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EFFECT OF PLANT BIOMASS, MANURE AND INORGANIC FERTILISER ON MAIZE YIELD IN THE CENTRAL HIGHLANDS OF KENYA

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ABSTRACT

Soil fertility degradation remains the major biophysical cause of declining per *capita* crop production on small-holder farms in sub-Saharan Africa. Appropriate soil fertility regimes, are therefore, critical for improved crop productivity. This study investigated the feasibility of using sole organics or their combinations with inorganic fertilisers to improve maize *(Zea mays)* production in the highlands central Kenya. Sole application of *Calliandra calotyrsus*, *Leucaena trichandra trichandra*, *Mucuna pruriens*, *Crotalaria ochroleuca*, *Tithonia diversifolia* and cattle manure at 60 kg N ha^{-1} or combined application of the organic materials (30 kg N ha^{-1}) plus inorganic fertiliser (30 kg N ha^{-1}) gave significantly ($P \leq 0.05$) higher maize grain yields than the recommended rate of inorganic fertiliser (60 kg N ha^{-1}). These treatments maintained maize yields at 4 to 6 t ha^{-1}. Farmers had their own innovations where they combined organic resources and generally appreciable yields (3.0 to 5.6 t ha^{-1}) were obtained from these innovations. However, there was a maize yield gap between on station and on farm trials with on station yields having on average 65% more yields than the on-farm yields. This was mainly attributed to differences in management practices arising from partial adoption of recommended rates. There is need therefore to develop and implement mechanisms tailored to ensure that farmers' modications recommended soil amendment regimes and other agronomic practices are appropriate for enhanced crop productivity. Further studies are needed to establish the optimum mixture of different organic materials.

Key Words: Crop production, organic materials, soil fertility, *Zea mays*

RÉSUMÉ

La dégradation de la fertilité de sol reste la cause biophysique majeure du déclin du par capita production agricole sur les fermes de petit exploitant en Afrique au sud du Saharan. Les régimes de fertilité de sol appropriés, sont donc, critiques pour améliorer la productivité des récoltes. Cette étude a examiné la possibilité d'utiliser des organiques seuls ou leurs combinaisons avec les engrais inorganiques pour améliorer la production du maïs *(Zea mays)* dans les pays de montagne au centre du Kenya. L'application de *Calliandra calotyrsus, Leucaena trichandra trichandra, Mucuna pruriens, Crotalaria ochroleuca, Tithonia diversifolia* et le fumier de bétail à 60 kg N ha^{-1} ou application combinée des matériels organiques (30 kg N ha^{-1}) plus l'engrais inorganique (30 kg N ha^{-1}) a donné significativement ($P \leq 0{,}05$) des hauts rendements de grain de maïs que le taux recommandé d'engrais inorganique (60 N kg ha^{-1}). Ces traitements ont maintenu des rendements de maïs à 4 à 6 t ha^{-1}. Les fermiers ont eu leurs propres innovations où ils ont combiné des ressources organiques et des rendements généralement appréciables (3,0 à 5,6 t ha^{-1}) ont été obtenu de ces innovations. Cependant, il y avait une différence entre le rendement de maïs des essais sur station et sur ferme, le premier ayant en moyenne 65% plus de rendements que les rendements de sur ferme. Ceci a été principalement attribué aux différences dans les pratiques de gestion résultant de l'adoption partielle de taux recommandés. Il y a donc besoin de développer et appliquer des mécanismes adapter pour s'assurer que les modifications recommandées des régimes d'amendement de sol et les autres pratiques d'agronomiques par les fermiers soient appropriées pour l' amélioration de la productivité de récolte. Plus d'études sont nécessaire pour établir le mélange optimum de matériels organiques différents.

Mots Clés: La production de récolte, les matériels organiques, la fertilité de sol, *Zea mays*

INTRODUCTION

Soil fertility decline is increasingly viewed as a critical problem affecting agricultural productivity and environmental welfare in sub-Saharan Africa (SSA) (Bationo *et al*., 2004). Studies indicate the decline is a a result of a combination of high rates of erosion, leaching, removal of crop residues, continuous cultivation of the land without adequate fertilisation or fallowing (Sanchez and Jama, 2002). This is aggravated by the inherent poor fertility in most tropical soils (Okalebo *et al*., 2003). Consequently, SSA has experienced a decrease in overall per capita food production with soil fertility being recognised as the fundamental root cause for declining food security.

In Kenya, maize *(Zea mays)* is a major food crop and dominates all food security considerations with a capita consumption of 103 kg yr^{-1} (Pingali, 2001). Smallholder farmers in the central highlands of Kenya, rely on maize as the staple food crop but its production is low, estimated at 0.5 to 1.5 t ha^{-1} yr^{-1} (Ouma *et al.*, 2002). The major cause of this low yields is soil nutrient depletion indicated by negative nutrient balances. The average annual loss in soils nutrients of 42 kg N, 3 kg P and 29 kg K ha^{-1} in Kenya is among the greatest in Africa (Smaling *et al*., 1997). Reversal of soil fertility depletion is required to increase per capita agricultural production. Use of inorganic fertilisers is one of the ways of addressing this situation but is constrained by the high costs that the resource poor farmers cannot afford. A study by Odhiambo (1994) revealed that the rising cost of inputs has resulted to many smallholder farmers reducing or abandoning the use of chemical fertiliser altogether.

