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Impact of Fertilizer Tree Fallows in Eastern Zambia

A study on Impacts of Agroforestry

O.C. Ajayi, F. Place, F. Kwesiga, P. Mafongoya and S. Franzel
World Agroforestry Centre

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World Agroforestry Centre, Nairobi, Kenya
United Nations Avenue, Gigiri | PO Box 30677-00100 Nairobi, Kenya
Phone: 254 20 7224000 or 1 650 833 6645 | Fax: 254 20 7224001 or 1 650 833 6646
Email: icraf@cgiar.org | http: www.worldagroforestry.org

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O.C. Ajayi, F. Place, F. Kwesiga, P. Mafongoya and S. Franzel

World Agroforestry Centre, P.O. Box 510046, Chipata, Zambia
World Agroforestry Centre, P.O. Box 30677, Nairobi, Kenya
World Agroforestry Centre, Southern Africa Regional Agroforestry Programme, P.O. Box MP 128,
Mount Pleasant, Harare, Zimbabwe

1. Introduction

This synthesis presents 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 World Agroforestry Centre (ICRAF) staff and by other scientists. The authors describe the diagnosis of problems that lead to the use of the fertilizer tree system as an intervention. They also highlight ICRAF's role in promoting fertilizer trees in Zambia.

Section 1 introduces the reader to the geographical area under study. Section 2 details the problem of low soil fertility—the target of the development of fertilizer trees. Section 3 describes how the fertilizer tree system works. Section 4 shows the costs and benefits of fertilizer tree fallows. Section 5 presents evidence of impact (both biophysical and socioeconomic) of fertilizer trees. Section 6 analyses the adoption and dissemination of the fertilizer tree system. Section 7 gives a summary of conclusions.

Eastern Zambia lies between latitude 10° to 15° S and longitude 30° to 33° E. It borders Malawi to the east and Mozambique to the south. Eastern Zambia covers an area of 70,000 km^2—about 9% of Zambia's total territory. There are 3 distinct seasons: the warm wet season or agricultural season, from November to April; the cool dry season from May to August; and the hot dry season from September to October. The average annual rainfall is 1000 mm, with most of the rains occurring between December and March. The length of the growing season varies from 139 to 155 days.

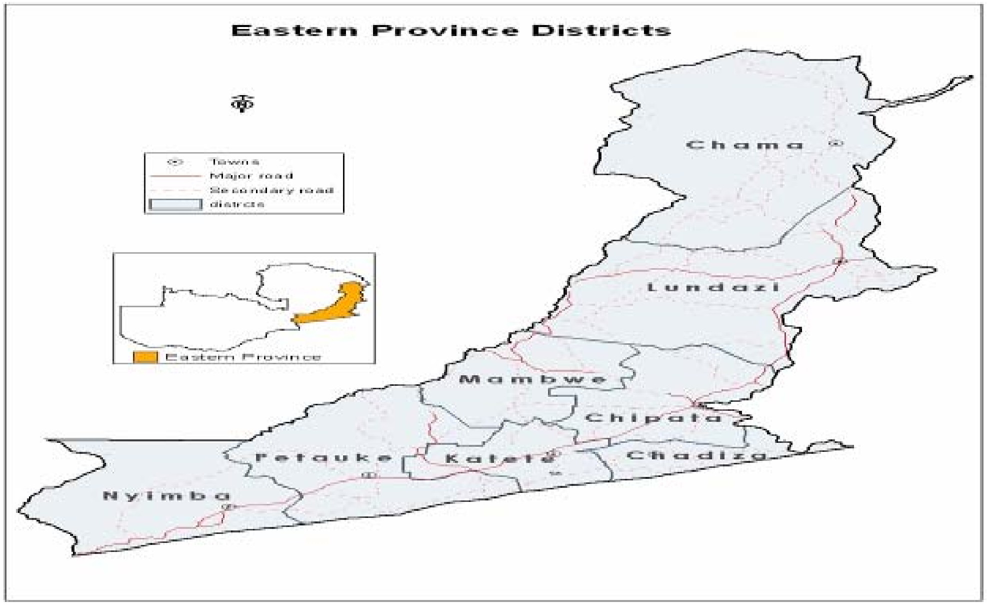

Figure 1: Map of eastern Zambia

Eastern Zambia: the main intervention area where ICRAF, the Zambian government and other partners developed and extended fertilizer tree systems.

The plateau area of eastern Zambia has a flat to gently rolling landscape with altitudes ranging from 900 m to 1200 m. Seasonally waterlogged low-lying areas, locally called 'dambos,' are 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 (Zambia/ICRAF 1988 and Raussen et al. 1995). The vegetation is typical of the eastern and central plateau Miombo woodland that is dominated by tree species such as *Brychystegia, Julbernadia* and *Isoberlina*. Population density varies between 25 and 40 people per km^2. The major ethnic groups are the Chewa, Ngoni, Tumbuka and Nsenga. Some of these groups, the Chewa, for example have matrilineal land inheritance systems. About 1/3 of the farmers own oxen while others cultivate the land using hand hoes. The average area cropped ranges from 1.1-1.6 ha for hoe cultivators to 2.3-4.3 ha for ox cultivators. The two groups intermingle and grow similar crops. But ox cultivators tend to use more purchased inputs. Average numbers of cattle per household range from 1.5 to 3, depending on the district and goats are also common (Kwesiga et al. 2004).

Maize, groundnut, cotton and vegetables dominate the agricultural economy. These crops are cultivated in small fields, totalling less than 2 ha. Almost all households grow maize and groundnut. About 1/2 of the farmers grow sunflower while 1/3 grow cotton and beans. The mix of crops planted reflects a desire to satisfy both household food security and cash requirements. It is also a mechanism for mitigating the risk of crop failure. Although maize is regarded as "the crop" and will most likely retain this status in the immediate future, other crops, such as cotton, are becoming increasingly important. In particular, cotton has become increasingly popular in recent years due to out-grower schemes launched by cotton companies.

