Agroforest Syst (2009) 76:467–485
DOI 10.1007/s10457-009-9217-y

Adoption potential of selected organic resources for improving soil fertility in the central highlands of Kenya

Jayne Mugwe · Monicah Mucheru-Muna · Daniel Mugendi · James Kung'u · Andre Bationo · Franklin Mairura

Received: 25 April 2008 / Accepted: 31 January 2009 / Published online: 15 March 2009

Abstract Soil fertility decline is the major cause of declining crop yields in the central highlands of Kenya and elsewhere within the African continent. This paper reports a study conducted to assess adoption potential of two leguminous trees, two herbaceous legumes, cattle manure, and *Tithonia diversifolia* either solely applied or combined with inorganic fertilizer, for replenishing soil fertility in the central highlands of Kenya. The study examined biophysical performance, profitability, feasibility and acceptability, and farmers experiences in managing and testing the inputs. The study was based on a series of studies incorporating both sociological and experimental approaches for two and a half years. Results of on farm trials showed that manure + fertilizer and tithonia + fertilizer treatments increased yields by more than 100% above the control. These treatments were the most profitable having highest net benefits and benefit cost ratios. They were also the most commonly preferred by farmers who used them on larger plots compared to the other inputs. In conclusion, cattle manure and tithonia were found to be the organic materials with the highest adoption potential for soil fertility improvement in this area. *Calliandra calothyrsus* and *Leucaena trichandra*, on the other hand, have potential for use as animal fodder. The herbaceous legumes had the least adoption potential due to poor performance recorded on

Andre Bationo was formerly working for Tropical Soil Biology and Fertility Institute of CIAT (TSBF-CIAT) as the African network Coordinator.

J. Mugwe
Kenya Forestry Research Institute (KEFRI),
P.O. Box 20412, 00200 Nairobi, Kenya
e-mail: jaynemugwe@yahoo.com

M. Mucheru-Muna (✉) · D. Mugendi · J. Kung'u
School of Environmental Studies, Department of Environmental Sciences, Kenyatta University (KU),
P.O. Box 43844, 00100 Nairobi, Kenya
e-mail: moniquechiku@yahoo.com

D. Mugendi
e-mail: dmugendi@yahoo.com

J. Kung'u
e-mail: Kung'u_james@yahoo.com

F. Mairura
Tropical Soil Biology and Fertility Institute of CIAT (TSBF-CIAT), c/o World Agroforestry Centre (ICRAF),
U.N. Avenue, Gigiri, P.O. Box 30677, 00100 Nairobi, Kenya
e-mail: F.mairura@gciar.org

A. Bationo
Soil Health Program (Research & Extension), CSIR Office Complex #6 Agostino Neto Road, Airport Residential Area, PMB KIA 114, Airport-Accra, Africa
e-mail: ABationo@agra-alliance.org

the farms that possibly led to low preference by the farmers. However, issues of sustainable seed production could have played a role. This study recommends some policy issues for enhancing adoption and research issues focusing on exploring strategies for increasing biomass production and use efficiency on farms.

Keywords Biophysical performance · *Calliandra calothyrsus* · *Crotalaria ochroleuca* · Economic returns · Feasibility and acceptability · On-farm trials · *Leucaena trichandra* · *Mucuna pruriens*

Introduction

Background

The intensification of agriculture in Africa has not been accompanied by sufficient inputs of nutrients through biological N_2 fixation, organic materials and mineral fertilizers to match the outputs of nutrients through harvested products and losses. As a result, poor soil fertility has emerged as one of the greatest biophysical constraint to increasing agricultural productivity hence threatening food security in the African continent. Annual soil loss is high, estimated at 22 kg N ha^{-1}, 5 kg P ha^{-1} and 15 kg N ha^{-1} (Smaling et al. 1997). To reverse the nutrient depletion in African soils, there has been renewed interest among researchers to promote the use of organic resources, with several authors reporting the materials ability to substitute or supplement mineral fertilizer (Vanlauwe et al. 2002; Bationo et al. 2004). The use of organic materials to replenish soil fertility is not new. It has been used for centuries in temperate agricultural regions, with crop rotations and winter cover crops. Organic resources have an important advantage over inorganic fertilizer in sustainability terms; they supply plant nutrients, contribute to soil organic matter build-up and maintenance, improves nutrient use efficiency and soil physical properties. In Africa, animal manure is one of the mostly used organic input but as the need for increased agricultural production rises; it has been found to be limited in quality and quantity (Mafongoya et al. 2006). During the last decade, alternative organic resources including *Tithonia diversifolia* (Jama et al. 2000), leguminous trees (Mugendi et al. 1999) and herbaceous legumes (Baijuka 2004) have been studied. Despite this research, results still indicate dismal adoption of these new organic resources and there is little evidence that farmers have benefited from the researchers efforts.

Hindrances to adoption among farmers have centered around technical feasibility of using the organic resources, which may not be consistent with actual farm conditions. This is because the development process of the options has not adequately incorporated socio-economic and livelihood conditions that are at the core of farmers decision making. For example, increased demands on production factors, such as land, labor and capital could limit their uptake. To address this concern recent studies have emphasized use of participatory on-farm research as one of the ways of increasing adoption of soil fertility management technologies (Stround 1993; Mutsaers et al. 1997). There has also been an increased number of adoption studies, especially focusing on using econometric models to determine factors influencing adoption of soil fertility management technologies (for example, Adesina and Chianu 2002; Lapar and Ehui 2004; Mercer 2004; Keil et al. 2005). Despite these efforts some shortcomings regarding adoption remain. Such adoption studies do not fully explain farmer's behavior towards technology adoption because adoption involves key attitudinal components e.g., perceived usefulness to address the underlying problem, acceptability and perceived economic returns between the new and the old technologies (Haggblade et al. 2004).

Most other studies have looked at biophysical performance (e.g., SSSEA 2003) and recommendations based on technologies that have the ability to achieve high crop yield response while ignoring evaluations by farmers and the economic implications of the technologies to the farmers. Few studies, so far, have examined these practices under farmers' management especially to determine their adoption potential. Information on adoption potential is important for improving the effectiveness of the research-development continuum.

Assessment of adoption potential by farmers is multifaceted, requiring an understanding of both biophysical performance under farmers' circumstances, profitability from the farmers' perspectives and its acceptability by farmers (Franzel et al. 2002). Such an assessment requires an interdisciplinary approach incorporating both sociological and experimental approaches. This paper adopts such an approach and examines adoption potential of three agroforestry trees, two herbaceous legumes, cattle manure and inorganic fertilizer under farmers' conditions. The study sought to answer the following questions:

– Biophysical performance: what are the effects of applying the soil fertility replenishment inputs on maize yields under farmers conditions?
– Profitability: what are the profitability levels of the soil fertility replenishment inputs introduced?
– Feasibility and acceptability: what inputs do farmers prefer and what are the reasons behind their preferences? How are the farmers managing the inputs on their farms and what are their perceptions about the benefits accrued? What are the constraints that farmers experience as they use the inputs and what opportunities exist for addressing the constraints?
– Feedback to research and extension: how do farmers modify the practices and what are the research priorities?

Problem context

The central highlands of Kenya is one of the most populated areas and with one of the highest rates of nutrient depletion in Africa. In an effort to feed their large families farmers practice intensive agriculture without adequate soil nutrient replenishment. Farming is characterized by low inputs, low crop productivity and soil nutrient depletion hence posing a major threat to sustainable agricultural production and food security. Soil nutrient depletion is a subject of major concern and debate in Africa because in many countries in sub-Saharan Africa, the economic growth and quality of life depends on the agricultural sector. The intensified form of agriculture being practiced requires nutrient replenishment via fertilizers but fertilizers are expensive and unaffordable to majority of the farmers. For example, fertilizer costs two to six times more in Africa than in Europe and Asia (Garrity 2004).

Many African countries subsidized fertilizer prizes to promote its use among farmers. In Kenya, for instance subsidies were completely withdrawn in 1978/1979 (Riugu et al. 1985). The withdrawal of such subsidies has made inorganic fertilizer unaffordable to most African small holder farmers. In Kenya, additional problems such as, lack of credit and delays in delivery of fertilizer due to poor transport and marketing infrastructure, continue to constrain fertilizer optimal use consequently causing declining crop yields. The alternative approaches developed by researchers, involving the increased use of biological organic resources are low cost and therefore friendly to the resource poor farmers. The main biological resources being promoted are nitrogen fixing legumes (cover crops and trees), animal manures, biomass transfer systems using agroforestry trees and more efficient use of trees and shrubs to supply plant nutrients either alone or in combination with inorganic fertilizers.

