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On-Farm Assessment of Legume Fallows and Other Soil Fertility Management Options Used by Smallholder Farmers in Southern Malawi

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Abstract: This study evaluated the performance of tree legumes and other soil fertility management innovations used by farmers. The objectives of the study were to: examine the extent that farm attributes, typology of farmers and field management practices have affected the adaptation and use of agroforestry technologies for soil fertility management and compare the agronomic performance and farmer assessment of agroforestry and other soil fertility management options, across a wide range of farmer types and field conditions, with a view to establishing the contribution of management variables to variations in yield estimation. Maize yield and farmer rating were assessed in Type II (researcher-designed, farmer-managed), Type III (farmer-designed and managed) trials and extension farmers. Results from 152 farmers show that agroforestry increased the yield of maize by 54-76% compared to unfertilized sole maize used as the control. When amended with fertilizer, the yield increase over the control was 73-76% across tree species. This indicates that farmers who had combined agroforestry with inorganic fertilizer experienced increase in maize yield attributable to the synergy between organic and inorganic fertilizer. In gliricidia-maize intercropping, higher maize yield was obtained by farmers who pruned twice. Combination of two prunings and fertilizer use gave the highest yield increase (148%) over the control and the third pruning was superfluous when fertilizer was applied. Without fertilizer, maize yield in agroforestry plots intercropped with pigeon pea was higher than those plots without pigeon pea. Planting date, fertilizer application, use of agroforestry and maize variety explained about 44% of the variation in maize yield on farmers' fields.

Key words: Agroforestry, field management, sustainable production, smallholder, maize, low-cost

INTRODUCTION

The quest to attain sustained food security in Southern Africa has increasingly become a matter of acute concern in recent years. Landholdings are diminishing in size, fertilizers are becoming unaffordable, soil fertility is fast depleting and off-farm income opportunities are few (Kwesiga *et al.*, 2003). Sustaining maize production at an acceptable level in southern Africa requires continuous addition of fertilizers. In view of the increasing cost of fertilizer, low-cost soil interventions that enhance crop productivity are needed. The World Agroforestry Centre (ICRAF) and partners have been testing and developing agroforestry technologies for sustainable soil fertility replenishment. The research was initially conducted on-station. Since the late 1990s, ICRAF's research emphasized on-farm testing, adaptation and country-wide scaling up and scaling out of proven technologies with increasing partners and farmer involvement and decreasing direct researcher involvement.

There has been an increasing emphasis on on-farm testing and dissemination since the mid-1990s. This ensured increased farmer participation in technology development and adaptation. A study in southern Malawi showed that 76% of farmers implementing agroforestry technologies had increased yields (Phiri and Akinnifesi,

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2001). A good proportion of the farmers who planted agroforestry trees increased the area that they initially planted ranging from 48% in Zambia (Ajayi *et al*., 2007) to 64% in Malawi (Phiri and Akinnifesi, 2001), respectively. In addition, a study in Zambia found that 75% of farmers that tested improved fallows have continued to practice those (Keil *et al*., 2005). Agroforestry technologies are a suitable practice under the socio economic conditions of small-holder agriculture in eastern Zambia (Franzel *et al*., 2002). The higher adoption rates of improved fallow by smallholder farmers in Zambia were associated with proper and effective diagnosis of farmers' problems, their participation in programs and encouragement to innovate (Franzel *et al*., 2001).

Despite the yield improvements on research stations and on-farm trials, no study in Malawi has compared *Gliricidia sepium*-maize intercropping (Akinnifesi *et al*., 2007) with rotational tree fallows (Kwesiga *et al*., 1999), relay cropping of maize with *Tephrosia* sp. and *Sesbania sesban*, intercropping of maize with pigeon pea (Snapp and Silim, 2002) and sole maize with and without inorganic fertilizer. There is also a dearth of information regarding synergistic effects between agroforestry and fertilizer in smallholder farmer's fields. Large variations exist between farmers' fields and researchers' plots in the performance of the technologies (Chirwa *et al*., 2003, 2006; Harawa *et al*., 2006). Considerable farm to farm variation is also expected due to variations in farm conditions, farmer practices and innovations. For example, farmers often apply fertilizer and or other soil management practices beside those planned, often after experiments had been established (Thangata and Alavalapati, 2003). However, the effect of such farmer modifications and innovations on crop yield variability has not been evaluated.

The traditional experimentation-validation dissemination approach used in agricultural research is largely inappropriate for practices such as agroforestry, because of the long-term nature of tree-based systems and the possibility of multiple solutions from agroforestry to alleviate environmental and livelihood problems (Kuntashula *et al*., 2004).

Participatory research methods have been advocated as a means of improving the relevance and adoption of technologies (Snapp and Silim, 2002; Kuntashula *et al*., 2004), as these help researchers to understand how farmers experiment on their own, to strengthen partnership between farmers and researchers, sharing knowledge and to integrate the knowledge into the technology development process (Franzel *et al*., 2001). Such constructivist approach has greatly helped in the development of the agroforestry technology, i.e., farmers were encouraged to assess, modify and adopt the technology based on their needs and experiences (Ajayi *et al*., 2008).

Farmer-designed trials are important for obtaining farmers assessments and for understanding the process by which they test new practices and incorporate them into the farming systems. In these trials farmers are in the best position to evaluate agroforestry tree species after they have obtained all products and services from them (Franzel *et al*., 2001).