2. *S*oil fertility 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, Interacademy Council 2004 and UN Millennium Project 2005). Smaling et al. (1997) estimate that soils in sub-Saharan Africa are being depleted at annual rates of 22 kg ha^{-1} for nitrogen (N), 2.5 kg ha^{-1} for phosphorus (P)and 15 kg ha^{-1} for potassium (K). In the case of Zambia, it has been found that the nutrient N is present in critically limited levels in the soil. The 2 other essential macronutrients, P and K, are not as critically limited as N and do not therefore pose such serious constraints to agricultural production.

The degradation of soils is caused by two related factors: (i) the breakdown due to population pressure, of the traditional production system involving adequate fallow periods, and (ii) low adoption of strategies for managing natural resources (Kwesiga et al. 1999). The need to improve soil fertility and its management across the continent has become a very important issue in development policy (Scoones and Toulmin 1999 and NEPAD 2003), because of the strong links between soil fertility and food insecurity on the one hand and the implications for economic development on the other.

After independence, Zambia's agricultural strategy focused on increasing maize production through interventions in input and output markets. These interventions included generous subsidies on fertilizer, easy access to agricultural credit, and the establishment of government-supported institutions and depots in rural areas. The institutions and depots supplied farm inputs and assured farmers of a market for their produce.

In the late 1980s, however, the government adopted a structural adjustment program (SAP) that removed subsidies on farm inputs, closed the agricultural credit programs and dismantled the parastatal marketing system. Private sector operators did not fill the gap in the fertilizer and credit markets as it had been assumed they would. As elsewhere in Africa, Zambian farmers suddenly had to pay extremely high prices for fertilizer. In 1999, it was found that a Lusaka area farmer paid about $368 per ton for urea (Jayne et al. 2003) While fertilizer prices were increasing, the maize prices received by producers remained static or increased more slowly than fertilizer prices. One country wide study has found that the use of recommended fertilizer doses at market prices for fertilizer and maize is often not profitable (Donovan et al. 2002). It is no wonder then that there has been a drastic reduction in fertilizer use among smallholder farmers (Place et al. 2001 and Sanchez et al. 1997). Farmers lacked any other significant livelihood besides maize—a crop that requires sufficient levels of N in the soil. An urgent remedy was needed. Agroforestry provided one answer in the form of fertilizer trees—species of trees that transfer nitrogen from the air into the soil. Since farmers were accustomed to investing in fertilizers for their maize, therefore, investing in nitrogen-fixing trees would not be a fundamentally new proposition. Fertilizer tree fallows would allow farmers to produce nutrients through land and labour rather than money, which they lacked.

Work started at the Msekera Research Centre near Chipata in eastern Province Zambia in 1986. Researcher-managed trials were conducted for several years before on-farm trials started in the mid 1990s. Following successful on-farm trials, demand for the fertilizer trees technology among development organizations and farmers rapidly grew, precipitating more widespread dissemination of the fertilizer tree system by the late 1990s. Table 1 summarizes ICRAF's milestones in developing the fertilizer tree system.

Table 1: Milestones in the development of fertilizer tree fallows in Zambia

Period	**Key milestones**
1987	Diagnostic and design ➢ Constraints to agricultural productivity and food production assessed ➢ Soil fertility problems highlighted as one of the key constraints
Late 1980s	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	➢ On-farm trials and farmer adaptation/modification
1998 and later	➢ Scaling up and dissemination

Modified from Kwesiga et al. 2004.

3. The development and practice of fertilizer tree fallows

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

Fertilizer tree fallows were not practised by farmers until after the arrival of ICRAF in southern Africa. At the beginning, ICRAF 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. Fertilizer trees are fast-growing tree species that accumulate N in the leaf and root biomass and recycle it into the soil. They produce easily decomposable biomass, are compatible with cereal crops in rotation and are adapted to the climatic and soil conditions of the Miombo woodland (Kwesiga and Coe 1994). Fertilizer trees act as a break crop by smothering weeds and improving the soil's physical and chemical properties.

This technology is based on the fact that although nitrogen (N) is scarce in the soil, it is very abundant in the atmosphere. Fertilizer trees transform N from the atmosphere and store it in the roots, the branches and the leaves. The roots of these trees also capture N at depths below that of maize roots and recycle it through the leaves. Indeed, under many conditions, the nitrogen that accumulates in the leaves of the fertilizer trees is well beyond the recommended rates of mineral fertilizer .The tag 'fertilizer trees' does not imply that the trees provide all major nutrients: these trees fix only N in the soil and P and K must be sourced externally if they are heavily depleted from the soil.

Tephrosia candida fertilizer tree fallows.

Fertilizer trees are established as a pure stand or are intercropped with food crops. The trees are allowed to grow for 12 or 24 months before being cut. . Their foliar biomass, which easily decomposes to release N for subsequent crops, is incorporated into the soil during land preparation. Crops such as maize are planted to take advantage of the improved soil fertility and the residual effect for 2 to 3 years. Thus, the complete cycle of fertilizer tree fallows is a fallow phase of 1 to 2 years, followed by a cropping phase of 2 to 3 years.

The major fertilizer tree species are *Sesbania sesban, Tephrosia vogelii, Tephrosia candid*a and *Cajanus cajan*. To avoid the risk of developing a technology that is based on a narrow plant genetic base, a range of other species (including some that can sprout or 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).

Table 2: Maize yields after 2-year *Sesbania sesban* and *Tephrosia vogelii* fallows in farmers' fields: 1998 to 2000

Fallow Species	**Maize Yields (tones ha $^{-1}$)**			
	Land Use System	**Year 1**	**Year 2**	**Year 3**
Sesbania sesban	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 vogellia	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).

Research results from on-station and on-farm trials consistently show the fertilizer tree technology to significantly increase maize yields compared with continuous maize production without fertilizer, which is what the vast majority of farmers had been doing. As shown in table 2, the annual yield increase from fertilizer tree fallows ranges between 2 and 4 times the yield from continuous maize production without fertilizer. Fertilizer tree fallows produce considerably more maize over 3 seasons than does continuous maize production without fertilizer over 5 seasons (in the trial shown in table 2, the increase was between 50 and 100 percent).

