

Labour inputs and financial profitability of conventional and agroforestry-based soil fertility management practices in Zambia

OC Ajayi¹, FK Akinnifesi², G Sileshi³ and W Kanjipite⁴

Abstract

Several agro-ecological practices have been developed to increase the range of soil fertility management options available to farmers, but little information is available on their labour input requirement and profitability relative to conventional practices. This study used a multiple visit cost-route method to estimate labour inputs and financial profitability of agroforestry-based and conventional (with and without fertiliser) soil fertility management practices in eastern Zambia. Results show that aggregated over a five-year cycle, labour inputs used under agroforestry practices were lower than fertilised maize fields but higher than non-fertilised continuous cropped maize. Agroforestry practices were more profitable (NPV ranging between \$233 and \$327 ha⁻¹) than unfertilised maize fields (NPV of \$130 ha⁻¹) but less profitable than fertilised maize fields. The NPV for the latter is \$499 ha⁻¹ under a 50% government subsidy on fertiliser but, it fell to \$349 ha⁻¹ when the subsidy effect is removed. In terms of return per unit investment cost, agroforestry practices performed better with a benefit to cost ratio ranging between 2.77 to 3.13 in contrast to 2.65 (subsidised fertiliser) and 1.77 (non-subsidised fertiliser). The returns to labour per person day was \$2.56 in (non-subsidised) fertilised maize field, \$3.16 in subsidised fertiliser field, \$2.63 in Gliricidia fields, \$2.41 in Sesbania fields, \$1.90 in Tephrosia fields, and \$1.10 in non-fertilised maize fields. The results do not support the popular notion that agroforestry practices are more labour intensive. It suggests that in addition to total labour use requirements, the temporal distribution of labour use during the farming season is important. It is concluded that agroforestry practices are profitable, and could contribute to food security.

Keywords: Benefit-cost analysis; impact assessment; land use management; project analysis; sustainable agriculture

¹ Senior Agricultural Economist, World Agroforestry Centre (ICRAF), PO Box 30798, Lilongwe 03, Malawi; Tel: +265-1-707332; Fax: +265-1-707323; Email: o.c.ajayi@cgiar.org

² Principle Tree Scientist, World Agroforestry Centre (ICRAF), PO Box 30798, Lilongwe 03, Malawi.

³ Agro-Ecologist, World Agroforestry Centre (ICRAF), PO Box 30798, Lilongwe 03, Malawi.

⁴ Monitoring and Evaluation Officer, Catholic Relief Services, Lusaka, Zambia.

1. Introduction

Low soil fertility is widely recognised as a major factor contributing to low agricultural productivity in sub-Saharan Africa (Sanchez, 2002; Vanlauwe and Giller, 2006). The amount of resources and the multiplicity of programmes devoted to soil improvement technologies attest to the enormity of the problem in Africa (Haggblade *et al.*, 2004). The degradation of soil fertility in many sub-Saharan Africa countries is caused by two related factors. First is the increase in human population that has led to a reduction in per-capita land availability and breakdown of traditional fallow system that smallholder farmers relied on for soil fertility replenishment. As fertile land becomes less available, farming is extending into more fragile lands, undermining the natural resource capital of the environment and the ability of countries in the region to produce food for their people. The second reason is non or sub-optimal use of inorganic fertilisers due to high cost of the input, especially after the removal of farm input subsidies and the collapse of parastatal agricultural input marketing agencies in the 1980s and early 1990s (Kwesiga *et al.*, 1999; Ajayi *et al.*, 2007). In Zambia, after the removal of subsidies on inorganic fertilisers, the ratio between the price of nitrogen and maize increased four-fold leading to a 70% decline in fertiliser use by smallholder farmers in the country (Howard & Mungoma, 1996). The search for sustainable technological options to improve soil fertility across a wide range ecologies and typology of households is an important challenge in the formulation of agricultural and development policy agenda in sub-Saharan Africa (Scoones & Toulmin, 1999; Ajayi *et al.*, 2003; NEPAD, 2003).

In response to these challenges, an extensive collaborative research undertaken by international and national research institutions in southern Africa led to the development of agroforestry-based soil fertility management practices as sustainable options to assist smallholder farmers replenish their soils within a short period of time. Among the agroforestry-based practices, "improved tree fallow" and maize-tree intercropping practices that are based on the use of legumes have received significant attention. "Improved tree fallows" involve the deliberate planting of fast growing nitrogen-fixing trees or woody shrub species for one to two years, followed by one or two years of cropping (Sanchez, 1999), and may go through several fallow-cropping-fallow rotational cycles. The underlining science of the practice builds on the knowledge that nitrogen is the most limiting macro nutrient in the soil, but it is highly abundant in the atmosphere. Agroforestry practices using legume species such as *Sesbania sesban*, *Gliricidia sepium* and *Tephrosia vogelli* replenish soil fertility through biological fixation of atmospheric nitrogen and recycling of nutrients thus contributing to conservation of natural resources.