Knowledge about the influence of fertilizer use, fallow species, pruning and weeding management and other site conditions, on the efficiency of the fertilizer tree systems are critical to identify priority options for farmers.

The objectives of the study were to: examine the extent that farm attributes, typology of farmers and field management practices have affected the adaptation and use of agroforestry technologies for soil fertility management and compare the agronomic performance and farmer assessment of agroforestry and other soil fertility management options, across a wide range of farmer types and field conditions, with a view to establishing the contribution of management variables to variations in yield estimation.

MATERIALS AND METHODS

The study area: The study was conducted in three districts in Southern Malawi, namely: Chiradzulu, Machinga and Zomba. The elevations of the study area range from 700-1200 m above sea level. Mean annual rainfall ranges from 1000-1400 mm, with highest around Zomba and lowest in Chiradzulu. The major ethnic groups in the study area are Chewa, Yao and Lomwe. The average landholding size in Southern Malawi is 0.4 ha per household and population densities range from 300-500 persons km^{-2}. Maize is the major staple crop in the study areas and tobacco is grown as a cash crop. Other crops include pumpkin, potato, pigeon pea and vegetables. The land tenure system is mainly based on matrilineal and matri-local systems (Place, 2001). Livestock is generally few and consists of predominantly goats and chicken, while cattle are not common.

Sampling procedure and data collection: A survey was undertaken during the cropping season from February to May 2001 in seven Extension Planning Areas (EPA), namely, Dzaone, Malosa, Mombezi, Ntubwi 1, Ntumbwi 2, Thekerani, Thondwe and Thumbwe. The survey team comprised of an on-farm specialist, two field technicians and a number of partners who helped to identify farmers and farmer modified treatments. On-farm trials were grouped into three main categories, namely, Type I, II and III trials. Type I trials are researcher-designed and managed on-farm trials. This type of trials began in 1992/93. They have been discontinued since 2000, as agroforestry research became more farmer-led in Malawi. Type II is a researcher-designed and farmer-managed trial. In this type of trial, researchers designed and laid out treatments in consultation with farmers but leave the management entirely to farmers. Initially, researchers provided information, frequent backstopping and required inputs such as seeds, fertilizer and labor. However, provision of inputs was discontinued since 2000. Researchers also participated in some decisions, e.g., establishment, harvesting and biophysical data collection for Type II trials. The plots were fully left to farmer's decisions in 2000 and 2001, except for facilitation of farmer groups involved in the trial, including attending farmer planning meetings and sharing of results and feedbacks. Type III is a farmer-designed farmer-managed trial, where farmers plant and manage the trials as they wish, with no researcher involvement in either treatment design or management (Franzel *et al*., 2001). Type II (beginning in 1994/95) and Type III (beginning in 1995/96) (Franzel *et al*., 2001) and these were compared with those of extension farmers (farmers who received information about agroforestry through extension agents and started planting in 1998/1999) and non-adopting, neighboring farmers. In this study Type II and III, extension farmers and the non-adopters were involved. At the time of this study, several tens of thousands of farmers were using agroforestry technologies in the Southern region of Malawi (Kwesiga *et al*., 2003). More than 85% of these agroforestry farmers were extension farmers, whereas the remaining farmers were Type II or III research farmers.

In this type of trial, researchers are mainly interested in learning from the farmers and incorporating farmers' knowledge in management at an early stage of systems development to enhance adoption of innovations. For reaching extension farmers, ICRAF staff and partners used different methods including awareness creation media, direct training of farmers, training of trainers, farmer field days and farmer-to-farmer exchange visits. Starter seeds, information and/or training materials were provided to farmers reached directly by the project or through partners including the government extension agents.

A non-random sampling approach was used for data collection, because the population is heterogeneous in terms of type of agroforestry species planted, length of practice, site physical conditions, management level, farmer type and the position of field along the soil toposequence. Therefore, stratification was necessary. Each EPA comprised of clusters of villages. Because of the large number of farmers adopting agroforestry through partner organizations or other farmers, a complete list of all individual farmers and households in each EPA was not feasible. In addition, random sampling of farmers from all population in a village (within EPA) was impractical, as only a few farmers practicing agroforestry may be found in some villages.

Selection of farmers in each village was done in proportion to total number of adopters in that village at a ratio of 1 out of every ten farmers practicing was selected on average (about 10% sampling intensity). Here, adopters are defined as those farmers who took up the agroforestry technology and continued to practice it on their own following management recommendations for at least three seasons. Where lists of farmers were not available, a snowball approach (Balley, 1982) was applied. Following this method, adopters and other key informants in a village were asked to identify other adopters, such that the total sample was gradually assembled, from a few farmers in each village, using key informants. The data were collected using a semi-structured questionnaire and interviews were conducted in the local language (Chichewa). The enumerators and farmers visited the fields together and documented the different modifications the farmers had made within the original plots of the trial.

Interviews were conducted during February-March 2001 when maize was about early/mid reproductive stage and followed up around harvesting period until the end of May 2001. We interviewed a farmer per household often in the presence of the other family members. One non-adopter was sampled for every six agroforestry adopters sampled within an EPA. A total of 161 respondents were sampled but datasets were completed for 152 farmers located in 51 villages and of these 18 non-adopters qualified. To ensure accuracy, size of farmers' landholding was estimated using tapes or calibrated paces.