3.1. Modifications and adaptation of fertilizer tree fallows

Farmers have made several modifications and adaptations to the fertilizer tree technology. These modifications were encouraged by researchers and have made the technology more flexible and attractive.

Farmer innovations of fertilizer tree systems

- Using *Sesbania* regenerations as planting material for establishing new fallows to save labour.
- Testing the effect of fertilizer tree fallows on crops other than maize (sunflower, cotton, paprika and groundnut).
- Removing *Sesbania* tips to stimulate lateral branching and thus biomass production.
- Using rain-fed nurseries as opposed to using hydromorphic ('dimba') garden nurseries during the dry season. Rain-fed nurseries reduce the labour required for transporting and watering the seedlings.
- Experimenting with non-potted seedlings to reduce nursery costs.
- Planting fertilizer tree seedlings directly into an existing maize field or bush fallow without preparing the land first to reduce the cost of land preparation.
- Gapping up *Sesbania* fields with seedlings planted 1 year after the 1st planting.
- Planting *Sesbania* at weeding time into parts of fields where maize performs poorly.

Source: Kwesiga et al. 2004.

These are summarized above. Among them were practices to reduce the costs of nursery operations and to reduce the overall labour requirements of the practice. For their part, researchers concentrated efforts on expanding the number of useful shrubs that would significantly improve soils and crop yields. Many species in the *Tephrosia* family as well as several other species like *Leucaena* spp., *Gliricidia*, *Cajanus* and *Calliandra* were tested to complement the initial dissemination of *Sesbania*.

A farmer admiring maize cobs in fertilizer tree fallows.

Experiments conducted to evaluate the interaction between chemical fertilizers and fertilizer tree fallows show that the addition of 1/2 the recommended fertilizer dose to tree fallows provides higher yields than fertilizer alone or tree fallows alone (10.7 t compared to 10.4 t over 3 years). These results show that at certain levels of fertilizer use there is some synergy between mineral fertilizers and improved fallows species such as *Sesbania sesban* and *Tephrosia vogelii*. Following all these adaptations by farmers and researchers, it is clear that there is no single fertilizer tree fallow practise, but rather, a range of management options that form an array of diverse fertilizer tree systems.

4. Inventory of Costs and Benefits from Fertilizer Tree Fallows

The main benefit from fertilizer tree fallows is increased crop yields. Fertilizer trees also reduce the impact of drought, increase the supply of fuelwoodand provide other useful by-products, such as insecticide made from *Tephrosia vogelii* leaves. *Sesbania* fallows greatly reduce striga (witchweed), which generally thrives under conditions of low soil fertility (Kwesiga et al. 1999). Environmental benefits accrue from the use of fertilizer trees. Such benefits include improved physical soil properties: better infiltration and aggregate soil stability, which in turn reduce soil erosion and enhance water retention. Fertilizer tree fallows can soak in carbon from the atmosphere and provide fuelwood, hence reducing pressure on the Miombo woodlands and the biodiversity they contain. Table 3 lists the overall benefits of fertilizer tree fallows.

Table 3: Costs and benefits of fertilizer tree fallows

	Individual	**Public**
Cost	• Land • Labour • Agroforestry seeds • Water for nursery • Pests (some fertilizer tree species only) • Working equipment • Field operations in fertilizer tree fallows coincide with those of traditional cash crops (groundnut and cotton)	• Incidence of *Mesoplatys* beetle pest (restricted to specific species only) • Limited free grazing during dry season
Benefit	• Yield increase • Increase in maize stover • Stakes for tobacco curing • Increase in fuelwood • Fish feed: *Gliricidia sepium* used as fish food • Improved opportunity to grow high value vegetables like garlic and onion • Biopesticide: *Tephrosia vogelii* • Suppressed growth of noxious weeds • Improved soil infiltration and reduces runoff • Greater soil moisture during dry periods • Technology not dependent on political or social standing • Reduced maize production risks	• Carbon sequestration • Suppression of noxious weeds • Improved soil infiltration and reduced runoff • Reduced pressure on woodland and its biodiversity

Source: Ajayi (forthcoming).

The chief cost of improved fallows to farmers is the cost of taking land out of cultivation. However, when the alternative is a natural fallow or cultivation with no nutrient inputs, this opportunity cost is nil or very low. Labour is also a major cost. Over the entire fallow rotation, labour compares favourably with continuous maize production, but farmers still perceive labour investments in the establishment and cutting of fallows and nursery. Over a 5-year cycle of fertilizer tree fallows, the labour input for a continuously cultivated maize field without fertilizer is 462 days ha-1 while the labour input for a continuously cultivated maize field with fertilizer is 532 days ha-1. The labour input for different species of fertilizer tree fallows ranges from 434 days ha-1 to 521 days ha-1.

Some fertilizer tree fallows have been plagued with the increased incidence of pests such as *Mesoplatys* beetles and nemotodes. Thus far, their damage has been small and limited mainly to the fallow trees and not on other plants. Other social and institutional costs include reduced grazing areas and lower tolerance of bush fires.

5. Impact of fertilizer trees

5.1 Economic impact

In this section, the economic impacts of fertilizer tree fallows is assessed firstly at the plot and farm scale and then at the level of eastern Zambia. In both cases, attempts have been made to calculate the net benefits – less investment costs by farmers and research costs.

5.1.1 Economic impact at the farm level

In agricultural research, it is well known that developing a technology that increases production is simpler than developing one that is profitable. The main purpose of this section is to evaluate whether the fertilizer tree fallow system is profitable and whether it does not create additional burdens on farmer resources. 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 is an important criterion in farmers' decision-making regarding the appropriateness of agricultural technologies.