Studies in the central highlands of Kenya have shown that manure is the most widely used organic fertiliser by approximately 80% of households (Kihanda, 1996). However, in the majority of farms, the available manure is not enough to fertilise the farms and the limited access to sufficient inorganic fertiliser continue to result in declining crop yields. There is therefore an urgent need to develop and promote alternative appropriate technologies that will replenish soil nutrients to enable farms to be more productive in order to meet the ever rising food demand. One of the approaches is the integrated nutrient management that combines use of organic inputs with chemical fertiliser. The beneficial effects of combined organic and inorganic sources on soil fertility, crop yields, and maintenance of soil organic matter have repeatedly been shown in field trials (Nandwa, 2003; Vanlauwe *et al*., 2002), yet there are no predictive guidelines for their management, such as those that exist for inorganic fertiliser. The success of combined nutrient management depends on several factors that include the types and quantities of organic materials available, and the rates and proportions at which the two nutrient sources are combined. Research in central highlands of Kenya on these issues is scanty and as such guidelines for their use and management are lacking. The objective of this study was therefore to assess the effect of applying organic materials, solely or combined with inorganic fertilisers into the soil on maize yields under both on-station and on farm conditions.

MATERIALS AND METHODS

Site description. The study was conducted in Chuka division of Meru South district of Kenya. Meru South district lies between latitudes $00^o03'47''$ N and $0^o27'28''$S and longitudes $37^o18'24''$ E and $28^o19'12''$ E. It covers an area of 1032.9 km^2 and Chuka division covers an area of 169.6 km^2. According to agro-ecological conditions (based on temperature and moisture supply), the area lies in the Upper Midland Zone (UM2-UM3) (Jaetzold and Schmidt, 1983) on the eastern slopes of Mt. Kenya at an altitude of 1500 m above sea level with an annual mean temperature of 20^{o} C and a total annual rainfall of 1200-1400 mm. The rainfall is received in two seasons; the long rains (LR) lasting from March through June, and short rains (SR) from October through December. The soils are mainly humic Nitisols (Jaetzold and Schmidt, 1983), which are deep, well weathered with moderate to high inherent fertility. The district is a predominately maize growing zone with small land sizes ranging from 0.1 to 2 ha with an average of 1.2 ha per household.

The area is characterised by rapid population growth, low agricultural productivity, increasing demands on agricultural resources and low soil fertiltiy (Gok, 2001). The main cash crops are coffee (*Coffea Arabica* L.) and tea *Camelina sinensi* (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), banans (*Musa* spp. L.) and vegetables that are mainly grown for subsistence consumption. Livestock production is a major enterprise especially dairy cattle that is of improved breeds. Other livestock in the area include sheep, goats and poultry.

The rainfall trends during the study period are shown in Figure 1. The total rainfall received in 2002 LR and SR was 858.1 mm and 790.1 mm, respectively while in 2003 LR and SR a total of 840.1 and 241.4 mm was recorded, respectively. The rainfall peaks coincided with the months of April and November during the study period, a rainfall pattern expected for this area.

On-station experiment. An on-station experiment was established in March 2000 in Kirege School in Chuka divisions, Meru South district. The trial had 14 treatments comprising of six organic resources applied solely or combined with inorganic fertiliser, sole inorganic fertiliser and a control. The organic resources were two herbaceous legumes; *Mucuna pruriens* and *Crotalaria ochloleuca* (intercropped with maize), two leguminous shrubs; *Calliandra calothyrsus*, *Leucaena trichandra* (biomass transfer), cattle manure and *Tithonia diversifolia* (biomass transfer) (Table 1). The experiment was a randomised complete block design with three replications. Maize (*Zea mays* L, var. H513) was the test crop. Plot sizes measured 6 m x 4.5, and maize was planted at a spacing of 0.75 m and 0.5 m inter and intra-row spacing, respectively. Fertiliser N was applied in split applications with

Figure 1. Rainfall amount during 2002 LR (March - September, 2002) and 2002 SR (October - February, 2002), and 2003 LR (March - September, 2003) and SR (October - February, 2003) at Chuka, Meru South District, Kenya.