The information gathered included: farmers' characteristics such as farmer type, farmers' age, gender and years of experience with agroforestry, crop management practice in the trial plots or in the case of extension farmers, in their agroforestry plots (tree management, fertilizer application, compost or other organic manure use, quality of weeding, planting time and intercropping with pigeon pea), physical characteristics such as land holding size, acreage planted to agroforestry, position of the plot in the catena, soil productivity and occurrence of flooding and maize variety planted (i.e., local vs. improved). For the purpose of this analysis composites and hybrid maize were categorized as improved varieties.

In order to compare the agronomic performance of agroforestry technologies with farmers' own assessment, two indirect but non-destructive approaches were used to obtain maize yield and performance data from farmers' fields: farmer rating of maize standing crop and estimated grain yield using allometric method based on relationship between measured yield attributes (cob size) and grain yield from equivalent area of land on researcher managed field plot at Makoka. These methods were selected instead of the more commonly used method of measuring dry yields after harvest for two reasons: First, it was observed that most farmers in the pilot sites commonly harvest some of their crops as green harvests that is before reaching maturity. It was deemed necessary to assess the maize performance from standing maize crop. Secondly, the location of selected farmers and sites were wide apart involving several kilometers and the number of farmers involved was relatively large. Therefore, it would have been extremely difficult to be present on all farms to measure yields at the time that farmers wanted to harvest.

Farmers were asked to rate the standing maize crop during the mid- to late-reproductive stage of growth when all grains are fully filled but cobs are still green, based on visual assessments on a scale of 1-4 corresponding to poor, fair, good, very good, respectively. The criteria used by farmers for ranking maize performance were also asked. Qualitative data on technology or tree species preferences were also obtained by asking farmers to rate alternative species using criteria as suggested for rating performance of mother-baby trials in Southern Malawi (Snapp *et al*., 2002). The farmer assessment approach relied on farmers ability to estimate the anticipated yield from each plot, based on the plot sizes and the crop performance. The criteria used by farmers to predict maize grain yield and for rating maize stand were also recorded. Farmers were allowed to use local units (usually in numbers of baskets or 50 kg bags of shelled maize). This permitted researchers to ascertain the yield levels that met farmers expectations or otherwise.

The allometric approach used to obtain a rough estimate involved randomly sampling five plants per farm from two middle rows for each subplot and removing and weighing the grain. In addition, maize cobs were randomly sampled from 200 plants in each treatment on a well-designed, replicated and researcher-managed experiment in Zomba area. This was used to establish and calibrate the allometric relationship between measured grain yield and grain yield estimated from cob diameter and cob length. Cob diameter and cob lengths were assessed using measuring tapes and vernier calipers, respectively. The maize cobs were then harvested dried and shelled separately.

Data analysis: Farm types and farmer characteristics were tabulated and descriptive statistics were generated. In order to further address the heterogeneity, some of these variables were used as covariates in the data analysis. In order to examine causes of variation in maize yield on farmers' fields as well as to understand the relative importance of management and site variables, a mixed modeling approach (MIXED procedure of SAS) was employed. Here treatments were used as the fixed and farms as the random effect. Statistical inference was based on the 95% confidence intervals. Means were considered to be significantly different from one another if their 95% confidence intervals do not overlap.

For comparison of two or more variables with discrete data, χ^2-test was used. Categorical models procedure with maximum likelihood estimation method was also used to analyze the relationship between farmers' pruning of gliricidia. Logistic regression was used to analyze: farmers' decision to apply fertilizer to their maize using, as independent variables, farmer type, age, gender and maize variety planted and factors that influence farmers practice of pigeon pea intercropping with maize. It was hypothesized that maize yield will vary with soil type, fertilizer use, maize variety, time of maize planting, weeding frequency and agroforestry practices. Therefore, soil type, fertilizer application (with or without), agroforestry (with or without) and date of planting (early, mid and late) were used as fixed effects. The independent variables used were farmer type, age, gender and maize variety planted.

To estimate maize grain yield from cob size an allometric equation was used. Maize cob size (length and diameter) was measured form each farmer's field at the two middle row plot. Maize crops were also harvested from experimental plots around Makoka representing different cob sizes and were used to calibrate the yield. This was necessary as farmers' harvest dates vary and destructive sampling was not feasible at farmer's fields. Destructive and nondestructive allometric models based on the relationship between plant biomass and morphometric variables have been used for many field crops including maize (Vega *et al*., 2000). The equation that best predicted grain yield (Y) from cob diameter (X_1) and cob length (X_2) was:

$$Y = 0.023\ X_1\ X_2 - 49.12$$

This relationship, based on the product of cob diameter x cob length as independent variables, was found to be significant ($R^2 = 0.60$; $p<0.05$) and more efficient than cob diameter and cob length alone or their sums in estimating the grain yield. Yield conversion was based on actual plot area estimated from farmer's fields. The grain yield estimates were corrected for stand loss on an area basis (i.e., based on counts per plot).

RESULTS

Farmer characteristics: The predominant age group of farmers was 35-64 years, representing 63% of the total of 152 respondents. The majority (58.6%) of the respondents were also women (Table 1). Some 20% were Type II farmers, 22% were Type III farmers and 46% were non-research farmers. Many of the adopters that initially started as Type II farmers had also established Type III trials instead of or in addition to their original Type II trials. The newer farmers were mainly the Type III farmers and non research farmers.

Households had several small parcels of land scattered around the village. The majority (74%) of respondents had their fields located within 2 km radius. Some 63% had at least an extra field and 14% had more than 2 extra fields (Table 1). There was no significant difference between men and women farmers in the size of cultivated land. The extension farmers had significantly larger average landholding (1.3 ha) than Type II (0.4 ha) and Type III farmers (0.7 ha) and non-adopters (0.5 ha). The 95% confidence intervals indicate that the mean acreage put to agroforestry by extension farmers (819 m^2) was significantly more than the other farmer types (236-413 m^2).