ICRAF has been assessing labour requirements and financial returns from fertilizer tree fallows ever since the early 1990s, to verify that new species and new management options were attractive to farmers. The most recent evaluation was done in 2003, where primary data was collected from farmers' fields on weekly basis. The financial impact of 5 soil fertility management options was evaluated: (i) Sesbania sesban fallow, (ii) Gliricidia sepium fallow, (iii) Tephrosia vogelii fallow, (iv) continuous cropping with fertilizerand (v) continuous cropping without fertilizer. The farmers were selected to represent different stages of the 5-year cycle -- 2 years of fallow establishment followed by 3 years of cropping. Thus, the analysis compares the returns from 3 years of maize crops in the fallow systems against 5 years of maize crops in the continuous cropping systems (this includes the opportunity costs of fallowing). This method of analysis works against fallow systems because benefits do not accrue until the 3rd year. The benefits are discounted by 30% each year to give more weight to early benefits.

Table 4: Profitability of maize production ha^{-1} using fertilizer tree fallows and *subsidized* fertilizer options over a 5-year cycle in Zambia

Production sub-system	Description of land-use system	Net present value	Cost- benefit ratio
		(US $)	
Continuous, no fertilizer	Continuous maize for 5 years	130	2.01
Continuous fertilizer (subsidized at 50%)	Continuous maize for 5 years	499	2.65
Continuous fertilizer (at non-subsidized market price)	Continuous maize for 5 years	349	1.77
Gliricidia sepium	2 years of *Gliricidia* fallow followed by 3 years of crop	269	2.91
Sesbania sesban	2 years of *Sesbania* fallow followed by 3 years of crop	309	3.13
Tephrosia vogelli	2 years of *Tephrosia* fallow followed by 3 years of crop	233	2.77

Note: Figures based on 1 ha, using prevailing costs and prices and an annual discount rate of 30%.

Source: Ajayi et al. (2004).

As shown in table 4, agroforestry-based soil management options are much more profitable than current farmers' practices, despite forfeiting 2 seasons of cropping. The net benefits from fertilizer tree fallows are 2 to 3 times those of the no-input system—a remarkable increase. However, the fallow system is still less profitable than the practice of full fertilizer application. The gap is widest at the government's current 50% fertilizer subsidy rate, but it closes to a narrow difference of $40 ha-1 at market prices. In terms of returns to labour, the differences between fully fertilized (and subsidized) maize and the fertilizer tree system shrink. The return on 1 day of labour is $3.20 for fertilized maize and as high as $2.50 for the best performing fertilizer tree system. These figures are closer together because the fallow system uses far less labour than the continuous cropping systems. By comparison, the return on 1 day of labour for the unfertilized maize system is only $1.10, while the daily agricultural wage is around $0.50.

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 Table 4.

An added benefit from fertilizer tree fallows is the mitigation of drought induced effects. In the event of drought (common in southern Africa), leading to crop failure, Franzel and Scherr (2002) identify several ways in which fertilizer tree fallows can mitigate risk for smallholder farmers. These include:

- Farmers who use mineral fertilizer would lose more in invested resource than those who invested in tree fallows.
- 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.
- 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 two separate long-term trials. In the researcher managed trial, a one or two 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 two 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.

Fertilizer tree fallows also provide wood for farmers. Kwesiga and Coe (1994) show that 10, 15 and 21 t ha-1 of fuelwood were harvested after 1, 2 and 3 years of Sesbania sesban fallow respectively—a significant amount of wood. At the average size fallow field (0.20 ha) and production level, fertilizer tree fallows can provide about 10% of a household's fuelwood needs (Govere 2002). In many locations in Africa, this amount would have considerable value. However, in eastern Zambia, fuelwood is infrequently sold on account of its relative availability from the woodlands. Moreover, the fallow species are not perceived to be of the same quality as the indigenous woodland species for fuel and thus if sold, would fetch a lower price (only $2 to $4 t-1). For this reason, fuelwood can be considered to be a marginal by-product in some areas.

5.1.2. Economic impact at the regional level

The annual return on a 1 ha fertilizer tree fallow averages about $140. However, a typical fallow measures about 0.20 ha and generates a net annual return of about $28. Extra maize production ranges from 85 kg to 170 kg annually. Though small, these returns are actually quite significant. Since maize consumption per adult in Zambia is about 1.5 kg per capita. Thus, the systems generate from 57 to 114 extra person days of maize consumption. Both the consumption and financial return would increase assuming different fertilizer tree fallow systems. For example, in the case where farmers sow the tree seed into existing maize fields and only fallow for one season, there is an increase of 85 to 143 extra person days of maize consumption.

It is possible to integrate the information on average fallow size, average maize yield response and average wood value, to produce an overall estimate of the economic benefits of the fertilizer tree system. This information is most accurate for Eastern Province, where the bulk of the analyses have been done. In 2004, the farmers who planted fallows in 2000, 2001and 2002 reaped some benefits. The total benefits are estimated at about $1.32 million for approximately 47,000 farmers. In the 2003 to 2004 season, it had been estimated that 77,500 farmers had planted a fallow. Thus, by the end of 2006, the total benefits should increase to over $2 million.

ICRAF's accounting systems have changed over the years, making the calculation of all the costs associated with the development of the fertilizer tree system challenging. Costs for soil fertility research in eastern Zambia, coupled with backstopping support from headquarters, ranged from $230,000 to $350,000 in most years between 1989 and 2004. It is fair to say that the net benefits from research are only now moving from the negative to the positive. Indeed, most of the payoff is expected over the next few years.

5.2. Impact on the environment

5.2.1 Impact on soil quality

Fertilizer tree fallows improve soil physically, chemically and microbiologically Soil physical properties can be improved by adding large quantities of litter fall, root biomass, root activity, biological activity and root macropores (Rao et al. 1998). Plots that had fertilizer tree fallows were found to have improved soil particle size, improved water infiltration and water retention capacity and reduced soil runoff (Chirwa et al. 2004). The higher number of larger 'soil aggregates' means that there is less nutrient seepage deep into the soil, that there is a greater potential for organic matter and carbon build-up and that there is less erosion potential. The effects on water infiltration and runoff are not long lasting however—they reduce once the trees are removed and maize is planted. It is not known whether repeated use of fallows can lead to longer lasting effects, but the use of a fertilizer tree intercrop (for example *Gliricidia*), sustains these effects.