The impacts of agro-ecological soil fertility management practices on household food security have been well documented (Hagblade *et al.*, in press). A recent meta-analysis conducted on peer-reviewed studies carried out independently by several researchers in West, East and Southern Africa concluded that there is consistent evidence for maize yield benefits from using the sustainable methods of soil fertility replenishment in Africa (Sileshi *et al.*, 2008). In addition to supplying nitrogen and improving crop yield, the plant species also increase soil organic matter and improve soil chemical, physical and biological conditions (Kwesiga *et al.*, 2003; Phiri *et al.*, 2003; Akinnifesi *et al.*, 2006; Mafongoya *et al.*, 2006; Sileshi & Mafongoya, 2006; Akinnifesi *et al.*, 2008), act as carbon sink to mitigate climate change (Makumba *et al.*, 2007; Kaonga & Bayliss-Smith, 2009), generate multiple ecosystems services (Sileshi *et al.*, 2007) and provide fuel-wood for household energy (Kwesiga & Coe, 1994). The latter has a positive effect on the rate of deforestation of the natural "miombo" woodland in some countries. Field studies in Kenya have demonstrated that agroforestry-based practices provide good weed control against *Striga*, a noxious weed due to the high contents of N added in the soil by the tree legumes species (Kiwia *et al.*, 2009).

Over the years, variants of agroforestry-based land management practice have been developed to suit a broad range of agro ecological zones and soil conditions. However, while the robustness of the biophysical performance of the agro-ecological methods has been confirmed, apart from few studies (Place *et al.*, 2002; Franzel, 2004), relatively little information is available on the financial profitability and returns to investment from the practices, relative to other conventional soil fertility management practices. The few economic studies mainly focused primarily on *Sesbania sesban*, but there is a lack of information on Gliricidia-maize intercropping and other variants of the agro-ecological practices, which have been attracting increasing interest of farmers and technology developers especially in eastern Zambia and southern Malawi in recent years (Chintu *et al.*, 2004; Akinnifesi *et al.*, 2006). There is also lack of information on the labour input requirements of improved tree fallows relative to conventional soil fertility management practices: are improved fallow practices more labour intensive relative to conventional soil fertility management practices as popularly perceived? What is the amount of labour inputs used in the different types of the agro-ecological practices? Policymakers and development workers have repeatedly inquired after this information as efforts are being intensified to scale up the dissemination of improved fallows to reach many more farmers who could benefit from the practices. These questions and information gap provided the *raison d'être* for this study. Two agricultural production models were compared in this study: (a) the conventional model which has increase in crop yield as its unique

objective, and (b) agroforestry model which is an agro-ecological model that envisions sustainable production, combining crop yield increase and environmental conservation. The specific objectives of the study are: (i) to compare the use of labour in agroforestry system with that conventional system, (ii) to assess the financial profitability and returns to investment in the two systems of production.

2. Study area, data and methods

2.1 Study area

The study was conducted in eastern Zambia, covering an area of 70,000 km² equivalent to about 9% of Zambia's territory. The average annual rainfall is about 1,000 mm, with most of the rains occurring between December and March. The length of growing season varies from 139 to 155 days per annum. The vegetation is typical "miombo" woodland and dominated by native tree species such as *Brychystegia* spp., *Julbernardia* spp. and *Isoberlina* spp. Population density varies between 25 and 40 people per km². Maize which is the staple food crop dominates the agricultural economy of the area although other crops such as groundnut, cotton and vegetables are also grown mainly for cash. These crops are cultivated in small fields of about 2 hectares. Eastern Zambia is an agricultural province but its infrastructure is poorly developed. This makes the cost of transportation of farm inputs such as fertiliser and outputs exorbitant compared with other parts of the country such as the "line of rail" in Southern and Central Provinces.

2.2 Sampling technique and data collection

The study used stratified sampling techniques to select farmers. First, a sampling frame consisting of all farmers who had agroforestry plots in eastern Zambia was drawn up based on information obtained from an agroforestry development organisation (Zambia Integrated Agroforestry Project, ZIAP) and the World Agroforestry Centre (ICRAF). Data was collected from the two models of agricultural production through multiple visit cost-route method throughout the entire agricultural season. The specific agroforestry models were: Gliricidia-maize intercropping (Gliricidia), rotation of maize with *Sesbania sesban* (Sesbania) and rotation of maize with *Tephrosia vogelii* (Tephrosia) fallows. The specific conventional models were unfertilised continuously cropped maize (unfertilised maize) and fertilised continuously cropped maize (fertilised maize). In total, 89 fields were selected for data collection. At the beginning of the farm season, each selected farmer was given a notebook to record detailed information (themselves or assisted by literate

children) in the local language, regarding activities that they carried out each time an operation took place in their fields. The information recorded included type of activity, duration of activity, number of workers who participated in a given field activity, quantity of inputs used, costs (in cash or kind) incurred, and outputs obtained. Field research assistants visited each farmer weekly to examine the information recorded in farmers' notebooks. The information was then aggregated on weekly basis and summarised into a weekly data sheet that was designed for the study.