Close to 63% of the farmers practicing agroforestry had begun practicing during the past 3-8 years. About 36% of them have less than three years experience. The majority of adopters were extension farmers (63%). The newer farmers were mainly the Type III farmers and extension farmers. Whether a farmer practiced agroforestry or not did not vary either with their age ($p = 0.792$) or gender ($p = 0.619$).

Use of agroforestry and other management options: The most common agroforestry practice was gliricidia-maize intercropping (51% of farmers), followed by annual relay intercropping with sesbania (26%) and tephrosia (24%) (Table 1). About 51% of the farmers had pruned twice compared to the recommended three pruning regimes. Some 23% had not pruned at all, 15% had pruned once and 11% had pruned thrice. The frequency of pruning significantly varied ($\chi^2 = 10.0$, $p = 0.007$) with farmer type; the highest (47% of farmers) being among extension farmers (Table 2). Across farmer types, frequency of pruning varied significantly ($\chi^2 = 42.1$, $p<0.001$). According to the logistic regression analysis, farmer age and gender did not influence the frequency of pruning. However, farmers' experience had a significant effect ($p = 0.019$) on whether they pruned or not. Those who had >2 years of experience were more likely to prune the gliricidia than those who were less experienced.

Pigeon pea was mainly used as intercrop and 60% of farmers had pigeon pea intercropped with maize. The land

Table 1: Characteristics of selected farmers and their farms in Southern Malawi (n = 152)

Variables	Category	Type II	Type III	Extension farmers	Non-adopters	Proportion (%)
Age of farmers (years)	35	11	8	17	7	28.3
	36-64	18	23	47	8	63.2
	>64	2	2	6	3	8.6
Gender of farmers	Male	13	12	31	7	41.4
	Female	18	21	39	11	58.6
No. of extra fields	0	5	14	7	8	22.4
	1-2	17	19	54	7	63.8
	>2	9	0	9	3	13.8
Maize varieties	Local	12	29	47	12	65.8
	Improved	19	4	23	6	34.2
Agroforestry options	Gliricidia-maize	16	27	52	-	50.8
	Sesbania relay	22	6	20	-	25.7
	Tephrosia relay	17	6	21	-	23.5
Landholding (ha)	-	0.4	0.7	1.3	0.5	-
Area planted to maize (m^2)	-	0.08	0.7	0.4	0.3	-
Maize area put under agroforestry (%)	-	59	9.0	63.0	-	-

Table 2: Farmers' management practices by farmer type

Management practice	Category	Type II	Type III	Extension	Non-adopters
Maize planting date	Mid November	48.0	70.5	64.6	57.1
	Late November	25.0	15.9	16.7	28.6
	Early December	16.0	11.4	14.6	14.3
	Late December	11.0	2.3	4.2	0.0
Pigeon pea intercropping	Yes	52.9	62.0	60.6	57.9
Fertilizer use	Yes	59.8	45.1	60.6	57.9
Compost use	Yes	19.6	18.3	15.8	0.0
Weeding	Yes	67.3	87.3	98.2	100.0

All figures are percent of farmers practicing area intercropped with pigeon pea was significantly influenced by farmer age (p = 0.004) and maize variety used ($p<0.0001$). However, it was not influenced ($p>0.05$) by farmer type, gender or the soil fertility status of the land. Older farmers (>65 years of age) were less likely to intercrop maize with pigeon pea than younger farmers (<35 years of age) and farmers were more likely to intercrop improved varieties of maize with pigeon pea than the local maize variety.

Farmers had applied mineral fertilizers to maize in both the non-agroforestry and agroforestry plots. Between 51 and 68% of all agroforestry subplots had received fertilizer during the 2000/01 planting season. A higher proportion (76%) of non-agroforestry plots were fertilized by Type III farmers compared to 68% for agroforestry plots. Farmer type and soil type did not significantly ($p>0.05$) influence farmer's the choice to apply fertilizer to their maize crops. On the other hand, farmers' age (p = 0.036), gender (p = 0.056) and the maize variety used influenced farmers' choice to apply fertilizer ($p<0.05$). Older farmers (>65 years of age) were less likely to apply fertilizer than younger farmers (<35 years of age). About 68% of the female farmers' fields were fertilized compared to 32% for male farmers. Some 69% of the farmers who planted local varieties did not apply fertilizer compared to 31% of those who plated improved varieties. Logistic regression analysis indicated that those who plant the local variety were less likely to apply fertilizer to the crop than those who planted improved varieties. Less than 20% of the farmers have used compost in all farmer types (Table 2). Farmer age (p = 0.011) and gender (p = 0.008) significantly influenced compost use, but not farmer type, soil type or maize variety.

All non-adopters, 98% of the extension farmers and 68% of the Type I farmers had weeded their fields (Table 2). The Wald statistic did not show significant variation in weeding by farmer type, age or gender.

Performance of maize with farmer management: Farmers grew >9 different maize varieties in the study areas. However, the majority planted local open-pollinated maize (66% of respondents). A significantly (χ^2 = 17.6; $p<0.001$) larger proportion of female farmers (74.0%) planted the local variety than male farmers (51.7%). The use of composite maize varieties was generally low (<3%). In all farmer types, the majority planted maize early (mid-November), while <15% planted later than early December (Table 2).