Palm (1995) shows that organic inputs of various tree legumes applied at 4 t ha-1 can supply enough N (roughly 100 to 120 kg) for maize grain yields of 4 t ha-1. Indeed, the fertilizer tree systems produce such quantities of biomass. However, most of these organic inputs cannot supply enough P and K to support such maize yields over time. Nutrient balances1 under different land uses were measured in a 10-year study. As shown in table 5, for all the improved fallow species, there was a positive N balance in the 2 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 10 years. Unfertilized maize had lower balances even though maize grain and stover yields were very low. However, in the 2nd year of cropping the N balance became very small in the fallow systems, partly due to large off-take in the large yields and partly due to leaching through the soils. This implies that if cropping goes beyond 3 years after fallowing, there will be a negative N balance.

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[1] The nutrient balances are the nutrients added through leaves and litter fall, which are incorporated after fallows as inputs. The nutrients in maize grain harvested, in maize stover removed and in fuelwood taken away at the end of the fallow period are then considered as nutrient exports.

Table 5: Nutrient budgets for different options in 2-year non-coppicing fallows (0 to 60 cm)

	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).

Most of the land-use systems showed a positive P balance. This is attributed to low off- take of P in maize grain yield and stover. However, it should be noted that this site already had a high P status. Fertilizer trees have been shown to increase plant available P through secretion of organic acids and increased mycorrhizal populations in the soil.[2]

Most land-use systems showed a negative balance for K. For fertilizer tree 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 was due to higher maize and stover yields which exported a lot of K (and therefore the current recommended dose of K may not be sustainable). Nonetheless, yields were not adversely affected because the K stocks in the soil were very high. However in sites with low stocks of K in the soil, maize productivity may be adversely affected.

5.2.2. Value of N fixed by fertilizer trees in southern Africa

Another way of valuing the fertilizer tree system is through the savings farmers and countries make on the purchase of mineral fertilizer.[3] On a regional scale, the Zambezi Basin Agroforestry Project (ZBAP) estimates that 180,000 farmers had established fertilizer tree fallows as of the 2003 season. If the average size of fertilizer tree fallows per farmer of 0.20 ha (Ajayi et al. 2004) prevailed in other areas, 36,000 ha were under improved fallows. Field trials in Zambia estimated the amount of N fixation by fertilizer tree fallows at 150 kg N ha^{-1} per year. The estimated total monetary value of the N fixed by fertilizer trees in the region is \$5.7 million per annum[4]. This is assuming that all 150 kg N would be available to the maize (during the following production seasons), but it is likely that some will be lost due to leaching or gaseous emissions, thus reducing this figure accordingly. Depending on distance and condition of the roads, the cost of transporting fertilizer bags from the shops in the major town/cities to farmers' village ranges from 10-25% of the purchase cost of fertilizer. In the five countries (Zambia, Malawi,

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[2] These issues continue to be investigated on-station and on-farm where the soils are lower in P.

[3] Note that this is not an added benefit to the economic benefits calculated above, but rather an alternative way of valuing the fertilizer system. It is also somewhat inferior in that assumptions need to be made about the conversion of the N produced by the fallows into the N from mineral fertilizer.

[4] Nitrogen fixation by fertilizer tree fallows estimated at 150 kg N ha^{-1} per year for a field area of 36,000 hectares, the total N fixed = 5,400 t of N or the equivalent of 12,857 t of urea per year. Price of urea in Zambia = ZKW 105,000 per 50 kg bag or \$22.34 per bag (At exchange rate US\$ = ZKW 4,700) or \$447 t^{-1} of urea.

Zimbabwe, Tanzania and Mozambique), the value of N fixed by fertilizer tree fallows in 2003 could be as high as $6.27 to $7.13 million per year.

5.2.3. Effect on deforestation of Miombo woodlands

Fertilizer trees a source of fuelwood.

Farmers who establish fertilizer tree fallows have some of their households' fuel and other wood requirements satisfied from their own fields. This may reduce the exploitation of wood from the communally owned Miombo forests and thus mitigate deforestation. A study was carried out in eastern Zambia to determine whether or not this was observed (Govere 2002). Of the total amount of fuelwood consumed (3.1 t per household), the improved fallows contributed 11% on average. The value is to the farmer varies according to local fuelwood supply conditions. However, this amount of firewood production has not necessarily 'saved' trees in the Miombo from being cut as shown by the conflicting evidence in table 6.

Table 6: Source of fuel-wood production per year in eastern Zambia

	Chipata North (kg)	Chipata South (kg)
Fuel-wood from fallows for adopters	261	431
Fuel-wood from Miombo for adopters (kg)	2,919	2,915
Fuel-wood from Miombo for non adopters (kg)	2,943	3,385

Source: Govere (2002)

Stems and branches of fertilizer trees are increasingly used as stakes in tobacco curing sheds. This may reduce the degradation of forests.

In Chipata South district, it appears that the fallows have contributed fuelwood that ultimately reduces the amount of fuelwood collected from the Miombo forests. But that is not the case in Chipata North district, where collection amounts are the same despite the additional wood from the fallows. Thus, there are some positive signs that fertilizer tree fallows may reduce pressure on the natural woodlands, but this is not guaranteed.

5.2.4. Effect on carbon sequestration

The debate on the link between carbon in the atmosphere and global warming has led to an increased scientific interest in measuring carbon sequestration in different land-use systems. Although agroforestry land-use systems have been cited to sequester the most soil C compared to other land-use systems, there is not much scientific evidence to support the claim. A study to measure the amount of soil C in long-term trials involving fertilizer tree fallows and other land-use systems was conducted.

Table 7: Carbon sequestration in fertilizer tree fallows and woodlot fields

	Non-coppicing fallows	Coppicing Fallows	Rotational woodlots
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

The results in table 7 show the different potentials of various fertilizer tree systems and rotational woodlots (a rotational woodlot is a longer-term rotational system of about 5 years, in which the wood product is a major product sought by farmers) to sequester C in the above and below ground biomass. The order was woodlots>coppicing fallows>non-coppicing fallows. Among non-coppicing 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 cm to 100 cm stored the largest amount of C. This is critical because at this level, the C is protected from anthropogenic disturbance such as ploughing and tilling. The amount of C stored depends on species, soil texture and depth. Evidence on soil C from similar fertilizer tree fallow systems in Kenya shows that the net amount of C sequestered (after deducting NO_2 emissions) was 4 t ha^{-1} (lasting one year) using time averaged methods. Current prices of C for land managers are \$3 to \$8 t^{-1}, so the potential for fertilizer tree fallows to increase the incomes of farmers is limited.

