Improving food production using 'best bet' soil fertility technologies in the Central highlands of Kenya

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Abstract

Declining crop productivity is a major challenge facing smallholder farmers in central highlands of Kenya. This decline is caused by continuous cultivation of soils without adequate addition of external inputs in form of manures and fertilizers. With this background, an on-station trial was initiated at Embu in 1992 to evaluate the feasibility of using two leguminous shrubs; *Calliandra calothyrsus* and *Leucaena leucocephala* for improving food production. In 2000, an off-station farmers' participatory trial aimed at offering farmers soil enhancing technologies for replenishing soil fertility was established in Meru South District. The results from the Embu on-station trial indicate that, over the 11 years of study, calliandra and leucaena biomass transfer with half recommended rate of inorganic fertilizer treatments gave the best average maize grain yields of 3.3 Mg ha^{-1}. Treatment where calliandra was alley cropped with maize but the prunings removed recorded the lowest maize yield of 1.2 Mg ha^{-1}. Treatments with calliandra and leucana biomass transfer had similar yields but treatments that were alley cropped with leucaena did better than those that were alley cropped with calliandra. On the other hand, results from the off-station trial in Meru South indicate that, on average, across the seven seasons, sole tithonia gave the highest maize grain yield followed closely by tithonia with half recommended rate of inorganic fertilizer with 6.4 and 6.3 Mg ha^{-1} respectively. Control gave the lowest yield of 2.2 Mg ha^{-1} across the seasons. On average, integration of organic an inorganic sources of nutrients gave higher yields compared to all the other treatments.

Key words: Leucaena, Calliandra, Herbaceous legumes, Tithonia, Farmers, Cattle manure

Introduction

The Central highlands of Kenya are densely populated with more than 700 persons km^{-2} (Government of Kenya, 2001) and declining land productivity with reduced crop yields has been a major challenge facing smallholder farmers in the region. Declining land productivity is as a result of soil impoverishment caused by continuous cropping without addition of adequate external inputs, and soil erosion on steep slopes (Minae and Nyamai, 1988). Land sizes are small, averaging 1.2 ha, leading to continuous cropping with limited scope for crop rotation and inadequate soil fertility replenishment. For instance, the use of inorganic fertilizers is as low as less than 20 kg N and 10 kg P ha^{-1} (Murithi et al., 1994). The amount is inadequate (below the recommended level of 60 kg N ha^{-1}), to meet the crop nutrient requirement for optimum crop productivity in the area. Kihanda (1996) observed that less than 25% maize growers in the central highlands of Kenya use inorganic fertilizers. Wokabi (1994) reported that, though high yielding maize varieties have been developed with

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yield potentials of 7–12 Mg ha^{-1}, maize yields at the farm level hardly exceed 1.5 Mg ha^{-1}.

Research work by Gachengo (1996), Kihanda (1996), Gitari et al. (1997), Mugendi et al. (1999), Mutuo et al. (2000) and Nziguheba and Mutuo (2000) reported positive results from use of biomass from mucuna, crotalaria, manure, tithonia, calliandra and leucaena for soil fertility improvement in Kenyan highlands. These organic inputs are important components in soil fertility replenishment and hence need to be evaluated on-farm by farmers. An on-station trial was established in Embu in 1992 to evaluate the performance of calliandra and leucaena on soil fertility replenishment. In 2000 a multidisciplinary participatory trial was established in Meru South District to bring feasible soil nutrient replenishment technologies to the smallholder resource poor farmers.

Materials and methods

Study area

The on-station trial was located at the Kenya Agricultural Research Institute Regional Centre (Embu), in the central highlands of Kenya. The site is characterized by a bimodal rainfall distribution, which ranges from 1200 mm to 1500 mm per annum. The soils are commonly known as "Kikuyu Red Clay Loams". They are extremely deep (> 2m), well drained, with moderate structure (Mwangi, 1997). They are derived from rich, basic volcanic rocks and have been classified as Humic Nitisols (Jaetzold and Schmidt, 1983).