Farmers used the following criteria for assessing maize performance: cob size (94% of farmers), plant vigour (55%), plant height (31%), leaf color (30%), soil color and other criteria (11.6%). All the participating farmers rated maize performance in the agroforestry plots as superior to sole maize without trees, but fertilized agroforestry plots were consistently preferred more and rated highest by farmers across the technological options (Table 3). The majority of farmers rated the unfertilized sole maize as below expectation (94%). Fertilized sole maize was rated as having met expectations in 51% of the cases where fertilizer was applied to sole maize. Agroforestry plots were rated better than fertilized sole maize in 63% of cases for gliricidia, 54% for sesbania and 58% for tephrosia plots. Fertilizer application in agroforestry plots also influenced farmers' ratings. Fertilized maize was rated as good or very good in 82% of the tephrosia, 69% of the sesbania and 77% of the gliricidia plots. Fertilized sole maize was rated as below expectation in only 9% of the cases. There was no difference between plots intercropped with pigeon pea and those without (Table 3).

Among the agroforestry practices, farmers rated maize performance as highest in plots with gliricidia (52%), with tephrosia (39%) and with sesbania (6%). Those farmers not preferring gliricidia saw the waiting period of 2-3 years before the tree starts to produce enough biomass as a hindrance to early returns. According to those farmers that preferred tephrosia, as first or second option, it was because it does not require nurseries for establishment and it also controls termites. Farmers indicated the pest problems in sesbania, especially insect infestation (Sileshi *et al*., 2008a) at the early stage as the reasons for ranking it as least preferred.

Table 4 shows the grain yield of maize and farmers ratings under different management options. There was significant effect of agroforestry practices ($p<0.001$),

Table 3: Farmer rating (percent of cases) of agroforestry practice and maize performance as very good, good, fair and poor

Treatments	Fertilizer	Entries	Very good	Good	Fair	Poor	Mean rank order value
Tephrosia	With	22	44	38	19	0	9.57
	Without	23	17	41	27	22	4.85
Sesbania	With	29	24	45	29	4	5.19
	Without	17	18	36	35	11	7.44
Gliricidia	With	68	24	53	22	2	2.72
	Without	65	15	48	18	21	1.88
Control	With	95	9	42	40	9	1.39
	Without	61	0	6	27	67	0.66

Table 4: Least square means and the lower and upper 95% confidence limits for overall effect of treatment combinations on estimated yield (t ha^{-1}) of maize on farmers fields and farmers' ranking

Variables	Fertilizer amendment	Treatment	Pigeon pea	Mean (95% confidence)*	Yield increase (%)
Yield estimate (t ha^{-1})	Without	Gliricidia	Absent	1.6 (1.0-2.3)	62.5
			Present	2.7 (2.3-3.2)	77.8
		Sesbania	Absent	2.0 (1.2-2.9)	70.0
			Present	2.9 (2.1-3.6)	79.3
		Tephrosia	Absent	2.1 (1.4- 2.8)	71.4
			Present	3.1 (2.3-4.0)	80.6
		Sole maize	Present	1.4 (0.9-1.8)	57.1
			Absent	0.6 (0.005-1.2)	0.0
	With	Gliricidia	Absent	3.8 (3.3-4.4)	84.2
			Present	4.3 (3.8-4.7)	86.0
		Sesbania	Absent	3.7 (3.0-4.4)	83.8
			Present	3.8 (3.1-4.4)	84.2
		Tephrosia	Absent	3.8 (3.1-4.5)	84.2
			Present	4.6 (3.7-5.5)	87.0
		Sole maize	Absent	2.7 (2.3-3.2)	77.8
			Present	3.2 (2.9-3.6)	81.3
Ranking	Without	Gliricidia	Absent	1.7 (1.4-2.1)	NA**
			Present	1.3 (0.9-1.7)	NA
		Sesbania	Absent	1.1 (0.6-1.7)	NA
			Present	1.2 (0.6-1.8)	NA
		Tephrosia	Absent	1.6 (1.2-2.1)	NA
			Present	1.4 (0.8-2.1)	NA
		Sole maize	Present	0.5 (0.2-0.8)	NA
			Absent	0.2 (0.01-0.5)	NA
	With	Gliricidia	Absent	1.4 (0.9-1.8)	NA
			Present	2.2 (1.8-2.5)	NA
		Sesbania	Absent	1.6 (1.1-2.1)	NA
			Present	2.0 (1.4-2.6)	NA
		Tephrosia	Absent	1.6 (1.1-2.1)	NA
			Present	2.6 (1.7-3.4)	NA
		Sole maize	Absent	1.0 (0.6-1.4)	NA
			Present	1.8 (1.5-2.1)	NA

*The first and second order interaction effects between treatment, fertilizer and pigeon were not statistically significant. Therefore, only main effects are shown. The yield increase was calculated against the control (unfertilized sole maize without pigeon pea) which had estimated yield of 0.6; **NA = Not Applicable

fertilizer amendment ($p<0.001$) and pigeon pea ($p = 0.023$) on the maize yield estimated on farmers fields. Maize yield ranged between 1.6 and 3.1 tones ha^{-1} without fertilizer amendment. Maize yield from agroforestry plots amended with fertilizer ranged between 3.7 and 4.6 tones ha^{-1}. This compares well with fully fertilized maize which yielded 3.2 tones ha^{-1}. Compared to the control (i.e., unfertilized sole maize), agroforestry practices increased maize yields by 62-80% without fertilizer amendment. When amended with fertilizer, the yield increase over the control was 83-87% (Table 4).