6. Adoption and dissemination of fertilizer tree fallows

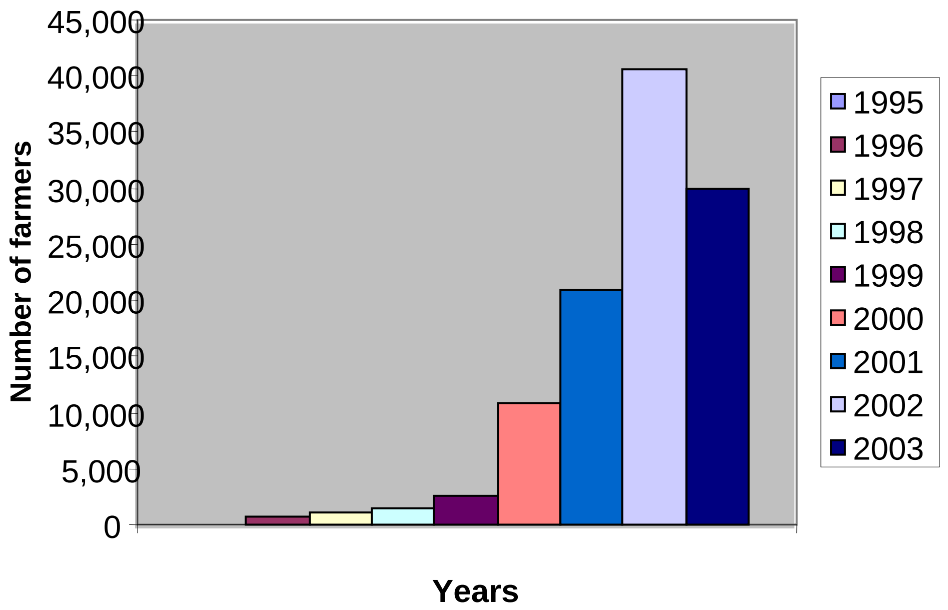
6.1. Adoption of fertilizer tree fallows

Wide dissemination of fertilizer tree fallows started in 1998, hence, almost all the farmers that are currently using the technology are still on their 1st cycle. Farmers that have planted for a second time are referred to as adopters while farmers that are still on a first cycle are referred to as testers or users. In practise, socio-economic research has not always distinguished between adopters and testers (users). In this paper, we refer to farmers who have planted fertilizer tree fallows as ‘users’ even though this is a broad term that encompasses adopters.

6.1.1. Number of fertilizer tree system users

From less than 100 users in the early 1990s, the number of farmers who have planted fertilizer trees has rapidly increased. The jump in numbers, especially from the year 2000 onwards, reflects the intensified scaling up of efforts by collaborating with development partners. Figure 2 shows the number of users in each year over a period of 15 years.

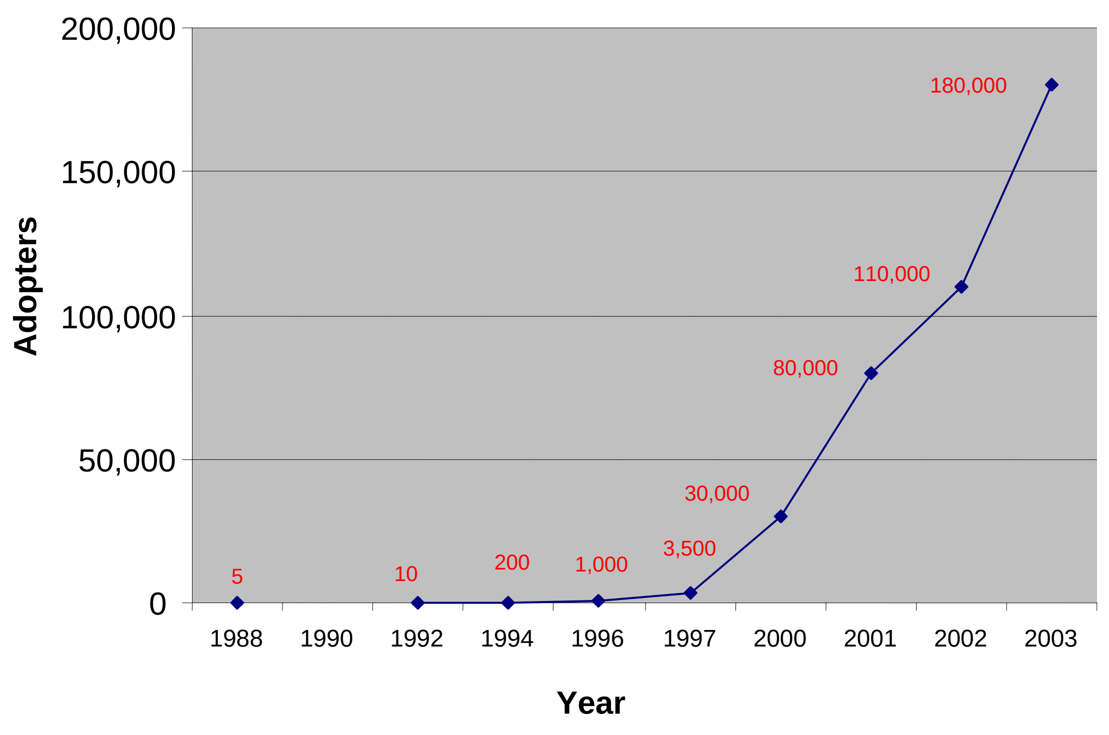
Figure 2: Number of farmers that planted fertilizer trees in eastern Zambia: 1995 to 2003



From 1999, the number of users leaped past 10,000. The number dramatically climbed in 2002 to over 40,000 users. In 2003, the number of users somewhat dropped in for 2 reasons. First, one of the major scaling-up projects (World Vision) ended. Second, a large number of new farmers were still waiting for the effects fertilizer trees would have on maize before planting the trees again. It is estimated that currently, the number of fertilizer tree system users is close to 100,000.

