved fallows, fertilizer trees, soil fertility, technology, adoption, economic analysis, environmental impact, fuelwood, deforestation, scaling up

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Contents

1. Introduction

In the past decade, there have been growing concerns regarding information gaps 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 – an improved fallow using trees or what might be called a fertilizer tree fallow – the development of which was led by the World Agroforestry Centre (ICRAF). The study describes the technology, provides historical information on its development, discusses patterns of adoption and finally 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

Constraints 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^{-1} for nitrogen, 2.5 kg ha^{-1} for phosphorus, and 15 kg ha^{-1} for potassium. 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; Sanchez et al. 1997) because of the strong linkage between soil fertility and food insecurity. To mitigate declining soil fertility, farmers in many areas had traditionally left their land under fallow for significant lengths of time. However, given the relative fixed quantity of available cultivable land, as the population increases, fallow periods became shorter and natural fallows became unable to restore soil fertility. Fertilizers could be used to substitute, but it has been proven that farmers in Africa purchase only paltry amounts of fertilizer (average of 9 kg per hectare in Africa) if unable to obtain credit and obliged to pay market prices for fertilizer.

The study site for this impact assessment is Eastern Province, Zambia. It covers 70,000 square kilometers, or about 9% of the total territory of Zambia. There is one rainy season from November to April. The average annual rainfall is 1000 mm and most of the rains occur between December and March. The plateau area of eastern Zambia is characterized by a flat to gently rolling landscape and altitudes ranging from 900 m to 1200 m. Seasonally waterlogged, low-lying areas, known locally as 'dambos,' are also common. The main soil types are loamy-sand or sand Alfisols, interspersed with clay and loam Luvisols. The Alfisols are well-drained and relatively fertile but have low water and nutrient-holding capacities (Kwesiga & Chisumpa 1992; Raussen 1997). The miombo ecosystem is visible in the open woodland area that still features in the province.

Population density is relatively low by African standards and varies between 25 to 40 persons km^2. There are few improved roads in the province. The combination of low quality roads and low population density means that many areas are not well connected to transport services or markets. The agricultural economy is dominated by mainly by maize – up to 70% of planted area – groundnut, cotton and vegetables all of which are cultivated in fields that sum to around 2 ha per household. Maize and groundnut are the most popular crops in the study area and are grown by nearly all households. Sunflower is grown by about half of the farmers, a third of the farmers grow cotton and beans. Although maize is regarded as 'the crop' and will most likely retain this status in the immediate future, other crops are becoming important in the cropping systems in recent times.

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 included 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 the structural adjustment program, under which there was a 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 smallholder farming. 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; the result was a dramatic decrease in fertilizer use in the region (Donovan et al. 2002).

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 (also referred to as tree fallows or improved fallows in this paper and in the literature) allow farmers to produce nutrients through land and labour rather than cash, which they lack.

Description of fertilizer tree fallows and identification of technology intervention

Fertilizer tree fallows were not practiced by farmers in Zambia until after the arrival of ICRAF in southern Africa[1]. The development of fertilizer tree fallows in southern Africa began with diagnostic and design surveys (Kwesiga and Chisumpa 1992) and ethnobotanical surveys in the late 1980s which revealed a breakdown of traditional strategies to sustain production of food. Nitrogen was identified as a key missing nutrient in the soils. 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 strategy uses leguminous fallows to accumulate nitrogen (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 (Kwesiga et al. 1999). The trees increase the availability of nitrogen (N) through atmospheric fixation of N2. 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, can be recycled by the tree fallows, but the two nutrients must be sourced externally if they are depleted from the soil.

The cycle of fertilizer tree fallows begins when tree 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 complete cycle of fertilizer tree fallows is a fallow phase of one or two years followed by a cropping phase (mainly maize) 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

[1] In fact, there was very little practice of improved fallows in the region. The maize-pigeon pea intercropping system had been practiced by some farming communities in Malawi for years prior to ICRAFs arrival in the region, however.

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).