Farmers are currently testing a wide range of organic and inorganic resources in several countries within the Southern, Central, West and East Africa. The testing is being done in collaboration with a number of stakeholders that include national agricultural research institutions, World Agroforestry Centre and the African Network for The Soil Biology and Fertility Programme (AfNet of TSBF). In addition considerable efforts are being made to disseminate and enhance uptake by farmers. Although these efforts have been going on for almost two decades, little has been reported on their performance under farmers' environment from a socio-economic context. Most published findings report biophysical data mainly drawn from on-station experiments, with scantly data based on-farm especially tackling adoption issues.

Historical perspective: research and dissemination activities

Diagnostic studies carried out in the central highlands of Kenya identified poor soil fertility as a major constraint limiting agricultural production (Minae and Nyamae 1988). A later study (Murithi et al. 1994) conducted under the auspices of the National Agroforestry Research Project (NAFRP) similarly identified the same problem of poor soil fertility and inability of the farmers to use adequate amounts of fertilizer to address the problem. Research activities by the NAFRP project showed biomass harvested from two leguminous shrubs to be effective in increasing maize yields (Mugendi et al. 1999). To scale up these promising technologies and other "best bets" developed by other projects in Kenya and in Africa, a project on integrated soil fertility management was initiated in the central highlands of Kenya in 2000. The aim of this project was to evaluate performance of selected soil fertility replenishment options, that involved use of organic materials and inorganic fertilizer, as well as to promote their adoption by farmers through participatory approaches.

The main approach used for dissemination was the mother–baby approach (Snapp et al. 2002). This approach was designed to improve the flow of information between farmers and researchers about technology performance and appropriateness under farmer conditions. The mother trial had many treatments, while in the baby trials treatments were fewer and consisted of a subset of the treatments in the mother trials, plus a control. The mother trial had 14 treatments replicated three (3) times and was planted at a public school to facilitate access by farmers. The treatments comprised of six organic resources that were applied solely or combined with inorganic fertilizer at a rate of 60 kg N ha^{-1}, sole application of inorganic fertilizer and a control. The organic resources were two herbaceous legumes (*Mucuna pruriens* and *Crotalaria ochroleuca*), two leguminous shrubs (*Calliandra calothyrsus* and *Leucaena trichandra*), *Tithonia diversifolia* (a road side shrub that produces large quantities of biomass) and cattle manure.

Using the mother–baby approach all the farmers within the vicinity (covering nine villages) of the "mother" sites were given equal opportunities to participate in the study through participation in joint-research-farmer-extension field days organized every growing season (two growing seasons in a year) at the grain filling stage. During the field days resource persons from the research and extension teams led farmers through the field trials in small groups. As the farmers toured the plots, the resource persons explained the different treatments as the farmers evaluated the treatments using farmer friendly criteria (cob size, crop vigour, color, height) that had been developed together with the farmers. After this exercise, trainings were conducted for each of the groups on how the inputs used in the trials were applied. For example, in the case of tithonia, calliandra, leucanea, crotalaria and mucuna, farmers were trained on how to harvest, prepare by chopping into small pieces and incorporation into the soil. For cattle manure and inorganic fertilizer, they were trained on good manure management and application procedures and rates. The farmers were also trained on the recommended agronomic procedures for growing maize, which was the test crop in the trial. Afterwards plenary sessions were conducted where farmers shared their opinions. They were encouraged to make choices of preffered technologies. The technologies farmers tested on their fields formed the baby trials.

To ensure provision of planting materials to participating farmers, on-farm group tree nurseries were started (Mugwe and Kung'u 2006). The tree nurseries were managed by farmer groups that consisted of farmers living close to one another. For the nurseries to run effectively, each group of farmers was trained on tree nursery practices and supplied with seeds of calliandra and leucaena. The nurseries were monitored by the research and extension teams to ensure that they were run properly. Since mucuna and crotalaria were new inputs in the area, they were bulked at the demonstration site and interested farmers accessed the seeds for free.

The mother–baby approach, in addition to generating data on which to assess the technology performance under realistic farmer conditions (through the baby trials), encouraged farmers to actively participate in the trials. This was expected to stimulate farmer adoption of the new technologies and practices. However, after 2 years of promotion activities (2000 and 2001), information was lacking on how farmers tested the inputs and particularly adoption potential of the introduced inputs. This information would help in designing of a more targeted approach.

Materials and methods

Description of the study area

The study was conducted in Chuka division of Meru South district of Kenya. The area lies between the Upper Midland Zone two (UM2) and Upper Midland Zone three (UM3) agroecological zones, on the eastern slopes of Mt. Kenya at an altitude of 1,500 m above sea level with an annual mean temperature of 20°C and a total bimodal rainfall of

1,200–1,400 mm (Jaetzold et al. 2006). The rainfall is in two seasons; the long rains (LR) lasting from March through June, and short rains (SR) from October through December. The soils are mainly Rhodic Nitisols (Jaetzold et al. 2006), which are deep, well weathered with moderate to high inherent fertility but over time soil fertility has declined due to continuous mining of nutrients without adequate replenishment. Recent studies have reported that they have generally low levels of organic carbon (<2.0%), nitrogen (<0.2%), phosphorus (<10 ppm) and are moderately acidic (pH ranges from 4.8 to 5.4), conditions that result in low crop production. The district is a predominantly maize growing zone with small land holdings ranging from 0.1 to 2 ha with an average of 1.2 ha per household.

The area is characterized by rapid population growth, low agricultural productivity and increasing demands on agricultural resources. In Chuka division, there are about 47,000 farm families and a population of 206,000 with an average family size of 7 persons in the upper zones (UM1-M3) and 9 in the lower zones (Lower midlands). Kirege location where the study was conducted has a high population density of 627 person's km^{-2}. The area is dominated by farming systems with a complex integration of crops and livestock, and smallholder farms that are intensively managed. The main cash crops are coffee (*Coffea Arabica* L.) and tea [*Camelina sinensis* (L.) O. Kuntze] while the main staple food crop is maize (*Zea mays* L.), which is cultivated from season to season mostly intercropped with beans (*Phaseolus vulgaris* L.). Other food crops include potatoes (*Ipomea batatas* (L.) *Lam*), bananas (*Musa* spp. L.) and vegetables that are mainly grown for subsistence consumption. Livestock production is a major enterprise especially improved dairy cattle. Other livestock in the area include sheep, goats and poultry.

Type 2 on-farm trials 'designed by researcher but managed by farmers'

On-farm trials designed by researcher and managed by farmers, classified as Type 2 trials (Franzel et al. 2002) were initiated on 15 farms during 2002 LR and data collected for four seasons (Table 1). The 15 farmers were selected from those who had participated in field days and trainings conducted during 2000 and 2001 growing seasons. The aim of the trials was to assess the performance of the different soil fertility replenishment inputs that were being tested and demonstrated at the mother trial, under a variety of farmers' conditions. They consisted of "one farmer" "one replication" trial design managed by farmers. A trial design of this type simplifies the design and makes it easier for farmers to evaluate the technology. In addition, having many replicates across sites makes it possible to sample under variations in farms management and environment (Mutsaers et al. 1997). These trials were also used to collect data for assessment of profitability of the technologies as recommended by Franzel et al. (2002). High variability in management among farmers is known to sometimes mask treatment performance and control of some factors is recommended for purposes of providing appropriate biophysical data (Mutsaers et al. 1997). In these Type 2 trials, variability was controlled by ensuring that all farmers participating in the trial used the same maize variety and inorganic fertilizer. The farmers were therefore provided with seed maize (H513) and compound fertilizer (nitro phosphate; 23:23:0) as the source of nitrogen.

Farmers for this trial were distributed across locations within Chuka division (many locations make a division). The treatments were similar to those in the mother trial (two leguminous trees, two herbaceous legumes, cattle manure and tithonia, either applied solely or combined with fertilizer) but farmers tested different numbers of treatments depending on availability of land. Seeds for the herbaceous legumes were provided to farmers and were intercropped between the maize rows. They grew together with the maize until harvesting time. After the maize was harvested, they were left to grow in the field until land preparation for the subsequent season when they were harvested, chopped and incorporated into the soil. Farmers had planted the leucaena and calliandra trees mainly along terraces and on farm boundaries, using seedlings from farmer group nurseries initiated in 2000. Tithonia, on the other, is traditionally found along home hedges and roadsides. At the beginning of each cropping season, farmers harvested prunings of calliandra and leucaena from their farms and of tithonia from the roadsides. After being cut into small pieces, they incorporated into the soil using hand hoes to a depth of 15 cm just like at the on-station trial where they had received training.