TABLE 1. Treatments as the on-station experiment at Chuka, Meru South district, Kenya

Treatment	Amount of N supplied (kg ha^{-1})	
	Organic	Inorganic
Mucuna pruriens alone	*	0
Mucuna + 30 kg N ha^{-1}	*	30
Crotalaria ochroleuca alone	*	0
Crotalaria + 30 kg N ha^{-1}	*	30
Cattle manure alone	60	0
Cattle manure + 30 kg N ha^{-1}	30	30
Tithonia diversifolia	60	0
Tithonia + 30 kg N ha^{-1}	30	30
Calliandra calothrysus	60	0
Calliandra + 30 kg N ha^{-1}	30	30
Leucaena trichandra	60	0
Leucaena + 30 kg N ha^{-1}	30	30
Recommended rate of fertiliser	0	60
Control (no inputs)	0	0

*Total N applied varied among seasons and depended on amount of biomass produced during the previous season (see Table 2)

33.3% being top-dressed 4 weeks after planting and the rest (66.6%) 4 weeks later. A uniform P application was done in all the plots at the recommended rate (60 kg P ha^{-1}) as triple super phosphate (TSP). Other agronomic procedures for maize production were approximately followed after planting.

The herbaceous legumes (*Mucuna* sp. and *Crotalaria* sp.) were intercropped between two maize rows one week after planting maize. After maize was harvested, these legumes were left to grow in the field until land preparation for the subsequent season when they were harvested, weighed, chopped and incorporated into the soil to a depth of 15 cm. The weight of the herbaceous legume biomass applied during the study period varied across the seasons (Table 2). The amount of N contributed into the soil via the incorporated biomass was calculated by multiplying amount of biomass (kg) with the N concentration in the biomass (%). The quantity of herbaceous legumes produced and their N contribution into the soil are shown in Table 2.

The other organic materials (calliandra, leucaena, tithonia and cattle manure) were incorporated into the soil to a depth of 15 cm during land preparation. Sub samples of all organic materials were collected uniformly at the beginning of each season and analysed. The samples were first washed with distilled water and oven dried at 65^{o}C for 48 hours. Samples were ground, packed in polythene bags, and stored under dry conditions. The dry plant samples were analysed at the International Centre for Research in Agroforestry (ICRAF) laboratory. Total N, P, K, Ca and Mg was analysed by Kjedahl digestion with concentrated sulphuric acid (Anderson and Ingram, 1993). Nitrogen and phosphorus were determined colorimetrically while potassium was by flame photometry (Parkinson and Allen, 1975; Okalebo *et al*., 2002). Magnesium and calcium was by atomic absorption spectrophotometer (Anderson and Ingram, 1993). Table 3 shows the mean nutrient composition of the organic materials used during the four seasons under study.

TABLE 2. Amount of herbaceous legumes produced and their N contribution into the soil during 2002 LR to 2003 SR at Chuka, Meru South district, Kenya

Treatment	2002 LR	2002 SR	2003 LR	2003 SR	Average	Mean N
		— — Biomass in t ha^{-1} season^{-1} — —				
Mucuna	1.7	2.8	0.8	0.2	1.38	34.4
Mucuna + 30 kg ha^{-1}	1.9	3.2	0.9	0.3	1.60	40.0
Crotalaria	2.3	2.3	0.6	0.2	1.36	36.7
Crotalaria + 30 kg ha^{-1}	2.8	2.5	0.8	0.3	1.59	42.9
SED	0.19	0.17	0.11	0.11	0.08	2.1

SED = Standard error of difference between means

TABLE 3. Average nutrient compositon (%) of organic materials applied in the soil during the study period at Chuka, Meru South District, Kenya

Treatment	N	P	Ca	Mg	K	Ash
Cattle manure	1.3	0.2	1.0	0.4	1.8	45.9
Tithonia	3.2	0.2	2.1	0.6	3.0	13.0
Calliandra	3.3	0.2	1.0	0.4	1.2	5.9
Leucaena	3.6	0.2	1.4	0.4	1.8	8.5
SED	0.4	0.004	0.04	0.01	0.05	0.27

SED = Standard error of differences between means

Maize grain and stover were harvested at maturity from a net plot of 21.0m^2 after leaving one row on each side of the plot and the first and last maize plants on each row to minimize the edges effect. Maize cobs were manually separated from the stover, sun-dried, and packed in paper bags before threshing. After threshing, moisture content of the grains was determined using a moisture meter and grain weights adjusted to 12.5% moisture content.

On farm trials. Researcher designed and farmer managed on farm trials, classified as 'Type 2' according to Franzel *et al*. (2002), were established during 2002 LR. The aim was to assess performance of the different soil fertility replenishment technologies, tested at the on station experiment, under a variety of farmers' conditions. 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 (Musaers *et al*., 1997). In these Type 2 trials, variability as controlled by ensuring that all farmers participating in the trial used the same maize variety and inorganic fertiliser. The farmers were therefore provided with maize seed, Hybrid 513 (H513) and compound fertiliser, nitrophosphate (NPK; 23:23:0). After planting the farmers carried out all the necessary agronomic practices independently.

During the growing season 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. These, according to Fanzel *et al.* (2002) were classified as Type 3 on farm trials. The farmers were also requested to avoid harvesting the crop until crop maturity. At crop maturity the researcher visited the farmers and organized the harvesting and data taking. During harvesting a representative net plot of 3 x 3 m was marked and maize yields taken.