ICRAF's contribution to the development and dissemination of the technology

ICRAF's research and development efforts can be summarized as consisting of two main phases. The first was from 1988 to around 1996 when the focus was on research, firstly researcher managed research and then an expansion into farmer managed research. Since the technology was new to the region, research was required on the methods of establishment of the improved fallows, suitable species and provenances, rotation periods and configurations of trees and crops, and cutting and incorporation of tree biomass. In the mid-1990s, ICRAF coordinated a multi-country trial to test for the biophysical limits of promising fallow systems and species. Some of this research continued after 1996, but the emphasis of ICRAFs efforts shifted after 1996 following the conclusion that the improved fallow system was beneficial both biologically and financially. Research areas began to reflect those associated with wider use, such as improving effectiveness and reach of seed and nursery systems, on institutional mechanisms for managing potential conflicts between tree growing and free grazing, identifying best-bet locations for testing or promoting improved fallows, and how to manage pests that may be associated with improved fallow species.

In addition to these research efforts, ICRAF facilitated development through (a) writing extension materials for distribution, (b) hosting visiting farmers and others at the station or nearby farms to view the performance of the fallows, (c) provision of training to farmers, extension, and project staff on the management of improved fallows, (d) training to entrepreneurs on seed collection and nursery development, (e) establishment of a network within which organizations involved in improved fallows could exchange information, and (f) collaboration with development organizations to help them raise funds for development activities.

Improvement on the antecedent technology

Research results from on-station and on-farm trials of fertilizer tree fallows consistently show significant increases in maize yields following *Sesbania sesban* and *Tephrosia vogelii* fallows compared with common farmers' practice of continuous maize production without fertilizer. The very first trial results were from 1988-1993 and many others have been conducted on different soils and with different management treatments (for a synthesis see Kwesiga et al. 2003). One example of these results is given in Table 1. To

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 (t 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

*LSD least significant difference
Source: Ayuk and Mafongoya (2002)

summarize this research, 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; Franzel 2004).

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).

Type III trials are based on a constructivist's approach, i.e. farmers assess adoption of fertilizer tree fallows as a socially constructed process through which they make sense of their experiences and are allowed to freely modify and adapt the technology the way they want. Kwesiga et al. (2004) documents key farmer innovations on fertilizer tree fallows presented in Box 1.

Further efforts at modification and generating diverse options of the technology include experiments which were conducted to evaluate the interaction between

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

Box 1. 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' labour 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 had 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 rainfed nurseries as opposed to nurseries in hydromorphic ('*dimba*') gardens during the dry season. These nurseries are preferred because they reduce the labour required for transporting the seedlings and reduce the labour 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

chemical fertilizers and fertilizer tree fallows. Results in Table 3 show that there is a synergistic effect between low doses of mineral fertilizer and tree fallows that produces a more than proportionate yield increase especially in later years following a fallow (Kwesiga and Coe 1994; Ayuk and Mafongoya 2002). Using stochastic dominance approach, results show that over all probability levels, recommended fertilizers offer superior benefits over the fertilizer tree fallow options (Figure 1). However, when ¼ and ½ doses of 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 (see Figure 2).

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 mineral fertilizer and availability of water.

Table 3. Maize yields (t ha^{-1}) following 2-year *Sesbania sesban* fallows in combination with different dosages of the recommended fertilizer level in eastern Zambia

Treatment	**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; Note that a drought occurred in the year 2000.
Source: Ayuk and Mafongoya (2002)