Table 1 Schedule of field and research activities from 2000 to 2004 at Chuka, Meru south district, Kenya

Season	Activity					
	Field days	On-farm trials Type 2	On-farm trials Type 3	Farmer survey (+ informal follow-up)	Economic assessments	Key informants interviews
LR 2000						
SR 2000						
LR 2001						
SR 2001						
LR 2002						
SR 2002						
LR 2003						
SR 2003						
LR 2004						

Shaded part, activity carried out during the season

SR short rains season (March to August), *LR* long rains season (October to February)

During planting, technicians were present to ensure that the required procedures were followed and right amounts of inputs were applied. For example, they weighed the amounts of organic materials to be applied to provide an equivalent of either 60 or 30 kg N ha^{-1} depending on the treatment. The net plots measured 3 × 3 m and were laid down by the research team while the planting was done by the farmer with supervision from the researcher. After planting, farmers carried out all the required agronomic practices independently, such as, weeding but the researchers always participated in harvesting activities. Biophysical data (maize and stover yields) and socio-economic (cost of inputs, labor) data were collected from these trials.

Type 3 on-farm trials "designed and managed by farmers"

A sample of 60 farmers, selected from a list of 182 farmers, who had attended the field days from 2000 to 2001, and were implementing and testing the technologies (they had learnt from the mother trial) on their own were monitored for four seasons. According to classification by Franzel et al. (2002) these were Type 3 on-farm trials. During the growing season of 2002 LR, 2002 SR, 2003 LR, 2003 SR farmers were visited and technologies they were testing assessed, plots for each of the treatments measured and marked, and a clear record made on the technologies each farmer was testing. The farmers were also requested to avoid harvesting the maize crop until maturity. At crop maturity the researcher visited the farmers and organized the harvesting and data taking. During harvesting, a representative net plot of 3 × 3 m under different technologies per farmer was marked and maize and stover yields taken.

Maize yields assessment

During harvesting maize cobs were manually separated from the stover, sun-dried, and packed in paperbags before threshing. After threshing, moisture content of the grains was determined using a moisture meter and grain weights adjusted to 12.5% moisture content.

Economic analysis

The economic analysis in this study was done without considering soil nutrients dynamics and the resultant maize yields due to long-term application of inorganic and organic inputs. The economic returns from

Table 2 Parameters used to calculate the economic returns for the different soil nutrient replenishment inputs in Meru South district, Kenya

Parameter	Actual values
Price of nitrophosphate fertilizer (NPK, 23:23:0)	1.38 USD kg^{-1} N
Labor cost	0.13 USD h^{-1}
Labor cost for planting maize	10.5 USD ha^{-1}
Labor for applying fertilizer	0.74 USD ha^{-1}
Labor for application of organic inputs	2.9 USD 100 kg^{-1} DM
Price of maize	0.146 USD kg^{-1}
Price of stover	0.012 USD kg^{-1}

DM dry matter basis. Exchange rate 76 Ksh = 1 USD (Feb 2004)

the application of each treatment were calculated based on partial budgeting. As the term partial budget implies, only those changes in costs and returns that are affected by the alternative scenarios are considered (CIMMYT 1988). Costs included all the expenses of buying, transporting and applying the inputs. Benefits included all the gains obtained from selling the maize grain and stover at the farm gate price during harvest. The local market prices of the various inputs were used in the analysis. Price of fertilizers, transport cost of fertilizer and price of farm yard manure (Table 2) were determined through a market survey conducted in the area. However, since the organic amendments did not have market prices in the area they were costed in terms of the labor involved in harvesting, transportation and incorporation. Labor was valued at the wage rate of hired farm workers. Monetary values were converted to US Dollars (USD) at the exchange rate of 76 Ksh = 1 USD (February 2004).

The experimental component was fully farmer managed, therefore the yields were not adjusted (CIMMYT 1988). Net benefit, benefit-cost ratio and return to labor were used in economic evaluation. The net benefit for each treatment was determined as the difference between the benefits and the costs for each technology. Benefit to cost ratio (BCR) was determined as the gross benefits from each technology divided by the respective total costs that varied. Return to labor was determined as the gross benefits less the costs of inputs divided by the cost of labor for each technology.

Farmers surveys

To assess feasibility and acceptability of the soil fertility replenishment inputs both informal and formal methods were used to collect data on preference, their management and farmers' experiences. The field days continued being held after starting the trials in 2002 LR and informal discussions were held with the farmers attending. Within the study period, a total of four field days were held; 2002 LR, 2002 SR, 2003 LR and 2003 SR growing seasons. To assess how farmers were testing the inputs, informal follow-ups were carried out for some of the farmers who had registered as testers of any of the inputs. The follow-ups were done during 2002 LR, 2002 SR, 2003 LR and 2003 SR (Table 1) and documentation made on how they were testing and managing the inputs on their farms. During this informal follow-ups, interviews and visual observations on crop performance under the different treatments were made. In addition, farmer's assessment of the treatments were sought and documented.

Formal surveys using interview schedules were also carried out during 2002 LR, 2002 SR and 2004 LR (Table 1). Attendance of the field days and acceptance to test the introduced soil fertility replenishment inputs by the farmers was used as criteria for selecting the sample of farmers to be interviewed. During a farmers field day held in February 22, 2002 (2001 SR) farmers who had tested/taken up the new soil fertility replenishment inputs were registered against the inputs they were testing. A total of 64 farmers were registered. From this list, 31 farmers were randomly selected. These farmers were visited and interviewed using a semi-structured interview schedule during 2002 LR and 2002 SR. During the interviews, visual assessment of the technologies performance was also done. During the field days held from 2000 LR to 2003 LR, a list of all farmers attending was compiled and was consequently used to randomly draw a list of 49 farmers who were interviewed during 2004 LR using a formal interview schedule. Information collected during this interview included: inputs farmers were testing, land sizes dedicated to the inputs, benefits accruing from the use of the inputs, and constraints experienced. The number of trees established for biomass transfer technologies was recorded and information on whether the farmer wished to continue planting more trees collected. Continuation of the use of the inputs was also important in this assessment and farmers were asked to state inputs they wished to discontinue/abandon and any new technologies they wished to add.

Key informants interviews

Key informants were selected from Kirege village and these consisted of farmers who had consistently attended field days and had used the new inputs throughout the seasons under study. These farmers were visited in September 2004, just after harvesting the 2004 LR crop (Table 1), and in-depth interviews conducted informally using standard guidelines. Information was collected on how they would rank the inputs in terms of their own preferences and reasons behind their ranking, practices they thought majority of the farmers in Kirege area would adopt easily, and constraints associated with the implementation of each of the technologies. Farmers were also asked to suggest some solutions to the identified constraints.

Data management and analysis

Biophysical data (maize yields, economic data) were subjected to Analyses of Variance (ANOVA) using Genstat software. Significant differences were declared significant at $P \leq 0.05$ and means were separated by least significant differences (LSD). Due to unbalanced nature of the experiments at the farmers' fields, regression modeling using Genstat programme was used to analyze differences in mean yields (Stern et al. 2004). This yielded predicted means that each had an estimated standard error (SE) but the average LSD or standard error of differences (SED) at $\alpha = 0.05$ was used to compare the means. To determine differences in yields variability between on-station and on-farm experiments, coefficient of variation (CV), which is a measure of scatteredness of data (Stern et al. 2004) was used.

Data obtained from the formal surveys was first subjected to descriptive analysis using Statistical Programme for Social Scientists (SPSS), version 11.2. Technology preference by farmers was examined by exploring technologies farmers had and summarized using frequency tables and percentages. Farmer management practices, benefits, and constraints experienced by farmers were also analysed and presented in form of frequency tables. The hypothesis that farmers preferred using a combination of organic resources and inorganic fertilizer to sole applications and planted the combinations in larger land sizes than sole applications was tested using the independent samples *t*-test and declared significant at $\alpha = 0.05$. Analytical data collected from the informal interviews were analysed thematically and used to complement data collected from the formal surveys.

Results

Biophysical performance

Maize yields from the on-farm trials varied significantly among the treatments and the seasons (Tables 3, 4). In the Type 2 trial, maize yields were significantly higher in cattle manure alone and cattle manure + 30 kg N ha^{-1} than in all the other treatments during 2002 LR. Maize yields ranged from 1.4 t ha^{-1} (control) to 4.8 t ha^{-1} (cattle manure + 30 kg N ha^{-1}) in 2002 SR, while in 2003 LR yields ranged from 1.0 t ha^{-1} (control) to 4.7 t ha^{-1} (cattle manure + 30 kg N ha^{-1}). During 2003 SR, mucuna, crotalaria, cattle manure and leucaena combined with fertilizer recorded significantly higher yields than sole application treatments. This suggests that the integration of these organic materials with fertilizer was more beneficial to the maize crop than the sole applications. The Type 2 trials generally showed that the lowest yields were obtained from herbaceous legumes and the control treatment, while manure, tithonia, calliandra and leucaena gave the highest yields in most seasons.