Soil characterisation. Before planting the experiments (both on-station and on-farm) soil characterization was carried out. At the on-station, soil was sampled in March 2000 at 0-15 cm depth. On the farms, soils were also sampled at 0-15 cm depth from 31 farms. Samples were taken from the cropland, which farmers demarcated as their main cropland where they mainly planted maize. The samples were analyzed for, pH, exchangeable magnesium (Mg), calcium (ca), potassium (K), available phosphorus (P), total organic carbon ©, and total nitrogen (N). All the analyses were carried out at the International Centre for Research in Agroforestry (ICRAF) laboratories using procedure outlined in the ICRAF laboratory manual (ICRAF, 1995). At the on-station experiment, results showed that pH of the soil was 5.2 Total N and C was 0.21% and 1.8%, respectively. Available P was 7.1 Cmol kg^{-1}, K was 0.3 Cmol kg^{-1}, Ca was 3.4 Cmo kg^{-1}, and Mg was Cmol kg^{-1}.

On the farms the pH ranged from 4.1 to 6.0 with a mean of 4.8, indicating that soils in the smallholder farms in this study were acidic. Total C and N were found to be low in most farms ranging from 1.45 to 2.26% and 0.05% to 0.25%, respectively. The mean C content was 1.73% while the mean N content was 0.16%. Available phosphorus was found to be low, ranging from 1.3 to 15.8 ppm with more than 70% of the farms being critically deficient in P. Only 2 farms (6%) has P in the adequate range of 13 to 22 ppm due to possibly user of some forms of manure or inorganic P fertiliser additions.

Statistical analysis. Capturing and exploration of all data was carried out in excel spread sheet while statistical analysis was performed using Genstat 5 for windows (Release 8.1) computer package (Genstat, 2005). After testing for normality the data were subjected to Analysis of Variance (ANOVA) that was used to test for significant differences among treatments.

Differences between treatment means were declared significant at $P \leq 0.05$ and treatment means found to be significantly different were separated by Least Significant Differences (LSD) at $P \leq 0.05$. Single degree of freedom contrasts were performed to compare maize yields from organic resources and inorganic fertiliser treatments. Due to unbalanced nature of the experiments at the farmers' fields, regression modelling 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 viability between on-station and on-farm experiments, coefficient of variation (CV), which is a mesure of scatteredness of data (Stern *et al*., 2004) was used.

RESULTS

On-station experiment. Maize grain yields were significantly affected by the treatments (P = 0.05). All treatments recorded significantly higher maize yields than the control treatment in all seasons (Table 4). Overall mean maize grain yields over the four seasons were highest, (greater than 5.0 t

TABLE 4. Maize grain yields from on-station on trial under different soil fertility replenishment inputs during 2002 LR to 2003 SR at Chuka, Meru South district, Kenya

Treatment no.	Treatment	2002 LR	2002 SR	2003 LR	2003 SR	Mean
		Maize yields t ha^{-1}				
1	*Mucuna pruriens*	2.5	4.6	3.0	1.5	2.9
2	Mucuna + 30 kg N ha^{-1}	3.1	5.5	4.2	2.1	3.7
3	*Crotalaria ochroleuca*	3.3	5.3	4.1	1.9	3.6
4	Crotalaria + 30 kg N ha^{-1}	4.1	6.1	4.8	3.3	4.6
5	Cattle manure	3.0	6.1	5.0	2.3	4.1
6	Cattle Manure + 30 kg N ha^{-1}	4.6	5.3	5.6	3.5	4.8
7	*Tithonia diversifolia*	4.9	7.9	7.3	3.9	6.0
8	*Tithonia* + 30 kg N ha^{-1}	4.0	7.6	7.1	4.5	5.8
9	*Calliandra calothrysus*	3.9	6.5	6.4	4.3	5.3
10	Calliandra + 30 kg N ha^{-1}	5.0	8.0	6.5	4.8	6.1
11	*Leucaena trichandra*	3.8	7.5	6.6	3.5	5.3
12	*Leucaena* + 30 kg N ha^{-1}	4.1	7.2	6.1	3.9	5.3
13	Fertiliser (60 kg N ha^{-1})	3.5	5.8	5.3	2.0	4.2
14	Control (no inputs)	1.3	2.6	2.4	0.6	1.7
P		0.002	0.001	<0.001	<0.001	0.001
SED		0.4	0.5	0.5	0.4	0.6

SED = Standard error of differences between means ha^{-1}) in treatments where *Tithonia*, *Calliandra* and *Leucaena* alone or in combination with 30 kg N ha^{-1} from inorganic fertiliser were applied. Also, the overall mean maize grain yields were higher in 2002 SR and 2003 LR with 6.1 t ha^{-1} and 5.0 t ha^{-1}, respectively, than in 2002 LR and 2003 SR with 3.7 t ha^{-1} and 3.0 t ha^{-1}, respectively.