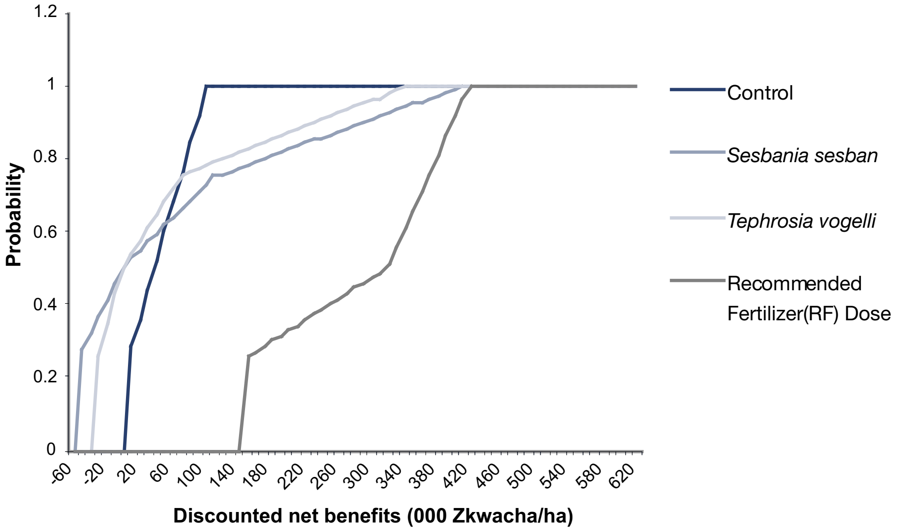
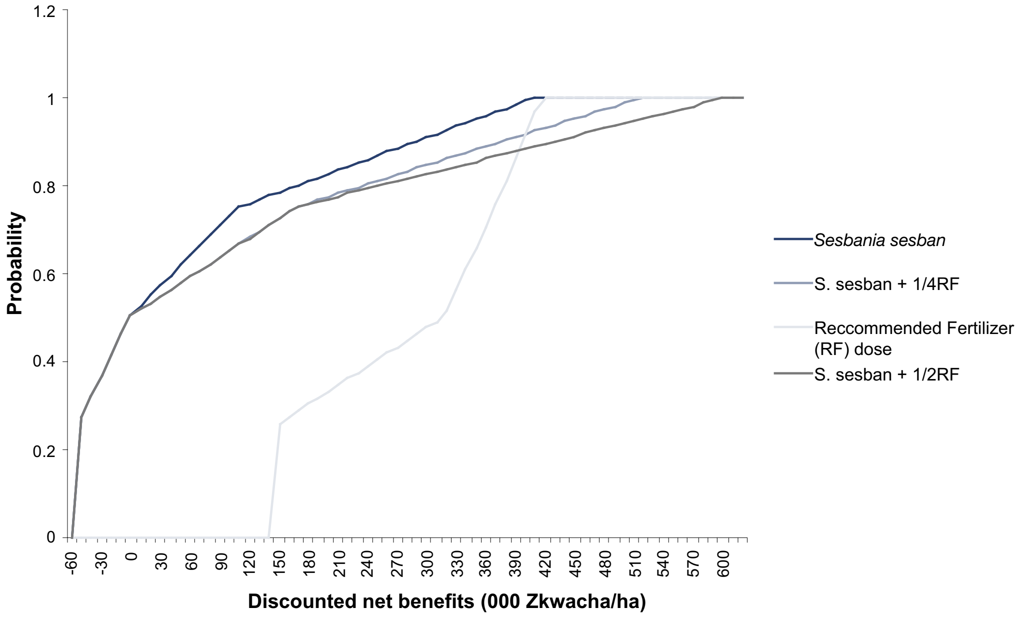


Figure 1. Cumulative distributions of discounted net benefits of full fertilizers vs pure fertilizer tree fallows.



Source: Ayuk and Mafongoya (2002) Recommended fertilizer (RF)=112kg N/ha; 20kg P/ha; 20kg K/ha

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

How innovation reached farmers and created benefits

An extensive on-farm research approach was undertaken partly to establish good relationships with extension staff. Researchers spent much time exposing the technology to extension officers in their target villages, where each extension officer is responsible for about 200 farm families. Extension officers were thus the main facilitators at the grassroots level and some villages were selected for technology demonstration and experimentation purposes. ICRAF began efforts to scale up/out the information about the technology and knowledge on seed systems to reach more farming communities in 1997/98. The scaling up effort is coordinated through the Adaptive Research and Development Network (ARDN) – comprising ICRAF, government research and extension, farmer organizations and NGOs. The ARDN framework enhances collaboration and exchange of germplasm and information among the many different types of organizations.

In the late 1990s, 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 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 catalyzing a farmer-to-farmer exchange process.

3. Use and users of fertilizer tree fallows

Use/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. Some socioeconomic research took place before there were any true adopters while other studies have lumped together first time planters and among those planting repeatedly. To avoid confusion, we have opted to use the terms 'use' and 'users' though we realize that in many cases, this reflects bonafide adoption.

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 (see Figure 3). The data are reliable, from regular assessments furnished by partners through the ARDN network, with some spot checking by ICRAF.