The off-station trial was conducted in Meru South District, an area classified as upper midlands 2 and 3 (UM2 and UM3) according to Jaetzold and Schimdt (1983) with an altitude of approximately 1500 m above sea level. The annual mean temperature is 20°C and annual rainfall varies from 1200 to 1500 mm. The soils are Humic Nitisols (Jaetzold and Schmidt, 1983), which are deep, well weathered with moderate to high inherent fertility. The rainfall is bimodal, falling in two seasons, the long rains (LR) lasting from March through June and short rains (SR) from October through December.

Experimental layout

The on-station experiment was initiated in 1992 at the Embu Regional Research Centre as a randomized complete block design with four replicates. The plot dimensions were 9×10 m while the sample plot was 6×4.5 m. The test crop was maize (*Zea mays* L, var. H511). In six of these treatments fresh leaf prunings of tree species (*Leucaena leucocephala* and *Calliandra calothyrsus*) were applied, the prunings being obtained from hedgerows grown in situ (alley-cropped) or ex-situ (cut and carry) from other sources. The treatment structure was as follows;

1) Calliandra alley crop; prunings incorporated
2) Leucaena alley crop; prunings incorporated
3) Calliandra alley crop; prunings not incorporated
4) Leucaena alley crop; prunings not incorporated
5) Calliandra prunings + no fertilizer
6) Leucaena prunings + no fertilizer
7) Calliandra prunings + fertilizer (25 kg N ha^{-1})
8) Leucaena prunings + fertilizer (25 kg N ha^{-1})
9) With fertilizer (50 kg N ha^{-1})
10) Without fertilizer

Lopping of calliandra and leucaena tree hedges was done at a height of 50 cm one to two days before maize planting. Leafy biomass and succulent stems were separated from woody stems and each weighed separately. The leafy biomass was evenly spread on the ground in the treatments designated to receive prunings (Treatment 1, 2, 5, 6, 7, and 8) and soil-incorporated by hand hoes as the land was prepared for maize planting. Sub-samples were collected for N content determination before the prunings were incorporated into the soil. Leafy biomass applied in treatments 7 and 8 (that received prunings from outside the experimental plots-biomass transfer) were obtained from block plantings of calliandra and leucaena hedges established near the site. These treatments received average biomass (dry matter basis) of 2 and 1 Mg ha^{-1} for calliandra and leucaena biomass containing approximately 60 and 30 kg N ha^{-1} season^{-1} respectively. Treatment 9 received the recommended level of inorganic fertilizer of 50 kg N ha^{-1} (FURP, 1987) as calcium ammonium nitrate while treatments 7 & 8 received half of the recommended rate (30 kg N ha^{-1}) (to approximate the lower levels commonly applied by most farmers in the area). Application was through top dressing in two doses; the first dose (one-third of the full dose) four weeks after maize germination and the second (two-thirds), four weeks later.

The off-station trial was established in March 2000 in Meru South on a farm with poor and impoverished soils and laid out as a randomised complete block design

Table 1. Soil fertility replenishment technologies under experimentation in Meru south District, Kenya.

No	Treatment	Amount of N supplied (kg ha^{-1})	
		Organic	Inorganic
1	Mucuna pruriens alone	–	–
2	Mucuna + 30 kg N ha^{-1}	–	30
3	Crotalaria ochroleuca alone	–	–
4	Crotalaria + 30 kg N ha^{-1}	–	30
5	Cattle manure	60	–
6	Cattle manure + 30 kg N ha^{-1}	30	30
7	Tithonia diversifolia	60	–
8	Tithonia + 30 kg N ha^{-1}	30	30
9	Calliandra calothrysus	60	–
10	Calliandra + 30 kg N ha^{-1}	30	30
11	Leucaena trichandra	60	–
12	Leucaena + 30 kg N ha^{-1}	30	30
13	Recommended rate of fertilizer	–	60
14	Control (No inputs)	–	–

(RCBD) with three replicates. The trial was researcher-designed and managed, and the test crop was maize (*Zea mays* L, var. H513). Thirteen external soil fertility amendment inputs (technologies) were applied to give an equivalent amount of 60 kg N ha^{-1} except for the herbaceous legume treatments where the N quantity was determined by the amount of biomass harvested and incorporated in the respective treatments (Table 1). The fourteenth technology was the absolute control.