There has been a spill-over of fertilizer tree fallow fields beyond the initial region of eastern Zambia. During the 2002/2003 planting season, the number of farmers who had established at least 1 fertilizer tree fallow field throughout the southern African region was estimated at 180,000 (ZBAP Annual report 2003). This figure included farmers that had been reached directly by ICRAF and indirectly by collaborating partners and farmer-to-farmer exchange programs.

Figure 3: Number of farmers using fertilizer tree fallows in Southern Africa



Source: ZBAP Annual report (2003).

Keil (2001) noted that 71% of a sample of farmers who planted fertilizer tree fallows in 1996 to 1997 continued to plant them over the next 3 seasons. Keil computed an index of intensity – the area dedicated to fertilizer tree fallows in proportion to the maximum farm area (1/4 of a farmer's maize area given a common cycle of 4 years). The average index of intensity was 52%. The index was highest for the fairly well-off farmers (57%) but the indices for the poor and very poor were very respectable – between 36% and 37%.

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 fallows increased to 0.20 ha in 2003. The distribution of the field size varies widely ranging from 0.01 ha to 0.78 ha per farmer. Two trends precipitated this increase in fallow size: farmers who planted for a second or third time usually expanded the area under fertilizer trees; and first-time planters allocate larger areas to fertilizer tree fallows than their predecessors in the 1990s. This expansion attests to the benefits of fertilizer tree fallows.

6.2. Factors that influence fertilizer tree system use

Studies regarding the use and adoption of fertilizer tree fallows have centred on 2 related issues: (i) the factors that drive the use of fertilizer tree fallows among the farming communities and (ii) gaining insights into the categories of farmers who use (or do not use) the technology. Table 8 presents summary results from these studies as synthesized by Ajayi et al. (2003). The synthesis highlights the lessons learned and identifies generic issues and their implication on policy and scaling up efforts.

The synthesis indicates that a farmer's decision to use fertilizer tree fallows is influenced by a matrix of several hierarchies of factors. The factors are 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 farmer within an agroforestry intervention zone and (iii) household-specific variables (like wealth status, gender and household size).

Table 8: Description of selected adoption studies and summary of factors that affect 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 ownership	Village exposure to improved fallows
Factors affecting the 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 the decision to use fertilizer tree fallows more than once											
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).

6.2.1. Institutional and government factors

The cross-cutting issues that strongly affect a farmer’s decision to use fertilizer tree fallows are subsidies on fertilizer and land tenure. In the early 1970s, the Zambian government introduced a support program for maize. This program entailed fertilizer subsidies, cooperative depots and agricultural credit. Subsidies averaged 60% by 1982. The expansion of the cooperative depot system during the early 1970s made inputs more accessible to farmers in remote areas. As a result, fertilizer use increased from 20,000 t in the early 1970s to 85,000 t in the mid 1980s, since government programs subsidized credit to smallholder farmers (Howard and Mungoma 1996). The removal of subsidies and the collapse of the parastatal marketing system in the late 1980s and early 1990s therefore negatively affected fertilizer use. Whereas in 1986/87 the ratio of the price of N to the price of maize was 3:1, it increased to 11:3 in 1995/96 resulting in a decline of up to 70% in fertilizer use.

This pre-existing appreciation for the benefits of soil nutrients contributed to farmers’ interest in the fertilizer tree technology. Farmers found fertilizer trees to be both complementary and competitive to mineral fertilizer. The rapid adoption of the fertilizer tree technology confirms that subsidies on fertilizer affect the demand and use of agroforestry-based soil fertility management technologies (Place and Dewees 1999). Financial analysis of fertilizer tree fallows (Ajayi et al. 2004 and Franzel 2004) show that fertilizer subsidies greatly affect the profitability and potential adoptability of fertilizer tree fallows, relative to other soil fertility management options.

Property rights as well as customary practises (such as bush fire setting and free grazing) affect the adoption of fertilizer tree fallows. 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 is an important factor that enhances (or inhibits) the widespread use of the technology. The study also found that privatizing seasonal commons is an issue of contention in the efforts to scale up the adoption of fertilizer trees. Because fertilizer tree fallows reduce the area where traditional free grazing systems are practised, the technology is met with some resistance from households with larger livestock herds. Fortunately, local leaders have been able to resolve such conflicts and enable the investment in improved fallows, ultimately resulting in net positive benefits for the whole community.

6.2.2. Spatial location factors

Community level variables and a farmer’s residence in an agroforestry intervention zone, significantly affect the continued use of fertilizer tree fallows. Analyses verify that these variables promote the use of fertilizer tree fallows: the presence of agroforestry-supporting institutions; the capacity and commitment of government agricultural extension services to the technology; and access to roads and markets.

6.2.3. Household and individual factors

Studies have identified several individual and household-specific factors that influence farmers to use fertilizer tree fallows.
Training and awareness: This is one of the most important factors since farmers who plant fertilizer trees are aware of this technology. Many farmers now using the technology have witnessed fertilizer trees improve soils in their neighbour's fields or on demonstration plots. Some farmers have been formally trained by agroforestry organizations.
Size of available land: The size of land holding positively correlates to the establishment of fertilizer tree fallows. Compared to farmers who have less land, those with larger holdings can afford to put part of their land to fallow. This correlation has been found elsewhere in Africa, such as Kenya (Place et al. 2002).

Farmers' groups: Farmers who belong to cooperatives or farmers' clubs are more likely to establish fertilizer tree fallows (Kuntashula et al. 2002 and Ajayi et al. 2001). This is because cooperative groups facilitate easier access to information and training opportunities for their members. For species that require a nursery stage before establishment in the field, groups are more likely to manage the nurseries (Bohringer and Ayuk 2002).