To ensure consistency of information across farmers, the weekly data sheet used a "double entry" recording system. For example, where field operation is planting, provision is made for a corresponding record under "seed" cost. This minimised problems associated with long memory recall methods, which are relatively cheaper but produce less accurate information. Cost of inputs such as maize seeds, agroforestry seeds were estimated at the prevailing market prices. Two different prices of fertiliser occurred in the market: one is the open market fertiliser price obtainable from agro-dealers while the other is subsidised fertiliser price. The latter is a half of the former due to the 50% subsidy given by the government of Zambia under the auspices of the Fertilizer Support Programme (FSP). Labour is estimated at the prevailing wage rate prevailing in the rural labour market in the study area. The two outputs considered in the study are maize grain and fuel wood (from the legume trees).⁵

Due to the wide margin of error associated with estimates of field area obtained from smallholder African farmers (Ajayi & Waibel, 2000), the Geographical Positioning System (GPS) technique was used to measure the size of all the selected fields accurately and rapidly.⁶ Additional information on household demographic structure was collected from farmers during the field study.

2.3 Analysis

Farm budget and profitability ratios were computed for the two models – agroforestry and conventional – for soil fertility replenishment practices based on the inputs and output information collected from the fields. A discounted cash flow analysis was carried out to estimate the benefit-cost ratio (BCR), net present value (NPV) and internal rate of return (IRR) of the agroforestry and conventional soil fertility management practices. A discount

⁵ The ecosystem services of agroforestry practices that were alluded to in the introduction section were not included in the computation of the costs and returns of the different practices.

⁶ The measuring time for the plots using the GPS was completed rapidly, taking less than 20 minutes per plot.

rate of 30% was used, reflecting the high inflation economy of Zambia. To ensure a comparison of profitability across different land management practices, profitability ratios were estimated using a five-year planning project period for all the soil fertility management practices. We used a five-year period because it marks the complete cycle for *Sesbania* and *Tephrosia*, i.e. two years of fallow and three years of crops. It is noted though that *Gliricidia sepium* is a coppicing tree species (it re-sprouts after being cut) and therefore can continue to replenish soil fertility for a much longer period. The implication on the profitability of the different soil fertility practices from of using a longer investment planning period is discussed in Section 4. The computation method and the critical minimum of the financial indicators are shown in Table 1.

Table 1: Computation of financial profitability indicators and their critical minimum values

Financial Indicator	Computation	Critical minimum value
Benefit cost ratio (BCR)	$\text{BCR} = \frac{\sum_{t=1}^5 \frac{B_t}{(1+r)^t}}{\sum_{t=1}^5 \frac{C_t}{(1+r)^t}}$	BCR > 1.0
Net present value (NPV)	$\text{NPV} = \sum_{t=1}^5 \frac{(B_t - C_t)}{(1+r)^t}$	NPV > 0
Internal rate of return (IRR)	$\text{IRR} = \sum_{t=1}^5 \frac{(B_t - C_t)}{(1+r)^t} = 0$	IRR > r

Where $t = 1, 2, \dots, 5$

r = Discounting factor

B_t = Total income from the different soil fertility technologies in year t ,

C_t = Total cost incurred on the different soil fertility technology for year t

3. Results

3.1 Use of labour inputs in soil fertility management

The quantity of labour inputs for the different land management practices is presented in Table 2. In the first year, labour inputs of agroforestry practices were generally higher than that of continuously cropped maize. This is because of the extra labour required to establish nurseries and transplant *Sesbania* and *Gliricidia* seedlings in the field, in addition to the normal operations for clearing and preparing the land. The labour input used in

Tephrosia fields is lower than the two agroforestry practices, because Tephrosia seed is normally sown directly in the field thus effectively eliminating some field operations such as nursery establishment, watering and transplanting of seedlings. In year 2, the amount of labour inputs used in agroforestry was generally lower because only a minimal quantity of labour is required to maintain the fallows during this relatively “inactive” phase. The labour used in Gliricidia in the second is very low (2 person days) as the trees have formed reasonable canopy which prevented farmers from planting any maize crop in the field during that year. In year 3, the labour use increased greatly in all agroforestry fields compared with continuous maize fields because it was the year that the trees in the fallows were cut, incorporated into the soil, and the plots cleared in readiness for the cropping phase.