The herbaceous legumes were intercropped between two maize rows one week after planting maize. The legumes were left in the field after harvesting the maize until the start of the following season when they were cut, weighed, chopped and applied into the soil. The other organic materials (biomass transfer) were incorporated into the soil to a depth of 15 cm during land preparation. Compound fertilizer (23:23:0) was the source of N and was applied during sowing. Agronomic procedures for maize production were appropriately followed during all the seasons. At harvesting maize grain yield was determined.

Farmers' field days were held at the grain filling stage during each season where the farmers toured the experimental plots. The technologies used were described and farmers evaluated the various technologies and exchanged views about the different technologies. The farmers were then requested to select the technologies they wanted to take to their farms. Eventually, starting with the SR 2001, farmers started trying out some of the promising technologies in their own farms. The farmers applied the organic inputs as explained during the field days though some of them adapted the technologies to fit their socio-economic status. During harvesting, at the end of each growing season, maize grain yields and moisture content were determined.

All data on maize grain yields was subjected to analysis of variance (ANOVA) using Genstat and the means separated using LSD at 5% probability level.

Results and discussions

On-station trial (maize grain yield)

The average maize grain yields obtained in the on-station trial at Embu indicated that maize monocrop with prunings + 30 Kg N ha^{-1} gave the highest yields of 3.3 Mg ha^{-1} followed by maize monocrop + prunings, which gave 2.9 Mg ha^{-1} (Table 2). Calliandra with prunings removed gave the lowest yields (1.2 Mg ha^{-1}) followed by leucaena with prunings removed and control with 1.8 and 1.7 Mg ha^{-1} respectively. Leucaena alley cropped treatment with prunings incorporated (Treatment 2) gave better yields (2.8 Mg ha^{-1}) than the recommended fertilizer treatment (2.5 Mg ha^{-1}), whereas the equivalent calliandra treatment (Treatment 1) performed poorer than the fertilizer treatment by recording an average yield of 2.1 Mg ha^{-1}. It was further observed that all leucaena alley cropped treatments (with or without prunings incorporated) produced higher maize yields compared to similar calliandra alley cropped treatments.

These results concur with findings of Mafongoya and Nair (1997) and Mugendi et al. (1999) who reported significant maize yield increases following application of green manure. The leafy prunings incorporated into the soil (as green manure) at the beginning of the season decomposed and released nutrients especially nitrogen, which enhanced crop performance (Mugendi et al., 1999).

Treatments with prunings incorporated with fertilizer gave better maize grain yields compared to treatments with only prunings applied. This could be due to improved synchrony between nutrient release and uptake (Sanchez and Jama, 2002). Kapkiyai et al. (1998) reported that combination of organic and inorganic nutrient sources has been shown to result into synergy and improved synchronization of nutrient release and uptake by plants (leading to higher yields). Tian et al. (1993) reported that nutrient uptake and grain yield of the crop was higher when nitrogen was partially

Table 2. Mean maize grain yield (Mg ha^{-1}) from 1993 – 2003 seasons from various treatments at Embu, Kenya.