In 2002 SR and 2003 LR, treatments that had *Tithonia, Calliandra* and *Leucaena* prunings alone or with combination with inorganic N fertiliser applied recorded yields of more than 6.2 t ha^{-1} (Table 4). In 2002 LR, maize grain yield ranged from 1.3 t ha^{-1} (control treatment) to 5.0 t ha^{-1} (cattle manure + 30 kg N ha^{-1}). During this season, all the treatments except *Mucuna* alone, *Mucuna* + 30 Kg N ha^{-1}, *Crotalaria* alone and the control treatments, recorded maize grain yields that were more than 4.0 t ha^{-1}.

Maize grain yields during 2003 SR were the lowest among the four seasons under study, and ranged from 0.6 t ha^{-1} (control) to 4.8 t ha^{-1} (*Tithonia* + 30 kg N ha^{-1}) (Table 4). The low yields were probably due to low rainfall amount received during 2003 SR compared to 2002 LR and 2002 SR (Fig. 1). Herbaceous legumes generally recorded low maize yields ranging from 1.5 to 4.2 t ha^{-1} except in 2002 SR. However, supplementation with 30 kg N ha^{-1} increased maize yields slightly.

Contrasts performed to compare maize grain yields obtained from treatments that had sole organic materials applied with the inorganic fertiliser only treatment, i.e., treatments 1, 2, 5, 7, 8, 9 and 13, showed that in all seasons, maize grain yields obtained from sole application of *Tithonia* and *Leucaena* were significantly higher than from the inorganic fertiliser treatment (Table 5). During 2003 LR, maize yields from treatments that had sole application of *Tithonia, Calliandra* and *Leucaena* were more than 95% higher than the inorganic fertiliser treatment, while during 2003 SR treatments with *Calliandra* and *Leucaena* recorded particularly high maize yields of 125% and 116% beyond the fertiliser treatment, respectively (Table 5). Contrasts comparing maize yields from treatments that had combined application of organic materials plus inorganic

TABLE 5. Percentage yield change from contrasts comparing sole organic material treatments with fertiliser alone treatment and organic plus fertiliser, versus fertiliser treatment at Chuka, Meru South district, Kenya

Contrast	2002 LR	2002 SR	2003 LR	2003 SR
Sole organics vs Inorganic fertiliser	% increase (+) or decrease (-)			
1 vs 13	-21	-28	-43**	-23
2 vs 13	-5	-11	-21	3
5 vs 13	6	-14	-5	15
7 vs 13	35*	41*	37*	96*
8 vs 13	31*	15	33*	125**
9 vs 13	13	12	20	116**
Organics + feriliser vs inorganic fertiliser				
3 vs 13	-7	-21	-23*	-6
4 vs 13	16	-5	-10	67*
6 vs 13	32*	-9	5	76*
10 vs 13	41*	37*	23*	141***
11 vs 13	8	28*	24*	73***
12 vs 13	17	25*	15	94***

*, ** Significant at P = 0.05 and P = 0.01, respectively
1 = *Mucuna* alone, 2 = *Crotalaria* alone +30 kg N ha^{-1}, 5 = manure alone, 7 = *Tithonia* alone, 8 = *Calliandra* alone, 9 = *Leucaena* alone, 13 - fertiliser @ 60 kg N ha^{-1}

fertiliser with inorganic feriliser alone showed that combined application of organic materials with fertiliser recorded higher maize yields than sole inorganic fertiliser treatment in most seasons (Table 5).

On-farm experiments. Maize yields from the on-farm trials varied significantly among the treatments and the seasons (Tables 6 and 7). In the Type 2 trial, maize yields were significantly higher in cattle manure alone and cattle manure + 30 kg N ha^{-1} than in other treatments during 2002 LR. Overall mean maize yields were higher in 2002 SR than 2002 LR with an overall mean of 3.8 t ha^{-1} and 2.1 t ha^{-1}, respectively. Generally, lowest yields in Type 2 trials were obtained from herbaceous legumes and the control treatments, while manure, *Tithonia*, *Calliandra* and *Leucaena* gave the highest yields in most seasons.

In the Type 3 trials, highest maize yields during 2002 LR season were obtained from inorganic fertiliser, *Calliandra*, cattle manure alone and cattle manure + 30 kg N ha^{-1} (Table 7). In 2002 SR, highest maize yields were obtained from *Tithonia* + 30 kg N ha^{-1}. In 2003 SR, highest yields were recorded in cattle manure + 30 kg N ha^{-1}. In 2003 SR, highest yields were recorded in cattle manure + 30 kg N ha^{-1}, *Calliandra* + 30 kg N ha^{-1} in Type 2 trials. Except for herbaceous legumes, all organic materials alone or in combination with inorganic fertiliser gave reasonable yields of more than 3.5 t ha^{-1} in most seasons. Generally, the effect of combining organic materials with inorganic fertiliser on maize yields in the on-farm trials had no definite trend possibly because of the variability among fields especially in Type 3 trials. However, crotalaria, cattle manure, *Tithonia*, *Calliandra* and *Leucaena* in combination with fertiliser showed improved maize performance. These results also generally showed a similar trend to that of on-station trial, where cattle manure, *Tithonia*, *Calliandra* and *Leucaena* sole application