Without fertilizer amendment, the yield increase over the unfertilized sole maize was 59% in tephrosia, 58% in sesbania and 54% in gliricidia plots. When amended with fertilizer, the yield increase over unfertilized maize was 76% in tephrosia, 75% in gliricidia and 73% in sesbania plots. Compared to the unfertilized gliricida-maize intercrops, addition of fertilizer in gliricidia-maize intercropped plots increased yield by 57.9%. Fertilizer amendment of sesbania plots increased maize yield by 45.9% compared with the same plots that have not received fertilizer. Addition of fertilizer to Tephrosia plots increased maize yield by 44.7%. The 95% confidence intervals indicate that the presence of pigeon pea did not have any effects on maize yield from agroforestry plots (Table 4). However, pigeon pea had some effect on soil maize without fertilizer. In unfertilized maize plots, intercropping maize with pigeon pea increased maize grain yield by 57% over those plots without pigeon pea. Irrespective of pigeon pea intercropping,

The rating of agroforestry species on maize yield differed among management options. Tephrosia was rated highly, followed by sesbania and gliricidia in terms of yield performance. Maize grain yield significantly varied with agroforestry practices ($p<0.0001$), fertilizer use ($p<0.0001$) and intercropping with pigeon pea ($p = 0.0231$). The 95% confidence intervals show that maize grain yield was significantly higher in all treatments that had received fertilizer than those not fertilized (Table 4). Fertilizer application increased yield in the sole maize by 107%.

Farmer rating followed a similar trend with maize yield data (Table 4 and 5). Farmers rated pigeon pea intercropping higher than sole maize (Table 4). However, the 95% confidence intervals showed no differences in the rating. Farmers overall rating of maize performance was significantly higher with fertilizer application across

Table 5: Effect of pruning frequency and fertilizer on maize yield (t ha^{-1}) and farmer rating of maize intercropped with *Gliricidia sepium* in Malawi

	Grain yield (t ha^{-1})			Farmer rating	
Pruning frequency	Unfertilized (n = 56)	Fertilized (n = 68)	p-value	Unfertilized	Fertilized
Unpruned	1.1	2.9	0.005	1.10	1.10
Pruned once	2.1	3.7	0.038	1.72	2.02
Pruned twice	2.3	4.5	<0.001	1.68	2.26
Pruned thrice	3.8	4.9	0.424	2.09	1.95
p-value	<0.001	<0.001			

treatments and pigeon pea intercropping compared to without fertilizer application (Table 4). The overall rating of fertilized sole maize plots was lower than plots with agroforestry species.

Response of maize yield to tree pruning management: Some 21% out of the 52 farmers (40.4%) practicing gliricidia/maize intercropping had not pruned their fields, especially the farmers who started to plant agroforestry trees only recently, whose trees were still <2 years. Some farmers have modified the recommended pruning and incorporation method. Some have adopted the dollop method in which the second pruning is buried in spots around the maize plant rather than splitting the ridges and incorporating the prunings. A farmer at Machinga was noted to have dried the prunings under shade and powdered them before applying to the field as fertilizer. Studies are needed to explore the effects of such practices and their costs and returns.

To determine the effect of pruning on maize yield, the gliricidia-maize intercropping data was analyzed separately. Result showed that the frequency of pruning was significantly associated with grain yield of maize (Table 5). There was a 53% increase in maize yield where farmers had pruned gliricidia once during the season compared to those who had not pruned. There was an 80% when they pruned three times during the season compared to unpruned plots. In the unfertilized gliricidia plots, pruning increased maize yield by 122%, when done thrice and by 60%, when done only once compared to unpruned gliricidia plot.

The effect of fertilizer applications varied with number of prunings. Yields significantly differed with fertilizer application. Compared to unfertilized plots, fertilizer application increased maize yield 29% in plots pruned thrice, by 96% in those pruned twice, by 76% in plots pruned once and by 76% in plots pruned once and by 163% in unpruned gliricidia plots. Combination of two prunings and fertilizer use gave the highest yield increase (148%) and the third pruning seemed to be superfluous when fertilizer was applied. Farmers rated maize in unpruned plots lower than pruned plots. Farmer rating of performance of standing crop was consistent with patterns of grain yield variation (Table 5).

Table 6: Parameters of the most parsimonious model describing variability in maize yield

Parameters	Estimate	SE	t-value*	p-value
b0 (intercept)	2284.5	325.8200	7.01	<0.0001
b1 (Soil fertility)	275.0	160.5200	1.71	0.0881
b2 (Fertilizer use)	803.8	137.6600	5.84	<0.0001
b3 (Maize variety)	-200.0	144.8000	-1.38	00.1686
b4 (Agroforestry)	1395.7	135.2900	10.32	<0.0001
b5 (Planting date)	-411.6	77.3182	-5.32	<0.0001

*The degrees of freedom were 211

Predictors of maize yield: Individually, weeding, the maize variety used, use of fertilizer and agroforestry were not significant predictors of maize yield. On the other hand, planting date was a significant predictors of maize yield on farmers' fields. According to the Akaike Information Criterion (AIC), the most parsimonius model had soil fertility status of the farm, fertilizer application, maize variety, agroforestry and planting date. This model explained about 44% of the variation in maize yield. Fertilizer application and use of agroforestry species had significantly increased maize yield. On the other hand use of local maize varieties and late planting (late December) had negative effects on maize yield (Table 6).