TRT	LR 93	SR 93	LR 94	SR 94	LR 95	SR 95	LR 96	LR 97	SR 97	LR 98	SR 98	SR 99	SR 00	SR 01	LR 02	SR 02	LR 03	SR 03	Mean
1	2.4	0.1	0.3	3.2	3.4	2.4	2.0	2.3	4.3	2.7	0.7	2.7	2.5	1.5	0.8	1.8	2.7	2.9	22
2	2.2	0.2	0.2	3.8	4.4	3.9	3.6	3.1	5.0	3.8	0.6	3.9	4.2	2.5	1.3	1.9	2.6	4.1	2.9
3	1.7	0.1	0.4	1.6	1.1	1.0	1.3	1.9	3.6	1.3	0.5	1.3	1.4	1.0	0.2	0.9	1.4	1.4	1.2
4	1.5	0.2	0.5	2.7	1.8	1.7	1.5	1.7	4.6	2.2	0.7	2.0	1.7	2.6	0.4	1.7	1.9	2.3	1.8
5	1.9	0.6	0.3	3.6	4.0	4.9	3.8	3.0	4.0	2.8	1.0	3.8	3.9	3.2	1.9	3.8	2.6	3.6	2.9
6	1.6	0.3	0.9	3.3	4.2	4.7	3.9	2.5	7.1	2.7	1.2	3.1	3.5	2.9	1.4	2.8	2.9	3.2	2.9
7	2.1	0.7	2.1	3.6	2.2	5.6	4.2	2.2	7.9	3.4	0.9	3.9	4.3	3.2	1.9	3.5	3.4	4.9	3.3
8	1.8	0.3	2.5	3.2	3.1	5.0	4.0	1.8	7.5	2.6	1.1	4.4	4.6	3.3	1.9	3.6	3.2	4.6	3.3
9	1.6	0.3	3.0	3.1	3.1	3.5	3.6	2.0	4.1	2.9	0.7	2.8	2.1	2.5	1.6	2.1	2.1	4.3	2.5
10	1.4	0.2	1.1	3.0	2.8	2.0	1.8	1.9	1.8	2.3	0.6	2.4	2.2	1.8	0.8	1.6	1.5	2.2	1.7
SED	0.8	0.1	0.2	0.6	0.5	0.4	0.2	0.4	0.2	0.3	0.2	0.4	0.8	0.5	0.7	0.9	0.6	0.5	0.2

Abbreviations: SR = Short rains; LR = Long rains; TRT = Treatments; TRT 1 = Calliandra, prunings incorporated; 2 = Leucaena, prunings incorporated; 3 = Calliandra, prunings not incorporated; 4 = Leucaena, prunings not incorporated; 5 = Calliandra prunings + no fertilizer; 6 = Leucaena prunings + no fertilizer; 7 = Calliandra prunings + fertilizer (25 kg N/ha); 8 = Leucaena prunings + fertilizer (25 kg N/ha); 9 = fertilizer (50 kg N/ha); 10 = control; NB: There was a crop failure in the SR 1996, LR 1999, LR 2000 and LR 2001 seasons as a result of inadequate rainfall.

applied as prunings, indicating the importance of the combined addition of plant residue and fertilizer N for improving crop production.

Plots that received calliandra and leucaena prunings (biomass transfer), with and without fertilizer, gave identical average maize yields (Treatments 5 & 6 and 7 & 8). However, maize grain yields obtained in leucaena alley crop (with prunings incorporated or with prunings removed) treatments (Treatment 2 and 4) was significantly higher compared to calliandra alley crop (with prunings incorporated or with prunings removed) treatments (Treatment 1 and 3). This is an indication that leucaena can be used effectively in alley cropping arrangements to improve crop yields in the region (Mugendi et al., 1999; Mugwe and Mugendi, 1999). Other researchers working with calliandra have reported mixed performance. Some have reported improved crop yields (Heinneman, 1992; Rosecrance et al., 1992), while Gutteridge (1992) reported depressed or marginal yields. The poor performance of calliandra may be attributed to root morphology where root studies showed that over 95% of all maize roots were located in the top 90 cm while for calliandra and leucaena it was 60% and 25% respectively in the same depth (Mugendi et al., 2003).

Calliandra therefore competed with maize more intensely compared to leucaena whose greater percentages of roots were located below the effective rooting zone of the maize crop. Indeed, Jama et al. (1998) demonstrated that calliandra had the greatest root density in the top 15 cm of soil when compared to four other multipurpose tree species (*Eucalyptus grandis, Sesbania sesban, Markhamia lutea*, and *Grevillea robusta*) evaluated in the western highlands of Kenya.