In the Type 3 trial, highest maize yields during 2002 LR season were obtained from inorganic fertilizer, calliandra, cattle manure, cattle manure + 30 kg N, and manure + tithonia + fertilizer treatments (Table 4). In 2002 SR, highest maize yields were obtained from tithonia + 30 kg N ha^{-1}, cattle manure + 30 kg N ha^{-1} and inorganic fertilizer treatments. In 2003 SR, highest yields were recorded from cattle manure and mucuna + fertilizer + manure treatments. Except for herbaceous legumes, all organic materials alone or in combination with fertilizer gave reasonable yields of more than 3.5 t ha^{-1} in most seasons. Generally, the effect

Table 3 Maize grain yields from "Type 2" trial during 2002 LR to 2003 SR under different soil management inputs at Chuka, Kenya

Treatment	2002 LR	2002 SR	2003LR	2003 SR
Mucuna pruriens[a]	1.6	2.7	1.6	2.3
Mucuna + 30 kg N ha^{-1a}	1.2	1.4	ND	3.2
Crotalaria ochroleuca[a]	0.4	2.5	1.0	1.6
Crotalaria + 30 kg N ha^{-1a}	3.3	4.5	2.8	3.3
Cattle manure	3.8	4.2	4.2	2.6
Cattle manure + 30 kg N ha^{-1}	4.2	4.8	4.7	5.3
Tithonia diversifolia	1.3	2.4	2.4	5.0
Tithonia + 30 kg N ha^{-1}	2.8	3.4	3.7	3.2
Calliandra calothyrsus	3.2	4.1	2.2	3.4
Calliandra + 30 kg N ha^{-1}	1.7	4.4	4.0	4.3
Leucaena trichandra	1.8	4.7	2.1	1.9
Leucaena + 30 kg N ha^{-1}	2.1	4.2	3.3	3.9
Recommended rate of fertilizer (60 kg N ha^{-1})	3.0	3.9	3.2	3.2
Control	1.1	1.4	1.2	1.2
P	<0.001	0.001	0.032	0.001
Coefficient of variation (CV)	23%	21%	27%	32%
SED	0.4	0.6	0.9	0.6

SED Standard error of differences between means, *ND* not determined

[a] The legumes were intercropped with maize and application rate varied depending on the amount of biomass harvested during the previous season

of combining organic materials with fertilizer on maize yields in the on-farm trials had no definite trend possibly because of the variability among fields especially in Type 3 trial. However, crotalaria, cattle manure, tithonia, calliandra and leucaena in combination with fertilizer showed improved maize performance.

Some farmers in the Type 3 trial mixed different organic materials. Maize yields during 2002 LR for these mixtures ranged from 2.4 to 4.3 t ha^{-1} compared to 0.4 t ha^{-1} from the control treatment while during 2003, yields ranged from 2.0 to 5.6 t ha^{-1} against the control treatment that had 2.0 t ha^{-1} (Table 4). The yields from the farms were observed to be highly variable among the treatments and farmers. The Type 3 trials had higher variability than the Type 2 trials. For example, in 2003 LR coefficient of variation (CV) for the Type 2 trial was 27% while that of Type 3 trials was 43%. In 2003 SR, CV for the Type 2 trials was 32% while that of the Type 3 was 54%.

Economic returns

There were significant differences in net benefits, BCR and return to labor among the treatments. Manure plus half recommended rate of inorganic fertilizer gave the highest net benefit while control gave the lowest with USD 938.8 and 63.3, respectively (Table 5). This implies that manure + 30 kg N ha^{-1} was the most profitable followed by tithonia + 30 kg N with USD 795. On the other hand, the sole applications of tithonia and manure gave lower net benefits of USD 542 and 304, respectively. The BCR is used as an indicator of the profitability of a given practice. A BCR of one (1) is the breakeven point for the farmer while BCR of below one (1) implies that the farmer is not recovering the cost. Sole manure gave the highest BCR and return to labor with 2.9 and 3.6, respectively, followed by manure + fertilizer treatments. All treatments with organic materials, except calliandra plus fertilizer, recorded a BCR of about 2.0, the minimum acceptable for most smallholder farming communities (Mafongoya et al. 2006).

Feasibility and acceptability

Preference of soil fertility replenishment technologies

The results from farmer's surveys showed that the proportion of farmers using the different technologies varied and that technologies were practiced on different land sizes (Table 6). The first formal survey involving 31 farmers, carried out during 2002 LR showed that majority of the farmers were using

Table 4 Maize grain yields from "Type 3" trial during 2002–2003 SR under different soil management inputs at Chuka, Kenya

Treatment	Maize grain t ha^{-1}		
	2002 LR	2003 LR	2003 SR
Mucuna pruriens	0.1 (4)	–	3.3 (5)
Mucuna + 30 kg N ha^{-1}	–	1.2 (6)	1.6 (5)
Crotalaria ochroleuca	0.3 (4)	–	2.0 (5)
Crotalaria + 30 kg N ha^{-1}	–	–	2.3 (4)
Cattle manure	–	4.0 (8)	4.3 (7)
Cattle manure + 30 kg N ha^{-1}	4.9 (7)	5.6 (6)	2.9 (6)
Tithonia diversifolia	–	–	3.7
Tithonia + 30 kg N ha^{-1}	4.7 (8)	7.7 (6)	2.9 (6)
Calliandra calothyrsus	5.1 (4)	–	3.8 (5)
Calliandra + 30 kg N ha^{-1}	–	–	0.8 (4)
Leucaena trichandra	4.3 (4)	2.1 (4)	–
Leucaena + 30 kg N ha^{-1}	–	–	–
Fertilizer @ 60 Kg N ha^{-1}	5.0 (6)	5.5 (5)	3.5 (5)
Manure + tithonia	4.2 (5)	–	–
Manure + Tithonia + fertilizer[a]	–	1.1 (5)	–
Manure + Calliandra + Leucaena + fertilizer[a]	–	4.4 (4)	–
Mucuna + fertilizer + manure[a]	3.6 (3)	3.6 (4)	5.6 (4)
Calliandra + manure[a]	2.4 (3)	–	3.6 (6)
Calliandra + tithonia + fertilizer[a]	4.2 (3)	–	2.2 (6)
Crotalaria + leucaena[a]	–	–	2.0 (4)
Crotalaria + manure + fertilizer[a]	–	–	2.4 (4)
Leucaena + manure[a]	3.9 (4)	–	2.9 (3)
Mean	2.8	3.0	3.1
Control	0.4	2.0	2.0
P	0.004	<0.001	0.001
Coefficient of variation (CV)	45%	43%	54%
SED	0.5	1.1	0.9

[a] Farmers' modifications

– = not determined (number of farmers who had the treatment were less than four)

SED Standard error of differences between means; values in parenthesis = number of farms

Table 5 Net benefit, Benefit-cost ratio (BCR) and return to labor (USD) during the 2003 long rains season in Chuka, Meru South District, Kenya

Treat	Net benefit (USD)	BCR	Return to labor
Manure	542	2.9	3.6
Manure + 30 kg N ha^{-1}	938.8	2.5	3.1
Tithonia	304.3	1.8	2.1
Tithonia + 30 kg N ha^{-1}	795	2.2	2.8
Calliandra + 30 kg N ha^{-1}	337.4	1.2	1.3
Leucaena + 30 kg N ha^{-1}	462	1.8	2.1
Fertilizer @ 60 kg N ha^{-1}	360	1.3	2.7
Control	63.3	0.6	−0.2
LSD	96	0.4	0.5

manure plus fertilizer (41%) followed by sole fertilizer (24%). These were also the technologies being used on the largest land sizes of 487 and 625 m^2, respectively (Table 6).