Table 2: Labour inputs use (person-days ha⁻¹) in different land management practices in eastern Zambia

Type of soil management practice	Year 1	Year 2	Year 3	Year 4	Year 5	Total
Continuous maize without fertiliser	104	95	88	88	87	462
Continuous maize with fertiliser	110	121	101	103	97	532
Gliricidia-maize intercrop	130	2	132	125	130 ^a	519
Sesbania-maize rotation	111	45	128	121	116	521
Tephrosia-maize rotation	105	40	118	117	113	493

^a Yield adjusted for the fields that were burnt by fire during the dry season

The use of labour inputs in agroforestry practices is concentrated in the first year during the establishment of fallows and in the third year when the fallow is cut down and the field sown with maize. The labour inputs fertilised continuous maize cropping is higher than the non-fertilised plots because yield is higher and additional labour is required to harvest the higher maize yield. From year 1 to 5 year, labour inputs requirements in continuous cropping system follows a declining trend as a result of a decrease in soil fertility and crop yield. Over the five-year period, the aggregated quantity of labour used in agroforestry practices was lower than that in fertilised maize fields. The increased labour inputs in fertilised maize fields is due to the fact that normal agricultural field operations took place in all the five years, unlike in agroforestry practices where crop production operations take place in three out of the five years. Over the same five-year period, the lowest quantity of labour input was seen in the fields that farmers cultivated continuously without the application of fertiliser. This is because some, field operations (e.g. second weeding) were either not carried out or less time was spent doing them (e.g. less time spent to harvest due to lower yield). This land management practice typifies a low-input, low-yield production system. Overall, more than 90% of the labour inputs for maize production are sourced from within the household. Communal or rotational group labour is virtually non-existent (less than 1%) while use of hired labour (locally called *ganyu*) contributed less

than 10% of the total labour inputs. Due to the heavy dependence of household members for the supply of labour, the health status and productive capacity of household members plays a critical role in the performance of maize fields and food security. In terms of gender, adult female members of the households alone contributed the greatest share (36%) of all labour inputs in maize fields. Three field operations accounted for 70% of the total labour inputs: land preparation (23%), weeding (29%) and harvesting (18%).

3.2 Financial profitability of soil fertility management practices

The financial profitability of the different practices is presented in Table 3. Agroforestry practices produced a discounted net benefit ranging between US\$233 and US\$309 ha⁻¹. All the three agroforestry practices were more profitable than unfertilised maize, the commonest practice used by an average smallholder farmer in Zambia, which had net a benefit of US\$ 130. The net benefit of agroforestry practices is 44 to 58% superior to non fertilised continuous maize production practice. With a net profit of US\$ 499 ha⁻¹, subsidised fertilised maize was the most financially profitable of all the soil fertility management practices, given government's 50% subsidy on fertiliser. But when the subsidy is accounted for in the computation, the net benefit of fertilised maize falls to US\$ 349 ha⁻¹, and the difference between fertilised maize and agroforestry practices reduced sharply from 61% to 13%.

Table 3: Profitability of the different maize production systems over a five-year cycle in eastern Zambia

Soil fertility management practice	Fallow period (no. of years)	Maize cropping (number of years)	NPV (US\$ ha ⁻¹) ^a	BCR
Continuous maize without fertiliser	0	5	130	2.01
Continuous maize with fertiliser (fertiliser subsidised at 50%)	0	5	499	2.65
Continuous maize with fertiliser (open market priced fertiliser)	0	5	349	1.77
<i>Gliricidia</i> -maize intercrop	2	3	327	3.11
<i>Sesbania</i> -maize rotation	2	3	309	3.13
<i>Tephrosia</i> -maize rotation	2	3	233	2.77

^a US\$ 1=4,500 Zambia Kwacha

In terms of returns per unit of investment cost, all the three agroforestry practices performed better than conventional practices as they yielded higher returns per unit investment cost than continuous maize fields with or without fertiliser. Each unit of money invested in agroforestry practices yields higher returns ranging between 2.77 and 3.13, (i.e., an extra gain of between 1.77 and

2.13 per unit) in contrast with 2.65 (or a net gain of 1.65 per unit of money invested) obtained in fertilised maize practice (subsidised), and 1.77 units in fertilised maize (non-subsidised). The return per unit cost invested in agroforestry practices is superior to maize without fertiliser by between 27% and 36%. In contrast, fertilised maize (subsidised) performed better than non fertilised maize by 14%, but is worse off than non fertilised maize if fertiliser is not subsidised. The internal rate of return is higher than interest rate for all the practices evaluated. The return to labour per person day was \$3.16 in fertilised fields (subsidised), \$2.56 in fertilised maize (open market price) and \$1.10 in unfertilised maize fields. For the three agroforestry practices, the return to labour per person day was \$2.63 for *Gliricidia*, \$2.41 for *Sesbania* and \$1.90 for *Tephrosia* fallow. These figures contrast favourably with the daily agricultural wage of about \$0.60 prevailing in the study area. The IRR of all the production practices is higher than the discount rate. It is over 100% for the conventional land soil fertility practices (with or without fertiliser) and ranges from 83% to 99% for agroforestry practices.