Off-station

Table 3 shows the average maize grain yields in the different treatments across the seven seasons from the off-station trial in Meru South. The maize grain yields were significantly different ($P < 0.05$) between treatments in the seven seasons.

Sole tithonia recorded the highest maize grain yield of 6.4 Mg ha^{-1} followed closely by tithonia with half recommended rate of inorganic fertilizer (6.3 Mg ha^{-1}). The control recorded the lowest maize grain yields across the treatments and seasons with 2.2 Mg ha^{-1} followed closely by sole crotalaria with 2.6 Mg ha^{-1}(Table 2).

It was observed that in most of the seasons, the integration of organic and inorganic nutrient sources of N gave higher maize yields than all the other treatments during the seven seasons of the study. These results concur with results by Gachengo (1996), Mugendi et al. (1999), Mutuo et al. (2000) and Nziguheba and Mutuo (2000) on the integration of organic and inorganic soil fertility inputs. As noted by Vanlauwe et al. (2002), the integration of inorganic and organic nutrient inputs increases fertilizer use efficiency and provides a more balanced supply of nutrients to the crop.

Table 3. Maize yields (Mg ha^{-1}) under different technologies from 2000 to 2003 in Chuka, Meru South District, Kenya.

Treatment	Seasons Grain weight (Mg ha^{-1})							
	LR 2000	SR 2000	LR 2001	SR 2001	LR 2002	SR 2002	LR 2003	Mean
1	1.3	4.0	2.4	3.7	3.2	5.1	3.0	**3.2**
2	0.9	2.1	1.9	1.8	3.5	4.3	4.0	**2.6**
3	1.4	4.4	3.2	2.7	3.8	4.8	4.3	**3.5**
4	1.4	3.4	2.4	3.2	4.3	5.9	4.9	**3.6**
5	1.2	6.7	3.7	4.6	4.2	6.1	5.0	**5.3**
6	1.2	6.5	4.9	2.9	5.9	5.0	6.5	**5.5**
7	1.2	6.6	4.3	6.5	5.4	7.0	7.4	**6.4**
8	0.7	6.0	2.8	4.5	4.5	7.6	6.5	**5.4**
9	1.0	6.1	4.0	5.8	4.7	6.3	6.4	**5.7**
10	1.3	6.8	5.4	5.6	5.4	6.2	7.2	**6.3**
11	1.1	5.8	4.3	5.1	4.3	7.2	6.2	**5.7**
12	1.3	6.1	3.7	4.4	5.0	7.2	6.2	**5.7**
13	1.4	6.3	5.0	3.2	4.3	5.8	5.5	**5.3**
14	0.6	2.6	1.2	1.5	1.8	2.6	2.8	**2.2**
LSD	**0.2**	**0.2**	**0.4**	**0.4**	**0.3**	**0.4**	**0.5**	**0.3**

Treatment (1 = Mucuna; 2 = Crotalaria; 3 = Mucuna + ½ fert; 4 = Crotalaria + ½ fert 5 = manure; 6 = manure + ½ fert; 7 = tithonia; 8 = calliandra; 9 = leucaena; 10 = tithonia + ½ fert; 11 = calliandra + ½ fert; 12 = leucaena + ½ fert; 13 = rec fert; 14 = control).

On-farm

Farmers visiting the field days in Meru South chose some of the technologies that were demonstrated to them and started trying them out in their farms starting with the SR 2001 season. Results showed that more technologies were implemented in LR 2002 and SR 2002 than in 2001 (Table 4).

Also, maize grain increased as a result of using the introduced technologies over the seasons (Table 3). However, the yields varied significantly among treatments/technologies and across seasons. Mucuna + 30 kg N ha^{-1}, cattle manure + 30 kg N ha^{-1} and leucaena alone gave the highest yields of more than 4.5 Mg ha^{-1}during SR 2002 an indication that these are some of the technologies that could be recommended as bets bet for farmers. Generally, modifications by farmers, mainly mixing of the different organic materials, were observed to give higher yields than most of the other practices implemented by the farmers. 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 soils were low in soil fertility and thus needed large amounts of biomass. The materials mixed mainly consisted of the easily available organics (tithonia and manure) and the herbaceous legumes. 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 (Mathews et al., 1992).