During 2002 SR, the trend observed in 2002 LR changed and majority of the farmers during this season were using manure plus fertilizer (47%) followed by tithonia + fertilizer (27%). During this

Table 6 Number of farmers using the different soil fertility replenishment inputs and their land sizes during 2002 LR, 2002 SR and 2004 LR seasons at Chuka, Meru south district, Kenya

Technology	Percentage (%)[a]			Land size (m^2)		
	2002 LR	2002 SR	2004 LR	2002 LR	2002 SR	2004 LR
Calliandra alone	8	4	20	44	38	55
Calliandra + fertilizer	8	18	16	26	36	61
Leucaena alone	4	–	10	63	None	86
Leucaena + fertilizer	8	14	18	23	29	64
Mucuna alone	6	4	12	24	28	30
Mucuna + fertilizer	10	10	31	76	26	90
Crotalaria alone	4	6	–	29	24	–
Crotalaria + fertilizer	2	16	6	27	30	30
Manure alone	12	20	31	109	388	303
Manure + fertilizer	41	47	65	625	315	267
Tithonia alone	10	10	31	66	28	199
Tithonia + fertilizer	16	27	39	288	36	65
Fertilizer	24	18	33	487	229	175

[a] Percentages do not sum to 100 because farmers often practiced more than one technology

season manure alone and manure plus fertilizer were being used on the largest land sizes of 388 and 315 m^2, respectively. These were followed by fertilizer, which had 229 m^2. During 2004 LR, majority of the farmers used manure plus fertilizer and tithonia plus fertilizer with 65 and 39%, respectively (Table 6). Manure alone and manure plus fertilizer were used on the largest land sizes of 303 and 267 m^2, respectively. Though this was a reduction in land size for these technologies compared to 2002 SR, land sizes dedicated to the other technologies generally increased. For example, the area under tithonia was 28 m^2 in 2002 SR but increased to 199 m^2 in 2004 LR.

Modifications

Farmers were observed to have modified application of inputs from what was demonstrated at the mother trial. Instead of using single input application like it had been demonstrated during the trainings, farmers mixed the inputs and the number of farmers using mixtures increased over the seasons. They mainly mixed the easily available organic materials (manure and tithonia) and the herbaceous legumes. The main reason advanced by farmers for mixing the materials was that they lacked adequate materials for incorporation and that they already knew that their soil suffered from infertility and thus needed large amounts of biomass. For example, farmers indicated that they added manure or tithonia to the legumes so that the legumes would grow vigorously and provide a lot of biomass for applying into the soil during the following season. This is important, as the amount of plant nutrients supplied via organic materials is highly dependant on the quantity of the organic materials applied.

Farmers also indicated that crop performance was better in plots where the mixtures were applied compared to those that received pure organic materials. A follow-up done in 2004 LR season identified a farmer who had used combinations of organic materials in all his plots and was excited about the exceptionally good performance (Mbae M'rachi, personal communication). Though 2004 LR was a season with poor rainfall, the farmer reported getting very good yields from these plots citing maize yields to be similar to those received during a normal rainy season.

Use of organics and organic–inorganic combinations

A comparison was made on the extent of use of the four major organic inputs (leguminous trees, herbaceous legumes, manure and tithonia) introduced to farmers during the different seasons. In 2002 LR,

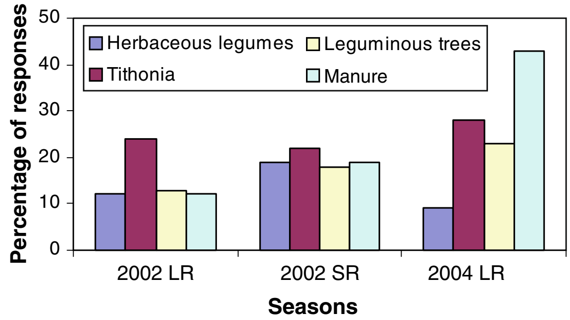

Fig. 1 Percentage of responses by farmers using the different organic materials during 2002 LR, 2002 SR, 2004 LR at Chuka, Meru south district, Kenya; *LR* Long rains, *SR* Short rains

Table 7 A comparisons of land sizes planted with applications of combinations of organic and inorganic fertilizer versus sole organic or inorganic fertilizer during 2002 LR

Treatment[a]	Mean land size (m^2)	*t*-test (*P* value)
Calliandra alone	44	0.027
Calliandra + fertilizer	26	
Mucuna alone	24	0.035
Mucuna + fertilizer	76	
Manure alone	109	0.002
Manure + fertilizer	625	
Tithonia alone	66	0.037
Tithonia + fertilizer	288	

[a] Only significant comparisons are reported

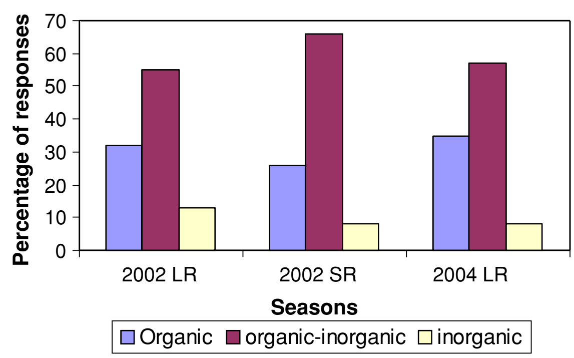

Fig. 2 Percentage of responses by farmers who had sole organic materials and organic–inorganic combinations in May 2004; *LR* Long rains**,** *SR* Short rains

tithonia was the organic material mostly used (25%) while in 2002 SR, all the organic materials were used almost equally (Fig. 1). However in 2004 LR, manure and tithonia were used the most while herbaceous legumes were used the least. Generally, the use of tithonia, leguminous trees and manure increased from 2002 LR to 2004 LR but the use of herbaceous legumes decreased. Farmers reported that the decreased use of herbaceous legumes was due to poor performance of these legumes as they produced little biomass and sometimes reduced maize yields. This is consistent with the data obtained from the trials. Farmers also reported that coiling of mucuna on maize stems could have resulted to poor maize yields in mucuna plots.

In all the seasons, organic–inorganic combinations were mostly used, while sole fertilizer was least used (Fig. 2). More than 50% of the respondents indicated that they combined the two resources because they could only afford modest amounts of fertilizer and as such supplemented with the organic materials. The main fertilizers that farmers used were diammonium phosphate (DAP) and nitrophosphate (NPK; 23:23:0 and 20:20:0) fertilizers and the amounts applied were small, supplying about 20–30 kg N ha^{-1}. The recommended rate of fertilizer rate application in this region is 60 kg N ha^{-1}.

In terms of levels of using an integration of organic and inorganic fertilizer, the results showed that farmers used organic-inorganic combinations on significantly larger plots than sole organic resources or inorganic fertilizer ($P < 0.05$). Plot sizes planted with sole mucuna, tithonia and manure were smaller than those that had these organic materials combined with inorganic fertilizer in 2002 LR (Table 7). The land sizes of other organic resources (crotalaria and leucaena) were not significantly different. However, in 2002 SR, there were no significant differences between land sizes planted with organic–inorganic combinations and sole organic resources but fertilizer was used on significantly larger plot sizes than all other resources. In 2004 LR season, treatments with mixed organic materials + inorganic fertilizer (tithonia + manure, manure + tithonia + fertilizer and mucuna + manure + fertilizer) were applied on larger plots than inorganic fertilizer ($P < 0.05$). During this season, sole application of manure and tithonia were used on significantly larger sizes than their combinations. This observation seems to be related to the general decrease in fertilizer use over the seasons as previously stated.

Farmers' continuation and addition of new technologies

Of the 31 farmers surveyed in 2002 LR, 12 (39%) wished to add new technologies during the following season (2002 SR). Of the 12 farmers, majority (92%) wanted to have leguminous shrubs followed by *Tithonia diversifolia* possibly because of the good yields they had observed at the demonstration site and on the farms. During the 2002 LR, 26 out of the 31 farmers wished to continue with all the technologies they had while only five wished to drop some of the technologies such use of crotalaria and fertilizer.

During 2004 LR season, 14 out of the 49 farmers (29%) mentioned that they wished to drop some of the technologies. Of these 14 farmers, 6 (43%) wished to drop crotalaria while 36% wished to drop mucuna mainly because of poor performance and future availability of seed. However, in case of mucuna, farmers also reported that they wished to discontinue its use because it adversely affected maize yields by coiling on the maize stems since the two were intercropped. Only a few, 3 out of the 14 (21%) wished to drop tithonia and calliandra citing problems of unavailability of adequate amounts of biomass.

Planting of trees for biomass production

Thirty (30) out of the 31 farmers surveyed were found to have planted calliandra, tithonia and leucaena during 2002 LR and 2002 SR mainly for producing biomass. They had obtained planting materials from on-farm nurseries that were initiated in 2000. Different niches were adopted for planting these shrubs, with majority of the farmers planting them along terraces (61%), 52% planted around homesteads while 23% planted them in the cropland. The farmers had used block, single and double row planting arrangements with majority (65%) adopting the double row arrangement followed by single row arrangement (51%). The number of trees planted by individual farmers was variable among the species and between the two seasons. The number of farmers planting each of the species and the number of trees planted were less in 2002 LR (48 trees per farmer) compared to 2002 SR (59 trees per farmer). In addition, a significantly higher number of calliandra and leucaena than tithonia was planted during the two seasons, with 131, 139 and 51 trees per farmer, respectively. Farmers indicated that they preferred planting calliandra and leucaena more than tithonia because tithonia could easily be found along the roadside while calliandra and leucaena were new species in the area.