TABLE 6. Maize grain yields from "Type 2" on farm trial during 2002 LR to 2003 SR under different soil management practices at Chuka, Meru South district, Kenya

Treatment	2002 LR	2002 SR	2003 LR	2003 SR
Mucuna pruriens alone	1.6	2.7	1.6	2.3
Mucuna = 30 kg N ha^{-1}	1.2	1.4	nd	3.2
Crotalaria ochloreuca alone	0.4	2.5	1.0	1.6
Crotalaria _ 30 kg N ha^{-1}	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 alone	1.3	2.4	2.4	5.0
Tithonia + 30 kg N ha^{-1}	2.8	3.4	3.7	3.2
Calliandra clothyrsys alone	3.2	4.1	2.2	3.4
Calliandra + 30 kg N ha^{-1}	1.7	4.4	4.0	4.3
Leucaena trichandra alone	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 fertiliser (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

TABLE 7. Maize rain yields (t ha^{-1}) from "Type 3" on farm trial during 2002 LT to 2003 SR under different soil management practices in Chuka, Meru South District, Kenya

Treatment	2002 LR	2003 LR	2003 SR
	Maize grain t ha^{-1}		
Mucuna pruriens alone	0.1	na	3.3
Mucuna + 30 kg N ha^{-1}	na	1.2	1.6
Crolalaria ochloleuca alone	0.3	na	2.0
Crotalaria + 30 kg N ha^{-1}	na	na	2.3
Cattle manure alone	na	4.0	4.3
Cattle manure + 30 kg N ha^{-1}	4.9	5.6	2.9
Tithonia diversifolia	na	na	3.7
Tithonia + 30 kg N ha^{-1}	4.7	7.7	2.9
Calliandra clothrysus	5.1	na	3.8
Calliandra + 30 kg N ha^{-1}	na	na	0.8
Leucaena trichandra	4.3	2.1	na
Leucaena + 30 kg N ha^{-1}	na	na	na
Fertiliser @ 60 kg N ha^{-1}	5.0	5.5	3.5
Manure + *Tithonia*	4.2	na	na
*Manure + *Tithonia* + fertiliser	na	1.1	na
*Manure + *Calliandra* + *Leucaena* + fertiliser	na	4.4	na
*Mucuna + fertiliser + manure	3.6	3.6	5.6
**Calliandra* + manure	2.4	na	3.6
**Calliandra* + *Tithonia* + fertiliser	4.2	na	2.2
**Crotlaria* + *Leucaena*	na	na	2.0
**Crotalaria* + manure + fertiliser	na	na	2.4
**Leucaena* + manure	3.9	na	2.9
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

na = treatment was not present on at least three farms
* = Farmers' modifications
SED = Standard error of differences between means

resulted into the highest yields, while herbaceous legumes and the control treatments gave the lowest.

In Type 3 trials, farmers had innovations in the use of the inputs where they mixed different organic materials. During 2002 LR, farmers had four innovations, while during 2003 SR, they had seven, recording an increase in modification of technologies/treatments (Table 7). Maize yields during 2002 LR for these innovations ranged from 2.4 to 4.3 t ha^{-1} compared to 0.4 t ha^{-1} from the control treatment. During 2003 SR and LR, yields from the modified treatments ranged from 2.0 to 5.5 t ha^{-1} against the control treatment that had 2.0 t ha^{-1}.

The yields from the farms were observed to be highly variable among the treatments and farmers. The Type 3 trials had higher variability than Type 2 trials. For example, in 2003 LR coefficient of variation (CV) for Type 2 trials was 27% while that of Type 3 trial was 43%. In 2003 SR, CV for Type 2 trials was 32% while that of Type 3 was 54% (Tables 6 and 7).

TABLE 8. Comparisons of overall maize yield (t ha^{-1}) over 4 seasons from on station and Type 2 on farm trials in Meru South District, Kenya

Treatment	On station	Type 2 on farm trial	% difference	t-test P- value
Mucuna pruriens	2.9	2.1	3.8	0.056*
Mucuna + 30 kg N ha^{-1}	3.7	2.0	85	0.01*
Crotalaria ochloreuca	3.6	1.4	157	0.002*
Crotalaria + 30 kg N ha^{-1}	3.6	1.4	157	0.045*
Cattle manure	4.4	3.3	33	0.04*
Cattle manure + 30 kg N ha^{-1}	4.8	4.8	0	0.89 ns
Tithonia diversifolia	6.0	2.8	114	0.001*
Tithonia + 30 kg N ha^{-1}	5.8	5.3	9	0.67 ns
Calliandra calothyrsus		5.3	3.2	66 0.01*
Calliandra + 30 kg N ha^{-1}	6.0	3.6	67	0.005*
Leucaena trichandra	5.3	2.6	104	0.006*
Leucaena + 30 kg N ha^{-1}	5.5	3.3	67	0.02*
Recommended rate of fertiliser (60 kg N ha^{-1})	4.0	3.3	21	0.53ns

* = significant at p = 0.05

A comparison of maize yields from similar treatments in on-station and Type 2 on-farm trials revealed a yield gap. Most treatments gave higher yields from the on station experiment than from the on farm trials (Table 8). On average, on station yields were 65% higher than the on farm yields and in some treatments such as *Crotalaria*, on-station yields were 157% higher than the on-farm yields.