These farmer innovations could hold the key to improving soil productivity in the region as farmers report inadequate biomass for incorporation into the soil as a major constraint. Akiwumi and Chinau (2002) reported modification of alley farming technology for soil fertility improvement in Nigeria and noted that farmers' innovations is what finally remain on farmers' fields as this is what best suits the farmers needs.

Impact of the introduced technologies

Farmers practicing the new technologies initially mentioned lack of sufficient biomass (tithonia, calliandra and leucaena) and finances to purchase manure and fertilizer in the required quantities as some of the constraints to adoption of the proposed soil fertility improvement technologies. However, with time they started planting trees for biomass production along fences and on terraces. They have also learnt how to manage manure more effectively. Some of the farmers have modified the technologies to fit in their

Table 4. Average on-farm maize yields (Mg ha^{-1}) under different technologies during the SR 2001, LR 2002 and SR 2002 seasons at Chuka, Meru South District.

Technology	Seasons Grain weight (Mg ha^{-1})		
	SR 2001	LR 2002	SR 2002
Mucuna	–	1.6	2.7
Crotalaria	–	0.4	2.5
Mucuna + 30 kg N ha^{-1}	2.4	1.2	5.3
Crotalaria + 30 kg N ha^{-1}	3.3	4.5	
Cattle manure	0.3	2.1	4.2
Cattle manure + 30 kg N ha^{-1}	2.8	3.0	4.8
Tithonia	1.9	1.3	2.4
Leucaena	3.7	0.2	4.7
Tithonia + 30 kg N ha^{-1}	–	2.8	3.4
Calliandra + 30 kg N ha^{-1}	–	1.2	4.4
Leucaena + 30 kg N ha^{-1}	2.4	2.1	–
60 kg N ha^{-1}	3.2	3.0	3.9
*Cattle manure + tithonia	1.8	–	4.2
*Cattle manure + mucuna + 30 kg N ha^{-1}	–	4.3	3.3
Control	1.0	0.4	1.4
SED	**1.1**	**1.2**	**1.5**

*Modification by farmers.

own environments in very innovative ways; for example, instead of maize some farmers started growing vegetables using tithonia. The participating farmers said that they had observed better performance of crops using the new technologies and that the cost of production had been reduced and soil fertility improved. In the SR 2002, 206 farmers were already working with these technologies.

Conclusions and recommendations

The on-station and off-station trials showed promising results in using organic inputs for soil fertility improvement when they are incorporated into the soil. At Embu on-station trial, maize monocrop with prunings of either calliandra or leucaena applied gave highest yields of about 3.5 Mg ha^{-1} $season^{-1}$. On average, leucaena alley cropping treatment gave better yields than the recommended rate of fertilizer, and calliandra alley crop treatments. At the off-station trial at Meru south, tithonia alone and tithonia combined with 30 kg N ha^{-1} gave the highest overall yields of more than 6.0 Mg ha^{-1}. Generally, integration of organic and inorganic nutrient sources gave highest yields which were attributed to increased fertilizer use efficiency and provision of more balanced nutrients to the crop. On the individual farms, farmers modified the technologies by mixing the different organic materials, for example, manure plus legumes. These farmer modifications gave among the highest yields possibly due to increased nutrient supply. Farmers practicing the new technologies benefited from increased crop yields and have tried to cope with the problem of lack of adequate biomass by planting trees for biomass production on their farms.

Application of organic materials, especially calliandra, leucaena and tithonia to improve crop production should be encouraged among smallholder farmers. Alley cropping using calliandra adversely affected crop production and should not be recommended for this area. There is need for farmer follow-up to assess adoption process and technology adaptation.

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