More than 50% of the farmers had started using the trees during 2002 LR and 2002 SR. Tithonia was solely used for applying into the soil while the leguminous trees were used for both fodder and for soil fertility improvement through direct application of prunings harvested from the trees into the soil. However, more than 80% of the farmers used them for fodder while only about 20% used them for soil fertility improvement by incorporating fresh prunings into the soil. During the survey, farmers were asked if they were planning to plant more trees in future. Farmers indicated that they planned to continue planting more trees for biomass production. Majority of the farmers (62%) planned to plant all the three species, i.e., calliandra, leucaena and tithonia during the following season. This was encouraging because it showed interest of farmers to continue implementing the technologies.

Benefits, constraints and copping strategies

Farmers reported that they received several benefits from the new soil fertility replenishment inputs (Table 8). During 2002 LR increased maize yields was cited by majority of the farmers (97%) while in 2002 SR, increased yields, improved animal health and increased soil fertility was cited by majority of the farmers. This scenario changed in 2004 LR with more farmers citing benefits of soil improvement, which included improved soil structure (23%) and improved soil fertility (36%; Table 8). However, farmers experienced a wide range of problems while using the inputs. A total of 42 (86%) farmers out of the farmers surveyed during 2004 LR reported experiencing problems. The most commonly cited problems by those farmers using the organic materials (tithonia, calliandra, leucaena and herbaceous legumes) were high labor demand (>60%) and scarcity of biomass for incorporation (52%). Other problems were lack of seed and presence of stalk borer, an insect pest that attacks maize. It was interesting to note that the problem of inadequate biomass, which had been cited earlier during 2002

Table 8 Benefits mentioned by farmers using the soil fertility replenishment inputs during 2002 LR, 2002 SR and 2004 LR at Chuka, Meru south District, Kenya

Benefits	Number of farmers[a]		
	2002 LR ($n = 31$)	2002 SR ($n = 31$)	2004 LR ($n = 49$)
Increased maize yields	30 (97%)	30 (97%)	47 (96%)
Increased soil fertility	8 (26%)	14 (45%)	14 (36%)
Improved animal health	6 (19%)	15 (48%)	5 (11%)
Increased milk	4 (13%)	11 (36%)	2 (4%)
Soil erosion control	None	4 (13)	5 (11%)
Moisture retention	2 (7%)	2 (7%)	None
Improved soil structure	None	None	11 (23%)
Increased fodder	6 (19%)	11(35%)	21 (45%)
Increased manure	None	None	2 (4%)
Boundary marker	None	None	2(4%)

[a] Percentages do not sum to 100 because farmers often reported more than one benefit

farmer surveys was not cited by many farmers in 2004 LR as expected possibly because farmers had planted trees on the farms for producing biomass. Farmers addressed the labor constraint by hiring labor (26%), early land preparation (24%), planting materials on the farm (21%), and application of organic materials without chopping (14%).

Discussions

Biophysical performance

The consistently high maize yields recorded in treatments with cattle manure, tithonia, calliandra and leucaena prunings either alone or in combination with fertilizer was attributed to high amounts of nutrients that were availed by these inputs for maize growth. This implies that use of these resources by farmers is an effective strategy of increasing maize production in the area. Several studies have shown large maize yield responses with application of tithonia, calliandra and leucaena biomass. For example, in Western Kenya, yield increase of up-to 200% was reported following application of tithonia biomass (Gachengo et al. 1999), while in central Kenya increases in maize with application of tithonia, calliandra and leucaena biomass has been reported (Mugendi et al. 1999; Kimetu et al. 2004). Studies from other parts of Africa have also reported increased maize yields following incorporation of tithonia biomass (Ganunga et al. 1998). The large responses in increasing maize yields upon application of these organic materials into the soil is attributed to the fact that they contain high amounts of nutrients especially N, as well as other nutrients such as phosphorus (P), potassium (K), and magnesium (Mg) that are released upon their (organic materials) decomposition.

One of the major reasons advanced for the low maize yields in herbaceous legumes treatments was low biomass production, as reported by farmers, consequently contributing low amounts of N and other nutrients. A similar observation was made by Mugwe (2007) in an on-station experiment who reported low biomass production in the range of 0.2–2.8 t ha^{-1} hence contributing less than 60 g N ha^{-1} (the recommended application rate for the area). This observation, however, does not agree with other studies that have reported high biomass production by herbaceous legumes (Dyck 1997). The low biomass production in the current study could mainly be attributed to rainfall distribution. The study area is sub-humid and during the study period, the total rainfall received in 2002 LR and SR was 858.1 and 790.1 mm, respectively, while in 2003 LR and SR a total of 840.1 and 241.4 mm was recorded, respectively, (Mugwe 2007). In all the four seasons, the rainy period was about 3 months, and therefore inadequate rainfall could have been responsible for poor establishment and increased competition with crops. In other areas that receive rain for longer periods, this could not be a limiting factor. Other authors, for example, Baijukya (2004) and Kaizzi et al. (2006) reported low biomass production to be responsible for reduced maize yields in mucuna intercropping treatments.

However, the observed increases in maize yield with application of herbaceous legumes compared with the control demonstrate that the legumes made a significant contribution to maize production. Farmers would therefore benefit by incorporating these legumes in the farming systems as an option to their subsistence farming systems where farmers crop their farms without any inputs.

The high yields recorded from treatments where farmers' mixed the organic inputs, is attributed to increased availability of plant nutrients supplied by the incorporated biomass. Quantity of the organic materials applied influences the amounts of nutrients supplied and therefore lack of adequate materials is one of the factors that could limit use of organic materials to improve soil fertility on the smallholder farms. Palm et al. (1997) reported similar observations and it would therefore be important to search for ways of increasing biomass on the farms.

Information on farmers' strategy of mixing the organic inputs is an output that was obtained in Type 3 trials where farmers have a free hand. This confirms the complementary nature of these trials and the important role they play in providing information about farmers' perceptions, preferences and feedbacks. Modifications of agricultural technologies have been reported by other authors (Adesina et al. 1999; Pisanelli et al. 2000). Adesina et al. (1999) argue that farmers make modifications to fit their managerial and production systems. Other observations show that farmers do not usually adopt technologies as a package but adopt certain principles of the package while modifying particular components or management inputs. These modifications could lead to a final technological package for a farmer that is adopted easily as it is technically feasible, profitable and acceptable to farmers (Franzel et al. 2002).

Economic returns

The higher profitability of manure plus fertilizer and tithonia plus fertilizer compared to all the other treatments was attributable to high maize grain yields (see Table 3, yields for 2003 LR when economic analysis was assessed). The high BCR and return to labor from manure is similarly attributed to high yields and lower labor costs especially compared to the other organic materials used in this study that had to be cut and processed before application to the soil. Manure is locally available on the farms thus less costs associated with its collection and transportation. These results also demonstrate that the use of manure + fertilizer and tithonia + fertilizer would improve the efficiency of labor used. This is because in combinations, little organic materials are used to supply the 60 kg N ha^{-1} required compared to sole application. The findings concur with those reported by other authors. For instance, in Western Kenya, tithonia + fertilizer and manure + fertilizer treatments yielded the highest BCR of 1.08 and 1.04, respectively, (Kipsat et al. 2004). The positive economic returns portrays the importance of encouraging use of the combinations to enhance crop productivity.

In this study labor costs (data not shown) formed a major part of the total variable costs in the use of organic resources. These arose from the additional labor required for cutting, transporting, chopping and applying the organics inputs. This findings are consistent with those of Jama et al. (1997), in Western Kenya, who reported lower added costs in mineral fertilizer than calliandra (biomass transfer) reflecting the high labor requirements for biomass transfer systems. High labor costs associated with biomass transfer technologies involving trees has also been reported elsewhere (Mafongoya et al. 2003). However, the high labor demand by tithonia contradicts its preference among farmers in the current study. Explanation for this is that the farmers did not consider tithonia treatment costly because of low valuation of their time and labor and the inability to assign a market value for tithonia.

Feasibility and acceptability

Manure plus fertilizer and tithonia plus fertilizer were the inputs that were found to be the most financially and socially profitable options. In addition, these treatments gave high yields and explain the high preference by farmers whose priority is to increase crop yields. These findings demonstrate the need to integrate organic and inorganic soil fertility management inputs to obtain economically viable options. Apart from the immediate benefits of increased yields, the organic resources have additional benefits, such as, supply a balanced form of nutrients relative to inorganic fertilizers, they are more environmentally friendly and provide long term effects to the soil, for example, soil organic matter build up (Palm et al. 1997). However, inorganic fertilizers, which are a more concentrated form of nutrients, are expensive, thus more difficult for farmers to access and they cannot maintain fertility over the long run. The strategy of integration will create synergy and therefore boost crop yields as well as improve soil properties necessary for enhancing nutrient availability.