4. Discussion

The total quantity of labour input used in agroforestry practices over the five-year cycle was lower than in fertilised continuously cropped maize fields but, higher than in non-fertilised maize. Similar results were reported in a study carried out on *Sesbania* in some parts of eastern Zambia. The study found that over a five year period, total labour requirement in *Sesbania*-maize fallow rotation was 13% lower than unfertilised maize, and far less than in fertilised monoculture maize (Franzel *et al.*, 2002; Franzel, 2004). These results do not support the popular notion (e.g. Vanlauwe & Giller, 2006) that agroforestry-based soil fertility management practices are more labour intensive given that the quantity of labour requirements per unit of cultivated land area is not higher than in fertilised maize.

The perception about labour inputs could be that some field operations of agroforestry practices may have occurred at the same time as those in other fields (especially cash crops) that are managed by the same households, and which depended on the same labour supply drawn from household members (Ajayi, 2007). But given that the size of agroforestry fields in the study area is relatively small, averaging 0.2 ha, in many cases, it was easy for household members to cope with the labour demand for such small-sized field. Levasseur *et al.* (2004) reported cases in West Africa where some field operations of agroforestry practice (live fences) occurred at a time when farmers were already busy with field activities in other crop fields. This suggests that both the quantity and temporal distribution of labour are important to farmers. It is

expected that as the land area that farmers cultivate to agroforestry increases, the temporal distribution of labour requirement for tree establishment and management may become more important than it is presently. As a result, a modification to the agronomic practices of the technology to shift some of the labour inputs away from the main cropping season to the “off peak” labour demand season is expected to enhance the acceptability of agroforestry-based soil fertility management practices among farmers.

Tripp (2005) described labour management in sustainable agriculture models as an initial investment involved when farmers move from conventional to sustainable agriculture models but that once farmers gain experience with sustainable models of production, they will be able to manage labour and field operations more efficiently. Through learning-by-doing, farmers in eastern Zambia have been adapting official recommendations on agroforestry practices to help them to manage labour use in their fields. Such innovations and adaptations include intercropping maize with trees during the first year of tree establishment to reduce the waiting period before trees start to impact on soil fertility, use of bare-rooted seedlings instead of the recommended potted seedlings method, pruning *Gliricidia* concurrently with weeding rather than carry out these two operations separately. Details of these innovations have been documented elsewhere (Kwesiga *et al.*, 2005; Katanga *et al.*, 2007).

In absolute economic terms, the discounted net benefit (NPV) of agroforestry practices is higher than continuous maize production without fertiliser (the commonest practice used by smallholder farmers in Zambia), but lower than in (subsidised) fertiliser fields. In relative terms, i.e. returns per unit investment cost, agroforestry practices perform better as they yielded higher returns per unit investment cost than continuous maize production with or without fertiliser. This is because the higher net profit recorded for fertilised maize was obtained through higher investment cost whereas a much lower cost is required for agroforestry practices. High rate of discounting negatively affects agroforestry practices much more than conventional soil fertility practices. Results of sensitivity analysis (Table 4) show that while a reduction in discounting rate improves net profit for all the practices, it results in greater proportional benefits for agroforestry practices than continuous practices. For example, if discount rate decreases from 30% to 15%, the net profit of agroforestry practices increases by 56% to 64% in contrast with non-fertilised maize where profit increases by only 29% and fertilised maize which increased profit by 36%. The main reason for the different effects is because the main benefits from agroforestry practices occur in the third through the fifth year only in contrast with conventional practices where benefits (maize yield) occur throughout the five year period. For countries such as Zambia where the rate

of interest on capital is relatively high, efforts to shorten fallow length of agroforestry practices (e.g. from two years to one) will improve their financial profitability and potential adoptability. One of such efforts is the current emphasis on the promotion of *Tephrosia candida* to replace *Tephrosia vogelii* because the former produces sufficient biomass that can be incorporated into the soil within one year, thus effectively shortening fallow period to 1 year only. In this study, we used a five-year period but over a longer period, the net profit of *Gliricidia* is expected to improve greatly over other practices. This is because once the *Gliricidia* trees are established; farmers can keep growing maize each year by cutting and incorporating the biomass of the tree into the soil each year to ensure steady soil fertility and maize yield. The net profit of *Sesbania* and *Tephrosia* is expected to remain similar to what it is for the five-year period because a longer period will simply be a repeat of the results of the five-year cycle. On the contrary, the net profit of continuous maize practices will be lower due to a steady decline in soil organic matter and yield over time.