DISCUSSION

Both male and female or young and older farmers practiced agroforestry suggesting that gender or age are not limiting factor for planting agroforestry species. This is in contrast with Thangata and Alavalapati (2003), who showed within the same area that age of farmers is an important determinant of farmers' participation in agroforestry trials. The fact that over 63% of farmers in the study had over three years experience with agroforestry and the shift of many farmers from Type II to III trials suggests adoption of the technologies. In addition, the majority (77%) of farmers who had started to use agroforestry in the last two years were extension farmers. This reflects the increasing up-scaling and adoption of agroforestry in southern Malawi.

The predominance of the local maize variety probably indicates that yield is not the only criterion for variety choice by farmers. Farmers generally preferred local maize for household consumption. The lower use of improved maize varieties could also result from the higher cost of hybrid maize seed. Men generally grew improved varieties for cash rather than for home consumption. The cultivation of mixtures of maize varieties by farmers may partly explain the low and varying yield levels observed on farmers' fields, even with soil fertility interventions such as agroforestry.

A very small proportion of the respondents used compost manures. The major hindrance to the use of compost manures was its unavailability in required quantities. Compost does not supply sufficient nutrients required for acceptable levels of maize yield due to low rates of fertilizer application and low quality of manures (Kuntashula *et al*., 2004).

More farmers are using gliricidia-maize intercropping compared to other agroforestry options in the study area probably because of the long-term nature of tree benefits after tree establishment (Akinnifesi *et al*., 2006, 2007). However, field management of gliricidia by farmers is variable. Although pruning three times a year is recommended to provide synchrony between N-release and N-demand by crop, many farmers pruned the trees and incorporated cuttings only twice. It is noteworthy that farmers with longer years of experience with agroforestry (>3 years) generally pruned their gliricidia more frequently than those with <3 years of experience with agroforestry. The lower number of extension farmers pruning their trees twice or more is due to the fact that gliricidia require at least 2 years before coppicing can be initiated as trees need to get established first.

The extension farmers' had larger farm sizes. In the experience, farm size is one of the main factors that may influence adoption of agroforestry technologies (Akinnifesi *et al*., 2008). In addition, the planting of agroforestry trees by larger numbers of female (59%) than male farmers may also be explained by extra benefits from fuelwood, which is a culturally-assigned responsibility of women.

The proportion of land fertilized under agroforestry was significantly higher for Type III than for extension farmers, but actual land by extension farmers were greater.

In the early years, Types II and III on-farm trial farmers were advised not to expand their plots until technologies had been sufficiently verified. This may have limited their zeal to expand their plots. The fact that varying levels of agroforestry and control plots were fertilized by farmers across farm types and that the rates are unknown, is a further factor that may confound the effects of fertilizer on yield comparisons and complicating the analysis.

Long-term trials elsewhere in Africa provide evidence for the effectiveness of combined organic and inorganic fertilizers to replenish N and carbon capital (Sanchez *et al*., 1997).

Although, there is evidence of integrated use of inorganic fertilizers with agroforestry, farmers usually apply fertilizers to less fertile areas of their fields, irrespective of treatment. Farmers may have been motivated to apply fertilizer to agroforestry plots in order to benefit from the synergy between organic and inorganic inputs (Akinnifesi *et al*., 2007).

However, this study's findings are in contrast to those of Keil *et al*. (2005) in Zambia, that farmers tend to use fertilizer on different plots than those where they apply agroforestry. The practice of combining agroforestry with other options should be encouraged, because there is high degree of synergy among the different options (Akinnifesi *et al*., 2007, 2008; Sileshi *et al*., 2008b).

When farmers use fertilizers, it has been observed that they apply low rates, often 25-30% of the recommended dosage (Akinnifesi *et al*., 2004). A high nitrogen-to-maize price ratio often inhibits both the uptake of fertilizer as well as the use of hybrid maize In addition, returns to fertilizer use in Malawi can be highly variable, suggesting that its use can be extremely risky, especially during the periods of low rainfall.

This study confirmed that soil fertility replenishment agroforestry technologies are superior in terms of maize performance compared with unfertilized sole maize, as evidenced by both farmer rating of standing maize crop and actual grain yield estimated through allometric measurement.

But farmers take other factors into account, e.g., labor requirements, when deciding whether to adopt a new practice. Therefore research is needed to identify farmers' criteria for evaluating the soil fertility practices tested in this study and determining farmers' assessment of them over time.

Farmer's higher rating of the maize performance in agroforestry options compared to fertilized sole maize suggests that fertilizer alone may not meet farmers' yield expectations and may be due to the fact that farmers use lower than the recommended rates of fertilizer. The findings are in agreement with results from earlier on station trials in southern Malawi (Ikerra *et al*., 1999; Akinnifesi *et al*., 2006, 2007) and on-farm adoption studies in Zambia (Ajayi *et al*., 2003; Kuntashula and Mafongoya, 2005) that the agroforestry technologies were robust and performed well across the farms, as shown by farmers own qualitative ratings (Table 3). The low performance of mineral fertilizer may be ascribed to the low rates generally applied by farmers.