The decision by farmers to use manure and tithonia or their combinations with inorganic fertilizer on larger plot sizes than the other resources (mucuna, crotalaria, calliandra, leucaena) could further be explained by the easy accessibility of these materials and the high yields obtained from plots that had these inputs applied. Livestock keeping for milk and manure production is a major enterprise in this region and therefore manure is easily available. Tithonia, on the other hand, is found growing along roadsides. Conversely, technologies involving calliandra, leucaena and the herbaceous legumes required extra effort to acquire them. The calliandra and leucaena needed to be planted and also faced a major challenge of competition with livestock. There was evidence of continued interest in planting and usage as revealed by the number of trees planted in each of the seasons. Indeed, their usage increased over the seasons as farmers continued planting calliandra and leucaena trees for biomass production. This demonstrates the need for institutional support in provision of germplasm if adoption is to be enhanced.

The seeds of herbaceous legumes (mucuna and crotalaria) had to be ordered from researchers a few days before planting time. During the study period, farmers were not able to produce own seed and always relied on supplies from the researchers. Production of own seed is a critical issue in adoption of herbaceous legumes because they need to be planted every season. This aspect was not covered in this study and experience showed that in exploring adoption potential strategies to make materials available needed to have incorporated issues of sustainable seed production by farmers. Seed availability has been reported to be a major constraint to adoption of herbaceous legumes (Odendo et al. 2006).

Apart from poor biophysical performance, socioeconomic factors could explain the low preference of the herbaceous legumes among the farmers. Experiences with projects introducing green manure report that farmers are motivated by the potential of the green manures to offer multiple benefits, such as food value and ability to smother weeds, and therefore farmers will seldom choose them purely for soil fertility improvement (Bunch 2003). In this region, where intercropping of common bean (*Phaseolus vulgaris)* is common, more benefits of using herbaceous legumes compared to the common bean will probably need to be demonstrated to motivate the farmers.

The multiple benefits obtained from the leguminous trees could be major drivers of their increased and continued adoption. The benefit of fodder and improved animal health cited by farmers was from the leguminous trees (*C. calothyrsus* and *L. trichandra*). Farmers preferred to use pruning harvested from these trees to feed their animals instead of applying the prunings directly into the soil, and possibly was the reason why farmers cited lack of adequate biomass for applying into the soil due to competition from livestock. Use of leguminous trees and shrubs for livestock feeding rather than for direct soil fertility improvement through application of fresh prunings into the soil especially in alley farming (a technology meant for incorporation of prunings into the soil) has been reported (Jabbar et al. 1992). Similarly, Jama et al. (1997) has noted that it is more economical to feed the prunings from the fodder trees to animals than applying to the soil for fertility improvement and afterwards recycle nutrients through manure.

Conclusions and recommendations

Cattle manure and tithonia were found to be the organic materials with the highest adoption potential for soil fertility improvement. They gave the highest yields and were the most profitable. However, as the results demonstrated they should be used in combination with inorganic fertilizer thus the need for policy to focus on making inorganic fertilizer affordable to farmers. It also emerged that the farmers used cattle manure and tithonia under the largest land sizes, a confirmation that these were the superior inputs among the tested ones. They are therefore likely to receive favorable adoption by many more farmers if appropriately disseminated. The potential to increase maize yields is an implication that their adoption would increase maize production in the area and lead to food security, the primary objective of smallholder farmers.

Calliandra and leucaena, in addition, have potential for use as fodder. Majority (80%) used these tree legumes for feeding livestock. This practice implies that soil improvement would be indirect through recycling of the manure. Planting of these trees by farmers showed an increasing trend and potential for continued planting. The herbaceous legumes seem to have the least adoption potential and showed low preference among farmers. The low preference was mainly associated with dismal biophysical performance in these sub-humid conditions, but the issue of seed availability is also critical. Farmers relied on supplies from the researchers throughout the study period and this may have created a feeling of inadequacy of seed supply among farmers.

The multiple benefits farmers accrued were a motivation for farmers to take up the use of organic inputs. Benefits of more food availability and animal fodder from the leguminous trees is likely to spur adoption since this is an area where households suffer from food insecurity and farmers value livestock keeping. Farmers experienced some problems especially lack of adequate biomass and high labor demand. The ability of the farmers to address them through various ways such as planting trees on the farms, suggests that farmers are able to cope and could therefore not be a constraint likely to severely limit adoption.

The farmers' strategy of mixing organic materials, to address the problem of low quantity of biomass available on the farms is a confirmation that availability of organic resources is limited and there is need to search for ways of increasing efficiency of utilising them. It is also an indication that farmers are interested in increasing crop production through the use of organic resources. It is also a lesson to researchers that they should facilitate the process of farmer learning, experimentation and practices controlled by farmers as this process is likely to generate additional information. The role of researchers in this process is to continuously monitor and assess how farmers continue using the technologies so as to identify ways of enhancing diffusion of the technologies to other farmers.

A lesson emanating from this study is that even with the design to avail all the inputs, some farmers may experience shortages, due to the variation in the way the inputs are availed and their production mode. Therefore, in assessing adoption potential this is one critical area that would need to be monitored and addressed during the implementation period. This study also demonstrated that increased adoption of organic resources need institutional support to provide germplasm sustainably.

Finally, emphasis on the following elements can help promote success in technology development and adoption of the tested organic materials in the study site and other similar areas. First, the adoption of newly introduced organic resources for sustainable crop production is likely to depend upon policy environment. The integrated approach of combining organics and inorganic fertilizer will need a policy intervention that would make fertilizers more affordable to farmers. In addition, for leguminous trees and herbaceous legumes, a germplam policy focusing at enhancing sustainable supply and efficient distribution network is critical. For example, institutional support to develop a local farmer-managed legume seed production system to enable farmer's access seed easily. Secondly, the study confirms the importance of participatory approaches in development of technologies for soil fertility management and the complementary role of on-farm trials. While the Type 2 trial (researcher designed and farmer managed) was useful for biophysical and economic analysis, the Type 3 trial (farmer designed and managed) proved very useful for assessing farmers' experiences and their modification because they managed the inputs as they wished. Thirdly, continuous monitoring of farmers especially during the growing season generates information that would otherwise be lost if done only at the end of the season. Fourthly, the issue of increasing biomass on farms deserves attention and future research strategies should explore ways of increasing biomass on the farms, through identification of spatial and temporal niches in the farming systems, as well as strategies for reducing labor demand. For the herbaceous legumes, a more in-depth investigation is required to assess competitive demand for the legumes during the intercropping phase inorder to develop appropriate timing regimes.

Acknowledgments Financial support for work was provided by the Bentley Fellowship and the Rockefeller Foundation. We also appreciate the contributions of collaborators from the Kenya Agricultural Research Institute, Kenya Forestry Research Institute, Kenyatta University and the African Network (AfNet) of Tropical Soil Biology and Fertility Programme (TSBF). The cooperation of farmers who participated in this study is highly appreciated.

References

Adesina AA, Chianu J (2002) Determinants of farmers' adoption and adaptation of alley farming technology in Nigeria. Agrofor Syst 55:99–112. doi:10.1023/A:1020556132073

Adesina AA, Coulibaly D, Manyong VM, Sanginga PC, Mbila D, Chianu J, Kamleu G (1999) Policy shifts and adoption of alley farming in West and central Africa. IITA and Meg Communication, Ibadan

Baijukya FP (2004) Adapting to change in banana-based farming systems of northwest Tanzania: the potential role of herbaceous legumes. PhD thesis, Wageningen University, Wageningen, The Netherlands

Bationo A, Kimetu J, Ikeera S, Kimani S, Mugendi D, Odendo M, Silver M, Swift MJ, Sanginga N (2004) The African network for soil biology and fertility: new challenges and opportunities. In: Bationo A (ed) Managing nutrient cycles to sustain soil fertility in sub-Saharan Africa. Academy Science Publishers and Tropical soil Biology and Fertility Institute of CIAT, Nairobi, pp 1–23

Bunch R (2003) Adoption of green manure and cover crops. LEISA Magazine, December 2003

CIMMYT (1988) From agronomic data to farmer recommendations: an economics training manual. Completely revised edition. International Maize and Wheat Improvement Centre (CIMMYT), Mexico

Dyck E (1997) Screening legumes for potential soil productivity improvement in Kenya: Kenyan legume research network. In: Proceedings of a conference on Green Manure Cover Crops in Santa Catarrina, Brazil, 6–12 April, 1997