Table 4: Effect of the reduction of discounting rate on profitability of land use practices in Zambia

Type of soil management practice	Description of change in discount rate and profit	NPV (US \$ ha ⁻¹)	BCR
Continuous maize without fertiliser	New discounting rate (15%)	167	1.96
	Old discounting rate (30%)	130	2.01
	Absolute difference	37	(0.05)
	% change	29	(2.36)
Continuous maize with fertiliser	New discounting rate (15%)	679	2.65
	Old discounting rate (30%)	499	2.65
	Absolute difference	180	(0.00)
	% change	36	(0.14)
Gliricidia-maize intercrop	New discounting rate (15%)	548	3.48
	Old discounting rate (30%)	327	3.11
	Absolute difference	221	0.37
	% change	67	11.77
Sesbania-maize rotation	New discounting rate (15%)	498	3.34
	Old discounting rate (30%)	309	3.13
	Absolute difference	1889	0.21
	% change	61	6.70
Tephrosia-maize rotation	New discounting rate (15%)	363	2.93
	Old discounting rate (30%)	233	2.77
	Absolute difference	130	0.16
	% change	56	5.67

5. Conclusion

Given the challenges that majority of smallholder farmers face with regards to declining soil fertility and poor yield on one hand and, high procurement cost of fertiliser and the poor status of market institutions and road infrastructure in rural areas in many countries of sub-Saharan Africa on the other, the need for an expanded soil fertility replenishment options to complement available methods is important for ensuring food security. Agroforestry-based soil fertility management practices have a role to play in the expansion of the range of affordable and appropriate options to meet the needs of smallholder farmers across different ecologies and typology of resource-endowed households.

The results of this study do not support the popular perception that agroforestry-based soil fertility management practices are more labour intensive than continuously fertilised maize as the quantity of labour inputs used per unit of cultivated land area is not higher. As farmers scale up the size of the field cultivated to agroforestry, the temporal distribution of labour may assumed greater importance than it is presently. Efforts to shift some field operations away from the main cropping season to the “off season” will be helpful to farmers.

The net benefit of agroforestry-based soil fertility practices is higher than that of continuous maize production without fertiliser, but less than subsidised fertilised maize fields. But, in relative terms (returns per unit cost of investment), agroforestry practices perform better than the two conventional (fertilised and non-fertilised) maize practices as they yielded higher returns per unit investment cost. In rural areas where road infrastructure is poor and transport costs of fertiliser are high, agroforestry practices are most likely to outperform fertilised maize in both absolute and relative profitability terms. The cost and returns were computed for physical outputs only. Given this restriction, the value of outputs and inputs of the different practices may have been affected, e.g. ecosystem services of agroforestry practices were alluded to in the introduction section of the paper but not included in the computation of the costs and returns of the different practices. Such valuation would be an important subject for a much more comprehensive economic profitability study (Ajayi & Matakala, 2006), but it goes beyond the scope of financial profitability, which is the core objective of our study.

The high discounting rate affected agroforestry technologies more disproportionately compared with conventional soil fertility practices. This is because the main benefits of agroforestry (crop yield) began only in the third

year making the present value of the benefits to be much lower after discounting. In countries where the cost of capital is relatively high, efforts to shorten the length of fallow for agroforestry practices will improve their financial profitability and expectedly their potential adoptability. One of such efforts is the promotion of *Tephrosia candida* to replace *Tephrosia vogelii* because the former produces sufficient quantity of biomass within one year that can be incorporated into the soil, thus effectively shortening fallow period to one year only.

To a reasonable extent, financial profitability of technologies is linked to their potential adoptability by farming community. Policies and price supports given to different soil fertility management practices provide incentives or disincentives that may influence the choice of soil fertility management practice that smallholder farmers make. The promotion of agro-ecological production systems could be enhanced if the dissemination of the technologies at the farm level is complemented by policies that are conducive to encourage smallholder farmers to adopt them.

Studies conducted in the region indicate that agroforestry practices are compatible with mineral fertilisers, and can be used alone or in a synergistic combination with fertiliser (Ayuk & Mafongoya, 2002; Akinnifesi *et al.*, 2007). A recent meta-analysis shows that agro-ecological methods of soil fertility management are compatible with mineral fertilisers, and their combined use has synergistic yield effects. Maize yield was up to 30% higher when these agro-ecological practices were amended with half of the recommended dose of mineral fertiliser, compared with similar plots that were not amended (Sileshi *et al.*, 2008). Given that only 20% of smallholder farmers have access to fertiliser in Zambia, rather than focusing on the “organic vs. inorganic fertiliser” debate, integrated soil fertility approach should be emphasised and future studies should evaluate the potentials and implications of integrating the two forms of nutrient supply to contribute to food security for the benefit of smallholder farmers.