The model on predictors of maize yield on farmers field (Table 6) has produced useful insights into crop management. It shows that the risk of crop failure is higher if planting is delayed, irrespective of the maize variety, or whether fertilizer is applied or not. Given the high number of farmers that use very low fertilizer rates in Malawi, the risk of losing applied fertilizers in low or very heavy rainfall years is high. With low fertilizer rates, the risk of low returns on fertilizer investment is also high on the exhausted farms with very low levels of soil organic matter. The risk can be minimized by the combined use of organic inputs from agroforestry with well-timed applications of inorganic fertilizer and timely weeding (Akinnifesi *et al*., 2007; Piha, 1993).

This highlights the need for farmers to use responsive farming techniques that use early rainfall information to help them decide on the amount of fertilizer needed. Responsive fertilizer practices could be based on the logic of applying low initial doses when early rainfall is inadequate and high amounts when early rainfall is more abundant. Efforts are also needed to promote the combined use of organic matter technologies and inorganic fertilizer application.

Pigeon pea has been known to improve soil fertility through N fixation (Adu-Gyamfi *et al*., 2007) and to solubilize phosphorus from unavailable forms (Ae *et al*., 1990). When sesbania, gliricidia or tephrosia plots were intercropped with pigeon pea and when fertilizer was applied, there was an improvement in yield (Table 4). Pigeon pea and other leguminous such as tephrosia and sesbania may compete very little with the maize crop as these are relay cropped with maize in the study area. The competition between the maize crop and gliricidia was also shown to be minimal in gliricidia-pigeon pea-maize intercropping systems in Makoka, Malawi (Chirwa *et al*., 2006, 2007; Makumba *et al*., 2009). In poor soils, reduced yield is expected when part of the added N is partitioned to seed production of pigeon pea and to weeds. Pigeon pea is a less aggressive user of N due to its slow initial growth and ability to fix N. Pigeon pea is considered a bonus crop for farmers as it provides edible seeds (Snapp and Silim, 2002). It can also be seen in the light of soil fertility when used as rotational fallow.

An on-station trial result by Chirwa *et al*. (2003, 2007) confirmed that intercropping pigeon pea with maize under Gliricidia-maize intercropping did not have any significant effect on maize yield. This highlights the need for further research to establish the effect of intercropping pigeon pea in agroforestry plots. According to Snapp *et al*. (2002), soil fertility was a minor component of farmers criteria for using pigeon pea and women in particular had limited interest in its ability to improve soil fertility. The high rating of pigeon pea above sole maize by farmers reflects their appreciation for its production of edible and saleable seeds. Further research is needed to determine whether the additional food harvested from intercropped pigeon pea seeds could compensate, in economic terms, for the yield depression observed in annual relay fallows intercropped with pigeon peas.

Relatively high maize yields can be attained when 25-50% of the recommended fertilizer is combined with agroforestry (Akinnifesi *et al*., 2006, 2007) and the additive effect of fertilizer and agroforestry on maize yield supports recent findings from a long-term on-station trial in Southern Malawi (Akinnifesi *et al*., 2006, 2007).

The majority of farmers (51%) had pruned twice and 18% had only pruned the trees once (Table 2) probably due to labour constraints or because trees were too young to prune. The majority of farmers who did not prune their trees at all were recent planters who were waiting for their trees to properly establish before pruning them, so were not actually expected to prune but were captured since the plots were cropped. This result in Table 5 showed that maize yield increased with pruning frequency, suggesting that pruning management is the key to the impact of gliricidia-maize intercropping on maize yield. Makumba *et al*. (2006) confirmed that the first pruning done in October or early November was the most critical for maize yield.

The significant increases in maize yield due to the agroforestry species compared to sole maize plot (Table 5) are a further confirmation of on-station results that showed doubling of maize yields on farmers' fields, without use of external fertilizer input (Kwesiga *et al*., 2003; Akinnifesi *et al*., 2007). The superior performance of maize under relay fallows with tephrosia and sesbania on farmers' fields is because tephrosia quickly establishes and accumulates biomass.

A long waiting period of 2-3 years has generally been reported for gliricidia-maize system (Chirwa *et al*., 2007). During the initial 2 years farmers are not expected to obtain positive increases in crop yield until trees are well established and prunings can be incorporated in the third season.

However, the advantage of gliricidia over tephrosia and sesbania is that the trees produce fertilizers continually without having to be replanted. An optimal arrangement for many farmers may be to grow sesbania and tephrosia so as to obtain short-term gains and grow gliricidia so as to obtain benefits over the longer term.

CONCLUSION

The findings from this study show that smallholder farmers recognized the positive impact of fertilizer and fertilizer tree systems (Agroforestry) as important soil fertility replenishment interventions. They also show that smallholder farmers adopting fertilizer tree agroforestry interventions are innovating by integrating these with other practices such as inorganic fertilizers and compost manure and intercropping with pigeon peas.

Relatively high maize yields are possible under agroforestry, with or without fertilizer application, especially when maize is planted early (depending on the onset of rains), efficiently weeded and fertilizer trees are pruned at least twice per season (for gliricidia). The predominance of the local maize variety, which is less responsive to fertilizer and the low rates of fertilizer applied to hybrid varieties may limit the yield potential and returns to investment. The use of both fertilizer trees and mineral fertilizer can lead to sustainable maize production provided other agronomic recommendations are followed. Agroforestry intervention based on fertilizer tree systems has the potential to contribute to sustainable food security in Malawi. Therefore, the national food security strategy should include the scaling up of proven agroforestry technologies as part of long-term investment in human capital and land resource-base. The strategy should also promote the integration of modest quantities of mineral fertilizers with nitrogen-fixing trees so as to guarantee increased maize productivity under small holder farmers' conditions in Malawi.

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