Franzel S, Scherr SJ, Coe R, Cooper PJM, Place F (2002) Methods for assessing agroforestry adoption potential. In: Franzel S, Sherr SJ (eds) Trees on the farm: assessing the adoption potential of agroforestry practices in Africa. CAB International, Wallingford, pp 11–36

Gachengo CN, Palm CA, Jama B, Othieno C (1999) Tithonia and senna green manures and inorganic fertilizers as phosphorus sources for maize in western Kenya. Agrofor Syst 44:21–36. doi:10.1023/A:1006123404071

Ganunga R, Terokun O, Kumwenda JD (1998) *Tithonia diversifolia*: an organic source of nitrogen and phosphorus for maize in Malawi. In: Waddington SR (ed) Grain legumes and green manures for soil fertility in Southern Africa: taking stock of progress. Proceedings of a conference (8–11 October, 2002) Leopard Rock Hotel, Vumba, Zimbabwe. Soil fertility Network and CIMMYT-Zimbabwe, Harare, pp 191–194

Garrity DP (2004) Agroforestry and the achievement of the millennium development goals. In: Nair PKR, Rao MR, Buck LE (eds) New vistas in agroforestry: a compendium for the 1st world congress of agroforestry, 2004. Kluwer Academic Publishers, Netherlands, pp 5–17

Haggblade H, Tembo G, Donovan C (2004). Household level financial incentives to adoption of conservation agricultural technologies in Africa. Working Paper No. 9, Food Security Research project, Michigan State University, East Lansing, Michigan, USA

Jabbar MA, Cobbina J, Reynolds B (1992) Optimum fodder mulch allocation of tree foliage under alley farming in South West Nigeria. Agrofor Syst 20:187–198. doi:10.1007/BF00053138

Jaetzold R, Schmidt H, Hornet ZB, Shisanya CA (2006) Farm management handbook of Kenya. Natural conditions and farm information, vol 11/C, 2nd edn. Ministry of agriculture/GTZ, Nairobi (Eastern Province)

Jama BA, Buresh RJ, Ndufa JK, Shepherd KD (1997) Agronomic and economic evaluation of organic and inorganic sources of phosphorus in western Kenya. Agron J 89:597–604

Jama B, Palm CA, Buresh RJ, Niang A, Gachengo C, Nziguheba G, Amadalo B (2000) *Tithonia diversifolia* as a green manure for soil fertility improvement in western Kenya: a review. Agrofor Syst 49:201–221. doi:10.1023/A:1006339025728

Kaizzi CK, Ssali H, Vlek PLG (2006) Differential use and benefits of velvet bean (*Mucuna pruriens* Var. utilis) and N fertilizer in maize production in contrasting agro-ecological zones of East Uganda. Agric Syst 88:44–60. doi:10.1016/j.agsy.2005.06.003

Keil A, Zeller M, Franzel S (2005) Improved tree fallows in smallholder maize production in Zambia: do initial testers adopt the technology? Agrofor Syst 64:225–236. doi:10.1007/s10457-004-2410-0

Kimetu JM, Mugendi DN, Palm CA, Mutuo PK, Gachengo CN, Bationo A, Nandwa S, Kungu J (2004) Nitrogen fertilizer equivalencies by organics of differing quantity and optimum combinations with organic nitrogen source in central Kenya. Nutr Cycl Agroecosyst 68:127–135. doi:10.1023/B:FRES.0000019043.33580.a6

Kipsat MJ, Maritim HK, Okalebo JR (2004) Economic analysis of non-conventional fertilizers in Vihiga district, western Kenya. In: Bationo A (ed) Managing nutrient cycles to sustain soil fertility in sub-Saharan Africa. TSBF-CIAT, Academy Publishers, Nairobi, pp 535–544

Lapar MLA, Ehui SK (2004) Factors affecting adoption of dual-purpose forages in the Philippines uplands. Agric Syst 81:95–114

Mafongoya PL, Bationo A, Kihara J, Waswa BS (2006) Approriate technologies to replenish soil fertility in Southern Africa. Nutr Cycl Agroecosyst 76:127–151

Mafonyoya PL, Mugendi DN, Jama B, Waswa BS (2003) Maize based cropping system in the sub-Saharan Zone of East and southern Africa. In: Gichuru MP, Bationo A, Bekunda MA, Goma HC, Mafongoya PL, Mugendi DN, Murwira HM, Nandwa SM, Nyathi, Swift MJ (eds) Soil fertility management in africa: a regional perspective. Academy Science Publishers, African Academy of Sciences, Nairobi, pp 73–122

Mercer DE (2004) Adoption of agroforestry innovations in the tropics: a review. Agrofor Syst 2044111:311–328. doi:10.1023/B:AGFO.0000029007.85754.70

Minae S, Nyamai D (1988) Agroforestry research proposal for the coffee based land use system in the bimodal highlands of central and eastern provinces, Kenya. AFRENA report No. 16. International Centre for Research in Agroforestry (ICRAF). Nairobi

Mugendi DN, Nair PKR, Mugwe JN, O'Neill MK, Woomer P (1999) Alley cropping of maize with calliandra and leucaena in the subhumid highlands of Kenya. Part 1: soil fertility changes and maize yield. Agrofor Syst 46:39–50. doi:10.1023/A:1006288301044

Mugwe JN (2007) An evaluation of integrated soil fertility management practices in Meru South District, Kenya. PhD thesis, Department of Environmental Sciences, Kenyatta University

Mugwe JN, Kung'u JB (2006) Promotion of leguminous trees for soil fertility management through group tree nurseries in the central highlands of Kenya. In: Mugendi DN, Mucheru M (eds) FARM Africa technical MATF end of year 2 report. Kenyatta University, Kenya

Murithi FM, Thijssen HJC, Mugendi DN, Mwangi JN, O'Neill MK, Nyaata OZ (1994) Report of a survey on Agroforestry technologies used for fodder production and soil fertility improvement in Meru District, Kenya. National Agroforestry Research Project. Regional Research Centre, Embu

Mutsaers HJW, Weber GK, Walker P, Fischer M (1997) A guide for on-farm experimetation. IITA/CT/ISNAR

Odendo M, Ojiem J, Bationo A, Mudeheri M (2006) On-farm evaluation and scaling up of soil fertility management technologies in Western Kenya. Nutr Cycl Agroecosyst 76:369–381. doi:10.1007/s10705-006-9060-8

Palm CA, Myers RJK, Nandwa SM (1997) Organic–inorganic nutrient interactions in soil fertility replenishment. In: Buresh RJ, Sanchez PA, Calhoun F (eds) Replenishing soil fertility in Africa. Science Society of America Special (SSSA) Publication 51: Soil Science Society of America, Madison, pp 193–217

Pisanelli A, Franzel S, Dewolf J, Rommelse R, Poole J (2000) Adoption of improved tree fallows in Western Kenya. Farmer practices, knowledge and perception. International Centre for Research in Agroforestry (ICRAF) (WAC), Nairobi

Riugu G, Schluter M, Kimuyu P (1985) A review of the fertilizer import allocation and pricing system. Nairobi Chemical Engineering Consultants. Fertilizer infrastructure improvement support. Report No. 9

Smaling EMA, Nandwa SM, Hanssen BH (1997). Soil fertility is at stake. In: Buresh RJ, Sanchez PA, Calhoun F(eds) Replenishing soil fertility in Africa. SSSA. Special Publication No. 51, Soil Science Society of America, Madison. pp 47–62

Snapp S, Kanyama-Phiri G, Kamanga B, Gilberts R, Wellard K (2002) Farmer and researcher partnerships in Malawi: developing soil fertility technologies for the near term and far-term. Exp Agric 38:411–431. doi:10.1017/S0014479702000443

Soil Science Society of East Africa (SSSEA) 2003. In: Mureithi JC, Macharia P, Gichuru M, Mburu M, Mugendi D, Gachene CNN (eds) Proceedings of the 18th conference and end of the millennium celebrations. Sustainable use for land resources to alleviate poverty in the new millennium. Soil Science Society of East Africa Conference (SSSEA) 4–8 December 2000, Mombasa, Kenya, pp 17–26

Stern RD, Coe R, Allan EF, Dale IC (2004) Good statistical practice for natural resources research. CAB International, Wallingford

Stround A (1993) Conducting on-farm experiments. Publication No. 228. Centro Internacional de Agricultura Tropical (CIAT), Cali, Colombia

Vanlauwe B, Diels J, Aihou K, Iwuafor ENO, Lyasse O, Sanginga N, Merckx R (2002) Direct interactions between N fertilizer and organic matter: evidence from trials with ^{15}N-labelled fertilizer. In: Vanlauwe B, Diels J, Sanginga N, Merckx R (eds) Integrated plant nutrient management in sub-Saharan Africa: from concept to practice. CAB International Wallingford, Oxon