Acknowledgements

The authors are grateful to the Rockefeller Foundation, Irish-Aid through the Agroforestry Food Security Programme (AFSP), Canadian International Development Agency (CIDA), and European Union for providing financial assistance to support agroforestry research and development in southern Africa. We thank the two anonymous reviewers of this journal for their thoroughness and questions that helped to improve the paper. We are also grateful to Rebecca Selvarajah-Jaffery, who carried out a professional editing of the earlier draft of the paper. The usual disclaimer applies.

References

- Ajayi OC (2007).** User acceptability of soil fertility management technologies: lessons from farmers' knowledge, attitude and practices in southern Africa. *Journal of Sustainable Agriculture* 30(3):21-40.
- Ajayi OC & Matakala P (2006).** Environmental conservation and food security in developing countries: bridging the disconnect. Proceedings of the 26th Triennial Conference of the International Association of Agricultural Economists (IAAE), Queensland, Australia, August 2006 [Online]. <http://agecon.lib.umn.edu> (Accessed 27/11/2008).
- Ajayi OC & Waibel H (2000).** How accurate are the farm size estimates obtained from smallholder farmers in west Africa? Lessons from Côte d'Ivoire. In: G Renard, S Krieg, P Lawrence & M von Oppen (Eds). *Farmers and scientists in a changing environment: assessing research in West Africa*. Weikersheim, Germany: Margraf Verlag.
- Ajayi OC, Akinnifesi FK, Sileshi G & Chakeredza S (2007).** Adoption of renewable soil fertility replenishment technologies in southern African region: lessons learnt and the way forward. *Natural Resource Forum* 31(4):306-317.
- Ajayi OC, Franzel S, Kuntashula E & Kwesiga F (2003).** Adoption of improved fallow soil fertility management practices in Zambia: synthesis and emerging issues *Agroforestry Systems* 59(3):317-326.
- Akinnifesi FK, Chirwa P, Ajayi OC, Sileshi G, Matakala P, Kwesiga F, Harawa R & Makumba W (2008).** Contributions of agroforestry research to livelihood of smallholder farmers in southern Africa: Part 1. Taking stock of the adaptation, adoption and impacts of fertilizer tree options. *Agricultural Journal* 3(1):58-75.
- Akinnifesi FK, Makumba W & Kwesiga F (2006).** Sustainable maize production using *Gliricidia*/maize intercropping in Southern Malawi. *Experimental Agriculture* 42:441-457.
- Akinnifesi FK, Makumba W, Sileshi G, Ajayi OC & Mweta D (2007).** Synergistic effect of inorganic n and p fertilizers and organic inputs from *Gliricidia sepium* on productivity of intercropped maize in southern Malawi. *Plant and Soil* 294:203-217.

Ayuk ET & Mafongoya PL (2002). Risk and returns characteristics of improved fallows in eastern Zambia: an application of stochastic dominance methods. In F. Kwesiga, E Ayuk & A Agumya (Eds.), *Proceedings of the 14th Southern African Regional Review and Planning Workshop*, 3–7 September 2001, Harare, Zimbabwe. Harare: ICRAF Regional Office. pp 28–34.

Chintu R, Mafongoya PL, Chirwa TS, Kuntashula E, Phiri D & Matibini J (2004). Propagation and management of *Gliricidia sepium* in sub-humid eastern Zambia. *Experimental Agriculture* 40:341-352.

Franzel S (2004). Financial analysis of agroforestry practices. In JRR Alavalapati & DE Mercer (Eds.), *Valuing agroforestry systems*. Dordrecht: Kluwer Academic Publishers. pp. 9–37.

Franzel S, Phiri D & Kwesiga F (2002). Assessing the adoption potential of improved fallows in eastern Zambia. In S Franzel & SJ Scherr (Eds.), *Trees on the farm: assessing the adoption potential of agroforestry practices in Africa*. Wallingford, UK: CAB International. pp. 37–64.

Haggblade H, Tembo G & Donovan C (2004). Household level financial incentives to adoption of conservation agricultural technologies in Africa. *Michigan State University Food Security Research Project Working Paper no. 9*, Lusaka, Zambia.

Haggblade S, Tembo G, Kaboré D, Reij C, Ajayi OC, Franzel S, Mafongoya P & Place F (in press). Sustainable soil fertility management systems. In S Haggblade & P Hazell (Eds.), *Successes in African agriculture: lessons for the future*. Johns Hopkins University Press. pp. 279-340.