There were slightly fewer planting fallows in 2003 than in 2002 mainly because of the termination of the World Vision project. All told, it was estimated that about 77,500 farmers had a fallow in their field in 2003. In a World Vision project target zone of almost 90,000 households, 27% had planted an improved fallow by 2003 (Hooper 2004). A study by Keil (2001) showed that once started, most farmers continue to plant fertilizer tree fallows; 71% of a sample of farmers who planted fertilizer tree fallows in 1996/97 continued to plant them over the next three seasons.

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 (Ajayi et al. 2003b and Hooper 2004). However, the distribution of the field size varies widely ranging from 0.01 ha to 0.78 ha per farmer.

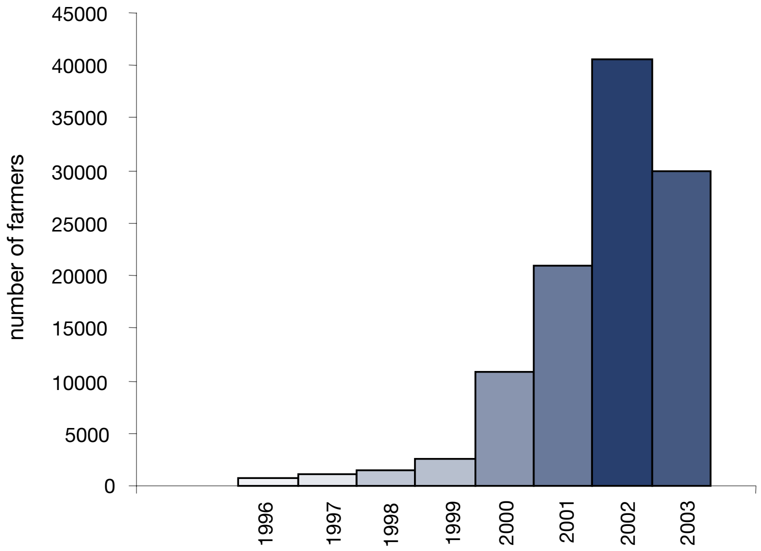


Figure 3. Number of fertilizer tree fallows planted in eastern Zambia.

Policy and institutional factors governing the use of fertilizer trees

The degree to which fertilizer tree fallows are being used by farmers is influenced by broad factors that shape access to information and farmer incentives for investment (Place and Dewees 1999). One factor is active promotion of the technology by ICRAF, extension, and several major NGO-led projects. Mechanisms for the introduction of germplasm and technical support for managing tree fallows are vitally important.

A second factor is the emerging interest by private sector organizations and individual entrepreneurs in the provision of support services and inputs for fertilizer tree fallows (including tobacco companies encouraging use of fallows and individual entrepreneurs establishing large hectares of seed orchards to meet rising demand for tree seeds. These have occurred partly because of the suitability of the technology which itself is a reflection of the participation that farmers had in its development.

Third is the high cost of fertilizer due to currency devaluation and withdrawal of subsidies and government sponsored credit programs. This situation prevailed throughout the 1990s and certainly increased farmers' interests in seeking alternatives (Peterson 1999, Ajayi et al. 2001). Recently, however, the government has reinstated fertilizer subsidies and this is likely to partly reduce interest in other soil fertility options including fertilizer tree fallows.

Lastly, several local institutions have been found to be accommodating to the introduction of fertilizer tree fallows. A study by Ajayi and Kwesiga (2003) found that bushfires and free grazing represented a threat to the spread of tree fallows but that local leaders could find ways to integrate the fallows into local resource management systems and to protect farmers' investments in them. A study (Place et al. 2001) of land tenure institutions found that almost all land is acquired by inheritance or allocation by the chief and is held in perpetuity by households, with little fear of losing land. Thus there were no serious tenure impediments to tree planting by households (the case of women is another matter – see Household and farm variables factors driving use and adoption of fertilizer tree fallows - *Gender*)

Household and farm variables factors driving use and adoption of fertilizer tree fallows

There have been many studies over the past few years related to understanding which types of households are trying or expanding use of improved fallows. Table 4 presents the qualitative results from selected studies on this topic which have been synthesized in Ajayi et al. (2003b). Many used descriptive statistics but two relied on multivariate econometrics (see table). The following paragraphs highlight the main findings from this body of research.