DISCUSSIONS

The consistently higher maize yields recorded in treatments where *Tithonia*, *Callinadra* and *Leucaena* prunings either alone or in combination with fertiliser was applied was attributed to higher amounts of nutrients than all the other treatments, mainly nitrogen that was availed by these inputs for maize growth. The lower maize yield in manure treatments in comparison to those of *Tithonia*, *Calliandra* and *Leucaena* could be attributed to lower rates of manure decomposition and therefore slow rate of availing nutrients to the maize crop. Though the amount of N added via all these organic materials was the same (60 kg N ha^{-1}), cattle manure contained lower nitrogen concentration than all the others (Table 2) and could have released the N slower due to higher C: N ratio compared to the other organic materials (Cadisch *et al*., 1998; Kimani *et al*., 2004) therefore affecting maize growth.

Several studies have shown large maize yields 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; Gachimbi *et al*., 2004; Kimetu *et al*., 2004). Studies from other parts of Africa have also reported increased maize yields following application of *Tithonia* biomass (Ganunga *et al*., 1998; Jiri and Waddington, 1998). The large response 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) and may thus, prevent micronutrient deficiencies (Murwira *et al*., 2002).

The exceptionally high yields recorded in 2002 SR and 2003 LR could be attributed to the good rainfall distribution during these two seasons (Fig. 1) and also probably due to nutrient accumulation over the seasons since the experiment was set up in 2000. Similarly, the large difference between yields from *Tithonia*, *Leucaena* and *Calliandra* plus fertiliser treatments and that of fertiliser alone treatment during 2003 SR could also be attributed to the same nutrient accumulation in organic materials treatments. Other studies have reported nutrient accumulation as a result of applying organic materials over several seasons resulting in increased yields (Goyal *et al*., 1992). This is because organic materials, e.g., *Calliandra* and *Leucaena* have tannin and lignin content, which slow their decomposition (Tian *et al.*, 1993) and therefore has a long-term effect on nutrient availability.

The higher yields from organic materials plus inorganic fertiliser treatments than sole inorganic fertiliser treatment is an indication that integrated use or organic and inorganic nutrient sources of N is advantageous over the use or inorganic fertiliser alone. Earlier studies demonstrated that use of organics could enhance efficiency of chemical fertiliser (Dudal and Roy, 1995). Other researchers have observed higher maize yields through application of high quality organic inputs such as *Tithonia* in combination with inorganic fertiliser as compared to sole application of inorganic fertilisers (Okoko *et al*., 2003; Esilaba *et al*., 2005). Integration of inorganic and organic nutrient inputs could therefore be considered as a better option in increasing fertiliser use efficiency and providing a more balanced supply of nutrients. Vanlauwe *et al*., (2002) reported that combination of organic and inorganic nutrient sources result into synergy and improved conservation and synchronization of nutrient release and crop demand, leading to increased fertiliser efficiency and higher yields.

The slight increase in maize yields following addition of 30 kg N ha^{-1} in herbaceous legumes treatments could be attributed to additional N provided via the inorganic fertiliser an indication that amount of nutrients supplied by *Mucuna* and *Crotalaria* biomass did not provide adequate nutrients for maize production. Indeed, *Mucuna* and *Crotalaria* biomass did not provide adequate nutrients for maize production. Indeed, *Mucuna* and *Crotalaria* treatments provided on average 35 kg N ha^{-1} via the incorporated prunings (Table 2). These observations agree with those of Kamidi *et al*. (2000) who reported that yields of plots under legumes and half recommended rates of inorganic fertiliser recorded significantly higher maize yields (*Mucuna pruriens* = 7.2 ha^{-1}, soyabeans = 6.9 t ha^{-1}, *Crotaralia ochroleuca* = 7.4 t ha^{-1}, cowpeas = 7.1 t ha^{1} and dolichos = 6.6 t ha^{-1}) than the obtained from farmer practice (4.8 t ha^{-1}). Hougnanda *et al*. (2001) and Kaizzi *et al*. (2002) also found that maize yields were nearly doubled where *Mucuna* was combined with fertiliser and noted that there was evidence of fertiliser being used more efficiently when combined with *Mucuna* than when used alone.

One of the major reasons advanced for low maize yields in herbaceous legumes treatments was low biomass production consequently contributing low amounts of N. This corroborates finding of Baijukya (2004) and Kaizzi *et al.* (2006) who obtained reduced maize yields in *Mucuna* intercropping treatments and attributed it to low biomass production. However, the observed increases in maize yield with application of herbaceous legumes compared with the control demonstrate that legumes could make a significant contribution to crop 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 results further indicate that application of mineral fertiliser can be reduced if herbaceous legumes are applied on the farms. Similar results have been reported in the Kenyan highlands (Niang, 2002), in the humid areas of Uganda (Wortmann *et al*., 1994; Kaizzi *et al*., 2006), in Tanzania (Kalumuna *et al*., 2001; Baijukya, 2004) and in moist savanna region of West Africa (Sanginga *et al*., 2002).