Howard JA & Mungoma C (1996). *Zambia's stop-and-go revolution: the impact of policies and organizations on the development and spread of maize technology*. Michigan State University International Development Working Paper no. 61, East Lansing, Michigan 48824, USA.

Kaonga ML & Bayliss-Smith TP (2009). Carbon pools in tree biomass and the soil in improved fallows in eastern Zambia. *Agroforestry Systems* 76:37–51.

Katanga R, Kabwe G, Kuntashula E, Mafongoya PL & Phiri S (2007). Assessing farmer innovations in agroforestry in Eastern Zambia. *Journal of Agricultural Education and Extension* 13(2):117-129.

Kiwia A, Imo M, Jama B & Okalebo JR (2009). Coppicing improved fallows

are profitable for maize production in striga infested soils of western Kenya. *Agroforestry Systems* 76:455-465.

Kwesiga F & Coe R (1994). The effect of short rotation *Sesbania sesban* planted fallows on maize yield. *Forest Ecology and Management* 64:199-208.

Kwesiga F, Akinnifesi FK, Mafongoya PL, McDermott MH & Agumya A (2003). Agroforestry research and development in southern Africa during the 1990s: review and challenges ahead. *Agroforestry Systems* 59(3):173-186.

Kwesiga F, Franzel S, Mafongoya P, Ajayi OC, Phiri D, Katanga R, Kuntashula E & Chirwa T (2005). *Successes in African agriculture: case study of improved fallows in Eastern Zambia*. Environment and Production Technology Division (EPTD) Discussion Paper 130, IFPRI, Washington DC.

Kwesiga FR, Franzel S, Place F, Phiri D & Simwanza CP (1999). *Sesbania sesban* improved fallow in eastern Zambia: their inception, development and farmer enthusiasm. *Agroforestry Systems* 47:49-66.

Levasseur V, Djimé M & Olivier A (2004). Live fences in Ségou, Mali: an evaluation by their early users. *Agroforestry Systems* 60:131-136.

Mafongoya PL, Bationo A, Kihara J & Waswa BS (2006). Appropriate technologies to replenish soil fertility in southern Africa. *Nutrient Cycling in Agroecosystems* 76:137-151.

Makumba W, Akinnifesi FK, Janssen B & Oenema O (2007). Long-term impact of a *gliricidia*-maize intercropping system on carbon sequestration in southern Malawi. *Agriculture, Ecosystems and Environment* 118:237-243.

NEPAD (New Partnership for African Development) (2003). Comprehensive African Agriculture Development Programme [Online]. www.nepad.org (Accessed 25/11/2008).

Phiri E, Verplancke H, Kwesiga F & Mafongoya P (2003). Water balance and maize yield following *Sesbania sesban* fallow in eastern Zambia. *Agroforestry Systems* 59(3):197-205.

Place F, Franzel S, DeWolf J, Rommelse R, Kwesiga F, Niang A & Jama B (2002). Agroforestry for soil fertility replenishment: evidence on adoption processes in Kenya and Zambia. In CB Barrett, F Place & AA Aboud (Eds.),

Natural resources management in African agriculture: understanding and improving current practices. Wallingford, UK: CAB International. pp. 155–168.

Sanchez PA (1999). Improved fallow come of age in the tropics. *Agroforestry Systems* 47:3-12.

Sanchez PA (2002). Soil fertility and hunger in Africa. *Science* 295:2019–2020.

Scoones I & Toulmin C (1999). *Policies for soil fertility management in Africa.* A report prepared for the Department for foreign Development (DFID) by IDS/IIED, United Kingdom.

Sileshi G & Mafongoya PL (2006). Long-term effect of legume-improved fallows on soil invertebrates and maize yield in eastern Zambia. *Agriculture, Ecosystem and Environment* 115:69-78.

Sileshi G, Akinnifesi FK, Ajayi OC & Place F (2008). Meta-analysis of maize yield response to planted fallow and green manure legumes in sub-Saharan Africa. *Plant and Soil* 307:1-19.

Sileshi G, Akinnifesi FK, Ajayi OC, Chakeredza S, Kaonga M & Matakala P (2007). Contribution of agroforestry to ecosystem services in the miombo eco-region of eastern and southern Africa. *African Journal of Environmental Science and Technology* 1:68-80.

Tripp R (2005). The performance of low external input technology in agricultural development: a summary of three case studies. *International Journal of Agricultural Sustainability* 3(3):143-153.

Vanlauwe B & Giller KE (2006). Popular myths around soil fertility management in sub-Saharan Africa. *Agricultural Ecosystem and Environment* 116:34-46.