Training and Awareness: Given that the implementation of fertilizer tree fallows is relatively more knowledge-intensive, this is one of the most important factors driving the adoption of the technology. 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: Early in the dissemination process it was the wealthier farmers who were more likely to test this technology (although 20% of the poorer households also tested). However, the wealthy were less likely to continue with improved fallows than other social groups (Kiel 2001). The fact that the poor had no means with which to purchase fertilizer was a contributing factor. Whether this pattern continues now that fertilizer prices are partly subsidized has not been studied.

Labour inputs: There is no conclusive evidence that fertilizer tree fallows require a higher quantity of labour inputs compared with traditional soil management practices. Over a five-year period, farmers used 11% less labour on fertilizer tree plots than on unfertilized maize because of reduced labour when the fallows

Table 4. 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	Labour/ 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. 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					+

+: 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)

are present (Franzel et al. 2002). Lack of availability of labour does not necessarily prevent farmers from establishing fertilizer tree fallows (because average area planted is small) but it was found to be important in two studies and may pose an important limitation to the area that a farmer allocates to the technology (Place et al. 2002).

Gender: Women may be disadvantaged in benefiting from improved fallows because of differences in decision making, land and tree rights, and ability to control benefits from productive resources. However, 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. In certain cases however, some married women are constrained from establishing improved fallow fields until they obtain consent of their husbands (Peterson et al. 1999).

Size of available land owned: Availability of land and size of land holding are 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 a permanent tree intercrop system which does not require that cropping phases be interrupted.

4. Impact of fertilizer tree fallows

Inventory of costs and benefits from fertilizer tree fallows

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 - Intermediate and long-term ecosystem impacts). 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. All the many benefits and costs of a private and social nature are listed in Table 5. We only discuss the main ones in this paper.

The positive productivity effects on smallholders and their yields will have the effect of shifting the supply curve for maize – see Figure 4. The shape of the supply curve has not been empirically estimated, but there is likely to be an inelastic portion reflecting the fact that maize is the main staple food and much of it is grown for subsistence purposes. At the initial level of demand, a shift in supply will move the equilibrium from A to C. Such a shift is predicted to bring about a fall in the price of maize yielding consumer surplus. However, there is no evidence to suggest this has happened in eastern Zambia. That may be because demand is highly elastic: there have been almost annual food distribution programs somewhere in the region[2]. Thus, from the supply shift, we have increased private benefits accruing to farmers (mainly for self-consumption), but we do not have an indication of consumer surplus resulting from lower prices.

The contribution of fertilizer tree fallows to environmental services such as carbon sequestration, may one day increase the demand for the maize production system that include carbon storing fallows. In such a scenario, society would articulate its demand through environmental service payments. This would result in a shift in the equilibrium from C to D in Figure 4 and boost the price received by farmers. This has not yet occurred.

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[2] On the other hand there is evidence that cabbages grown under improved fallow systems receive a higher market price as they are perceived as being sweeter than the normal marketed cabbage.

Table 5. Summary of the types of benefits and costs of fertilizer tree fallows

	Private	**Social**
Cost	· Land · Labour · Agroforestry seeds · Water for nursery · Pest (some fertilizer tree species only) · Working equipment · 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 · Fuelwood: available in field, and so reduces time spent 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 and Matakala (2005)

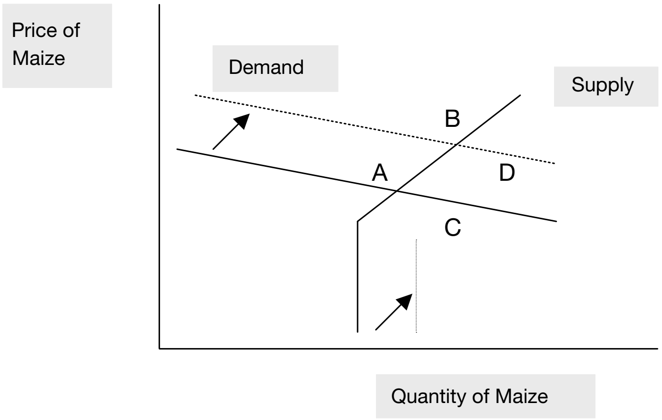

Figure 4. Effect of fertilizer tree fallows on the supply and demand for maize.

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 6, 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 labour inputs for continuously cultivated maize fields (without fertilizer) is 462 labour days equivalent per hectare, 532 labour days in maize production (with fertilizer) while it ranges between 434 and 521 labour days 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 nematodes. 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).