The good performances from farmers innovated technologies where they modified the treatments and combined different organic materials could be due to increased amount of nutrients supplied via the applied materials as well as soil moisture retention by the organic materials. This is an indication that the farmers' modified technologies could be effective in improving yields. Modifications of agricultural technologies have similarly been reported by other authors (Adesina *et al*., 1999; Pisanelli *et al*., 2000; Obonyo and Franzel, 2005). 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 farmers that is adopted as it technically feasible, profitable and acceptable to farmers (Fanzel *et al*., 2002).

The main reason advanced by farmers for mixing the materials was that they lacked adequate materials (biomass) for incorporation and that they already knew that their soil was low in soil fertility 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 seasons. 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). Due to lack of enough biomass for applying into the soil, mixing of the different organic materials could therefore be an important approach for improving soil fertility in these smallholder farms.

The higher maize yields from on-station experiment than the on-farm trials were probably due to on-station plots having higher soil fertility status than plots at the farms. From the characterisation data soil C and N in soils sampled from the farms was 0.73 and 0.16%, respectively, while it was 1.78% and 0.24% in soils sampled from on-station experiment. Another possible explanation for the higher yields from on-station treatments compared to on-farm is better management/agronomic practices at the on-station than on the farms.

The low variability in Type 2 on-farm trials than Type 3 trial among the treatments was attributed to some control in the Type 2 trial (researcher designed, farmer managed) where the same maize variety and fertilisers were used on all farms, while Type 3 farmers worked independently and used many different types of fertilisers. Also, the higher variability in on-farm trials than on-station trial could be due to inherent variability within each farm and the differences in the management of each farm in terms of quality and amount of inputs applied. For instance, the cattle manure applied in each farm could have varied in quality depending on the feed stuff, storage and decomposition duration. Probert *et al*. (1995) reported that though manure is a common soil fertility resource among farmers it has been found to be variable depending on the animal, storage and handling of the manure. In the central highlands of Kenya, Lekasi *et al*. (2000) and Kimani *et al*. (2004) found high variability in the chemical composition of farm yard manures notably organic, ligin, polyphenol, organic C, total N and C:N ratio and this influenced maize yield response and nitrogen mineralisation. In addition, variability in yield especially in the *Calliandra* and *Leucaena* treatments could have been due to farmers applying varying quantities of prunings.

CONCLUSION AND RECOMMENDATIONS

At the on-station trial sole application of the organic materials at 60 kg N ha^{-1} and combined application of organic materials (30 kg N ha^{-1}) and inorganic fertiliser (30 kg N ha^{-1}) gave similar maize yields. However, these treatments gave significantly ($P < 0.05$) higher yields than the recommended rate of inorganic fertiliser, indication that organic materials improved nutrient use efficiency from inorganic fertiliser. Overall conclusion is that biomass transfer technologies involving *Calliandra*, *Leucaena* and *Tithonia* applied solely or in combination with inorganic fertiliser at 60 kg N ha^{-1} could be used as nutrient sources and can meet N requirement for maize in smallholder farming systems maintaining maize yields at 4 to 6 t ha^{-1} .

Though herbaceous legumes yielded the lowest maize yields among the organic resources tested in this study, the observed increase in maize yield with application of herbaceous legumes compared with the control demonstrate that legumes make a significant contribution to crop production. Farmers would therefore benefit by incorporating these legumes in the farming systems as an option to subsistence farming where farmers currently crop their farms without any inputs. The results further indicate that maize yields above the control treatment when supplemented with inorganic fertiliser and application of mineral fertiliser can be reduced if herbaceous legumes are applied.

Use of manure and *Tithonia* alone or combined with fertiliser was most effective in increasing maize yields at the farm level and their use should be promoted. However, the yield gap between the on station and on farm trials is an indication that there exists a potential of increasing yields at the farm level through use of the tested inputs. There is therefore need to determine factors that cause the yield gap as this would help provide recommendations for maximizing production.

High variability in yields among the farms is of concern especially in farms where very low maize yields were recorded. Differences in the management are the most likely factors for the large variability and there is need to analyse the specific causes of variability. These will in turn explain yield variation among the farmers and help diagnose production constraints at the farm level that limit performance of improved technologies.

Lastly, this study has shown how farmers are likely to modify introduced agricultural technologies to fit their own circumstances. It is advisable that researchers remain open minded when evaluating technologies with farmers and analyze what farmers do rather that criticise when they change what has been introduced. As shown in this study the changes adopted by farmers might yield more benefits with potential for sustainability they fit within the existing farmers' environment. In this regard there is need to validate farmer's innovations and look for ways of improving them.

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