Wealth status: There is some evidence that the level of wealth and the planting of fertilizer trees are positively related (in 1 log linear model, $p < 0.08$). Whereas 53% of the well-off farmers planted fallows, 40% of the fairly well-off farmers, 22% of the poor farmers and 16% of the very poor farmers planted fertilizer trees (Phiri et al. 2004). Interestingly though, the proportion of farmers who continue to plant fertilizer tree fallows (adopters) did not appear to vary by wealth status. The most well-off farmers were the least likely to continue planting as compared to the other groups (Keil 2001).

Labour input: Over the full fallow crop cycle, farmers used 11% less labour on fertilizer tree plots than on unfertilized maize plots (Franzel et al. 2002). Nonetheless, there is concern that labour-constrained households may find it difficult to make the initial labour investments in the system. Empirical analysis has found some evidence that the more labour a household has, the greater the likelihood it will plant fertilizer trees. Other studies however, do not find a significant relationship between labour availability and the planting of fertilizer trees.

Gender: The existing power relations between men and women generally influence the adoption of new agricultural technologies in most African communities—agroforestry is no exception. The gender differences manifest in decision making, land tenure rightsand access to productive resources. However, studies (Ajayi et al. 2001, Franzel et al. 1999, Keil 2001, Gladwin et al. 2002 and Phiri et al. 2004) show that there are no significant differences between the proportions of women and men planting fertilizer tree fallows or between single women and married female heads of households. In certain cases, some married women may not establish improved fallows without the consent of their husbands (Peterson 1999). In some communities, improved fallow plots planted by women were significantly smaller than those planted by men due to greater land and labour constraints or risk aversion (Franzel et al. 2002).

Capacity to purchase fertilizer: Due to the volatility of policy and prices, some farmers who can afford fertilizer plant fertilizer trees because they are unsure of the continued affordability of fertilizer due to volatility of prices and policy (Peterson 1999 and Ajayi et al. 2001). Farm-level data also shows that once started, most farmers continue to plant fertilizer tree fallows.

6.3. Dissemination of fertilizer tree fallows

One of the major reasons for the success of fertilizer trees over comparable technologies is the active encouragement of a constructivist approach taken in the development of the technology. That is, farmers are encouraged to try the technology and then to modify and adapt it accordingly. In the mid 1990s, ICRAF began efforts to disseminate information about the technology and seed management to reach more farming communities in eastern Zambia. The scaling up effort continues to be coordinated through the Adaptive Research and Development Network (ARDN). The network comprises ICRAF, government research and extension units, farmer organizations and non governmental organizations (NGOs). Many partner organizations have fertilizer tree fallows (and agroforestry in general) as general components of their programs. 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 one organization does not affect the overall progress and the spread of fertilizer tree fallows among farmers.

After several years of modest dissemination efforts by ICRAF, several institutions that promote natural resource management options provided added impetus to the spread of the fertilizer trees technology 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, USAID-funded TARGET agroforestry training Project, PLAN International and KEPA (a Finnish development organization). The agricultural extension system staff were also active in promoting the technology.

Part of the dissemination effort includes the emerging involvement of private sector organizations and individual entrepreneurs in providing support services and inputs for fertilizer tree fallows. Individual entrepreneurs have established large seed orchards to meet the rising demand for fertilizer tree fallow seeds (especially *Gliricidia sepium*).

In partnership with ICRAF, some institutions reach farmers through direct training and provide the initial seed. These organizations focus on dissemination and training while leaving ICRAF to research and refine the technology. Such committed partners are necessary to help disseminate the fertilizer trees technology because it is new and is relatively knowledge-intensive. Partners provide repeated technical support at various stages of the fallow establishment and management for instance, managing a nursery, planting a fallow, cutting a fallow, and incorporating fallow biomass.

7. Conclusion

The high number of current fertilizer tree system users in eastern Zambia (about 100,000) and throughout southern Africa is attributed to a significant and concerted effort by several development partners with ICRAF's technical support. This study reveals that in order to make sustainable impact, agricultural technology should target the real needs of farmers in relevant locations. Farmers should be actively encouraged to modify and adapt the technology to suit them best. Such new and knowledge-intensive technology requires active dissemination and technical support for such dissemination. Several variables such as institutional and policy (especially fertilizer subsidies), spatial and geographic and household-specific variables, influence the adoption of the fertilizer trees technology.

The effect of fertilizer tree fallows on maize yield in several trials and from farmers' experiences has been found to be consistently impressive. In addition to increased maize yields, fertilizer tree fallows are also more profitable than continuous maize cultivation without fertilizer. However, the fallows are less profitable than fully fertilized plots, especially when the fertilizer is subsidized. The fertilizer tree system is a low-cost investment that requires less labour over its full cycle than other land uses over the same period of time. In Zambia, where the daily agricultural wage is around $0.50, the return per 1 day of labour ranges from $1.90 to $2.50 for different fertilizer tree species. This is substantially superior to the return per 1 day of labour devoted to unfertilized maize cultivation, which is only $1.10.

The economic impact of fertilizer tree fallows in eastern Zambia is soaring towards $2 million annually and will continue to increase as more farmers use the system. The study identified different types of costs and benefits of fertilizer tree fallows for individual adopters and a wide range of environmental benefits to the society at large. Some of the benefits have been quantified but a detailed study is required to quantify others. On a larger scale, the gross value of the N fixed by fertilizer tree fallows in the five countries participating in the southern Africa regional program is estimated to be as much as $6 million per annum. Evidence suggests that a lasting environmental impact such as improved soil structure, increased carbon sequestration and reduced cutting of woodlands for fuelwood can be generated by fertilizer tree fallow systems.

Although nutrient inputs are needed by almost all farmers in the southern Africa region, fertilizer tree fallows are not the solution for all of them. For smaller farms, permanent intercropping of fertilizer trees using a coppicing species is much more appropriate. This method is rapidly spreading among farmers in the densely populated nation of Malawi. In other situations, it is important for farmers to use manure, compost and especially mineral fertilizers. The fertilizer tree system is one very important option in an overall strategy of integrated soil fertility management of smallholder farmers in southern Africa.

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