Economic impacts

The technical effectiveness of improved fallow species to replenish soil fertility has been well established, but this does not mean it is attractive or profitable for farmers. Questions have been asked regarding whether labour input requirements for fallows are too demanding, especially in a relatively land abundant setting like eastern Zambia. Moreover, in view of the HIV/AIDS pandemic and its potential impact on the quantity (and quality) of household labour supply, more than ever before, the labour input implications of agricultural technologies are essential to consider. The profitability of fertilizer tree fallows compared to other land use and production systems must also be addressed.

Using primary data collected from farmers' fields on weekly basis throughout the 2002/2003 agricultural season in Zambia, the returns to 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 analysis factored in opportunity costs of taking land out of production by valuing all 5 seasons of maize production from the non-fallow options and comparing them to just 3 seasons of maize production in the fallow systems. Also, the increased maize under the fallow options occur starting in the third year and is therefore appropriately discounted (a rate of 30% is used which makes the discounted returns from the fallow systems all the more conservative).

The results presented in Table 6 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. Valued at real costs, the fertilizer option becomes much less profitable (reduced by 30%) and its net present value (NPV) is very close to one of the fallow options (NPV of 349 compared to 309). In terms of returns to labour, the differences between fully fertilized maize and the fertilizer tree fallow systems shrink, even if fertilizer is subsidized. 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. Thus, while the recommended dose of fertilizer option is the highest performer at current subsidized rates, at the full economic cost, the tree fallow options are only slightly less economically attractive. In areas where transport costs of fertilizer are high, the tree fallow options may outperform the fertilizer option.

Table 6. 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

*net present value **benefit-cost ratio

· 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

$ is always US$ in this report.

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 6.

Performance of fertilizer tree fallow systems under drought

Franzel and Scherr (2002) identified several ways in which fertilizer tree fallows can help mitigate risk for small-scale farmers relative to users of mineral fertilizers or no inputs at all. These include:

a. Farmers who use mineral fertilizer would lose more in invested resource than those who invested in tree fallows.
b. The benefits of improved fallows are likely to be spread over a three-year period whereas those of nitrogen fertilizer take place in a single 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.

These reasons appear to hold when our data are subjected to analysis. Simulations were made using data from a long-term researcher-managed trial between 1988 and 1993 during which there was a severe drought in 1992 as well as the farmer-managed trial data reported in Table 6.

In the researcher managed trial, a 1 or 2-season fallow always performed better than the no-input continuous maize system if a drought were to occur in any single year. The 1-year and 2-year fallows perform surprisingly well even if 2 drought years were to occur. The only case where a 2-year fallow was found to be worse than the no-input continuous cropping case is if drought occurred in consecutive seasons immediately after the fallow phase. The most critical season in the five-year fallow cycle is the first cropping year just after the fallow has been cut. A drought during the first cropping season will reduce profitability of maize production by a considerable amount ranging between 28% and 37% compared with a normal year. Similar reductions affect the continuous maize systems should a drought occur in the first year.

Estimate of total benefits to farmers and internal rate of return to research 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 about 20% of the value of the increased maize crop) 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 $1.32 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 nearly $2 million.

One may also value the impact of fertilizer tree fallows in terms of food security – by determining the number of days of additional food they provide to a household. To do this, we take the mean incremental increase in yields from the results presented and smooth these out into annualized returns. Such a system provides between 425 and 850 extra kilograms of maize per hectare per year (depending on species and performance). However, the average fallow plot is 0.20 hectares and if continuously practiced would generate additional maize of between 85 and 170 kgs per year. Daily maize consumption per adult in Zambia is about 1.5 kg per capita. Thus, the systems generate between and 57 – 114 extra person days of maize consumption. Another fallow management system, with just a single season out of maize production, has been found to provide more incremental maize and could contribute between 85 and 143 extra person days of maize consumption[3].

Internal rate of return (IRR) to research and development (R & D)

The calculation of an internal rate of return was challenging and the results should be treated cautiously. On the benefit side, ICRAF has been collecting reliable data on the number of farmers using improved fallows in eastern Zambia. However, the spillover effects of use/adoption by farmers elsewhere in the region are not as reliably documented, though they exist in the tens of thousands. For the baseline IRR, we have included only Zambian farmers (within and outside Eastern Province) in the counting of benefits, thus understating them. We have assumed that the number of plantings of fallows each year remains the same as it was in 2002/2003 period – 30,000. Eventually, this is assumed to decline around 2014. As benefits, we have included the impact on crop yields and firewood, assuming constant prices for both. We have not yet factored in any benefits for carbon sequestration because it is unlikely that carbon projects for smallholder communities will be viable in the near term.

On the cost side, it was not possible to obtain clear figures for soil fertility R & D at the Zambian site so some guesswork was involved. Some costs such as vehicles were smoothed out over time. It was not possible to separate out ICRAFs investments into research and development facilitation. Suffice it to say that all pre-1995 investments were in research and that the share invested in development facilitation increased steadily after that. Over the 1989-2004 period, the average annual cost in R & D for soil fertility ranged between $230,000 - $350,000. Costs were assumed to increase slightly over time in the future due to inflation, but diminish around 2010. Development costs of two major projects in the late 1990s and early 2000s were included and a figure of around $70,000 was assumed to persist over time. Because of the long period of research before benefits were observed on farm, we calculated an IRR for three different time horizons, 20, 25, and 30 years, each beginning in 1988.

The results show that the first year where benefits are larger than research and development costs was 2001. Cumulative net benefits (non-discounted) become positive in 2005. So the long period of research with few benefits requires a significant amount of time to pay off. By 2010, the cumulative net benefits (non-discounted) surpass the $20 million mark. Of course, with discounting, net benefits are much smaller as the very large benefits occur many years after the investment. The IRR calculated for the 1988-2008 period is therefore very low at 3.2%. However, if the time period is expanded to 25 years, the IRR increases to 15.2% and finally for a 30 year horizon it is 20.8%.

5. Intermediate and long-term ecosystem impacts

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; 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 tree fallow fields and this enhances water infiltration and water holding capacity and reduces water runoff and soil erosion (Phiri et al. 2003). As shown in Table 7, the two fallow systems increase the percentage of water-stable aggregates with a diameter greater than 2 mm compared with continuous maize cultivation. 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 rotational fallow species are used. To address this issue, studies have been carried out by mixing a permanent tree intercrop with

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[3] Another method of valuation of the system is through the substitute value of nitrogen. The nitrogen fixation by fertilizer tree fallows estimated at 150 Kg N per hectare per year. If this amount could be utilized by plants as efficiently as urea, this may translate into amounts as high as $6 million per year in the whole of southern Africa.

herbaceous legumes to obtain 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.

Effects on soil nutrient balances

Palm (1995) showed that organic inputs of various tree legumes applied at 4 tonne per hectare (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 an 8-year nutrient balance trial was conducted.

As shown in Table 8, 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 in each year. Unfertilized maize had lower balances even though maize grain and stover yields were very low over time. The tree-based fallows had a positive N balance due to biological nitrogen fixation (BNF) and deep capture of N from depth but the N balance became very small in the second year of cropping. 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 can 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. 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 (relative to N). The trees could have increased P availability through secretion

Table 7. 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

*M+F is maize with fertilizer
**M-F is maize without fertlizer
Means in a column followed by the same letter or letters are not significantly different at P<0.05
Source: Chirwa et al. 2004

of organic acids and increased mycorrhizal populations in the soil. However, it should be noted that this site had a high phosphorus status already. 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. 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.

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/or K that will be more affordable for farmers than existing NPK formulations.

Effect on deforestation of miombo woodlands

Farmers who establish fertilizer tree fallow fields are able to 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 reduce 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. 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 9).

Table 8. 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)

Table 9. Source of fuelwood production per year in eastern Zambia

	Chipata North	Chipata South
Fuelwood from fallows for adopters (kg)	261	431
Fuelwood from miombo for adopters (kg)	2919	2915
Fuelwood 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" woodlands. But that is not the case in the other district where collection amounts are the same despite the additional wood from the fallows. Thus 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. We have not yet studied whether the adoption of tree fallows has reduced the demand for clearing of new land nor whether the dramatic reduction in fertilizer use has increased clearing; nor are we aware of such a study.

Effects on carbon sequestration

Agroforestry land-use systems have been cited to sequester significant amounts of soil C without a lot of scientific evidence. The amount of carbon stored in the biomass and in the soil was measured in long-term trials involving improved fallows and other land uses.

The results in Table 10 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 from highest to lowest was woodlots>coppicing fallows>noncoppicing fallows. Among species, *Sesbania sesban*, *Tephrosia candida* and *Leucaena collinsii* showed the greatest potential to sequester carbon. Much of the C stored in the biomass would be lost if the wood was burned for energy. But the previous section indicated that in at least some cases, the fallow wood replaces that of naturally growing trees resulting in a net storage of carbon on the landscape.

Data on soil carbon showed carbon sequestration varied with soil depth. The soil layer of 60-100 cm 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. Soil carbon under the fertilizer tree systems varied according to species and location, with highest amounts being 2.5 to 3.6 t ha^{-1}. 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 (even if the full carbon stored of 12.7 t ha^{-1} over two years were to be compensated, for a fallow of 0.2 ha this amounts to about $7.50 per year).

Table 10. Carbon sequestration in fertilizer tree fallow and woodlot fields (tonne/hectare)

	Rotational fallows (1-2 seasons)	Permanent intercrops (2-3 seasons)	Woodlots (5 seasons)
C fixation in biomass t ha^{-1}	1.9 – 7.0	3.0 – 8.9	32.6 – 73.9
Intake of C t ha^{-1}	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

6. Summary and conclusions

The case study focuses on the development, adoption and impact of fertilizer tree fallows on smallholder farmers in Zambia. 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. Wealth and gender do not appear to be highly related to the use of rotational tree fallows, but land size was found to be an important determinant. About 77,500 farmers were practising improved fallows in Zambia in 2003.

Fertilizer tree fallows generate large increases in maize yields. With a 0.20 ha fallow system, between 57 – 143 extra days of maize consumption are produced. The fallow system is much more profitable than the traditional practice of continuous maize cultivation without fertilizer. The tree fallow system is less profitable compared to fully fertilizer plots, especially when the latter is subsidized, but is quite competitive most notably in terms of returns to labour. 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 for others. The economic impacts in Zambia alone are growing rapidly to nearly $2 million in 2005 with cumulative net benefits (above research costs) reaching towards $20 million by 2010. This is an underestimate of the returns to research since the improved tree fallow technology has been disseminated in many countries following its birth from research in Zambia.

In the absence of massive government investment in roads, credit, and fertilizer subsidy, there will remain a large proportion of the rural population who will not be able to afford fertilizer. For the many maize farmers who will not benefit from these types of public investments, possibly for a long time, fertilizer tree fallows will remain a productive and profitable option for increasing maize production. Because the system performs well in terms of returns to labour, it is expected to remain a demanded technology even during increased growth of agriculture and the development of better agricultural labour markets. Despite the impacts that tree fallows can have, the ability to alleviate poverty through production of maize or any other cereal on relatively small farms, is limited. Thus, the technology is likely to be transitory for some farmers and more lasting for others; in either case, it can provide a needed boost to income and potentially help to finance a shift into more profitable undertakings. There are very few other technologies one can think of which could provide such a boost for the very poor while at the same time not requiring cash investments.

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Occasional Papers

1. Agroforestry responses to HIV/AIDS in East and Southern Africa. Proceedings of the HIV/AIDS Workshop held at the World Agroforestry Centre in Nairobi 2003.
2. Indigenous techniques for assessing and monitoring range resources in East Africa.
3. Caractérisation de la biodiversité ligneuse dans les zones en marge du désert :Manuel de procédures
4. Philippine landcare after nine years: A study on the impacts of agroforestry on communities, farming households, and the local environment in Mindanao

Who we are

The World Agroforestry Centre is the international leader in the science and practice of integrating ‘working trees’ on small farms and in rural landscapes. We have invigorated the ancient practice of growing trees on farms, using innovative science for development to transform lives and landscapes.

Our vision

Our vision is an ‘Agroforestry Transformation’ in the developing world resulting in a massive increase in the use of working trees on working landscapes by smallholder rural households that helps ensure security in food, nutrition, income, health, shelter and energy and a regenerated environment.

Our mission

Our mission is to advance the science and practice of agroforestry to help realize an ‘Agroforestry Transformation’ throughout the developing world.

FUTURE
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