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Full Length Research Paper

Consequences of organic-mineral N soil fertility amendments on nitrogen uptake and maize grain yield in the smallholder farms of Meru South district, Kenya

Edwin Mwiti Mutegi[1]*, James Biu Kung'u[2], Mucheru-Muna[2], Daniel Mugendi[2]

[1]Tropical soil Biology and Fertility (TSBF) Institute of CIAT, P.O Box 823-00621 Nairobi, Kenya.
[2]Kenyatta University, Department of Environmental Science P.O Box 43844, Nairobi Kenya.

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The central highlands of Kenya is generally densely populated and declining land productivity with reduced crop yields has been a major problem facing the smallholder farmers in the region. Land sizes are small and this promotes continuous cropping with limited scope for crop rotation and inadequate soil fertility replenishment. Efficient use of soil N amendments in maize (*Zea mays* L.) production is necessary to maximize producer's economic returns and maintain soil and water quality. An experiment was carried out on the humic nitisols in Mucwa location, Meru South District, with the objective of determining maize grain yields and N uptake under different soil N amendments. The experiment was set in randomized complete block design (RCBD) with three replicates. The results reveal that maize grain yields in the organics and/or mineral N soil amendments was higher than the yields obtained where the recommended mineral fertilizers were used alone. The nitrogen (N) concentration in different parts of the maize crop varied, with the grain having the highest, followed by the stover during the 2005 short rain season. Sole application of calliandra recorded the highest N uptake (170.8 kg N ha^{-1}) while the control gave the lowest (49.31 kg N ha^{-1}). It is therefore concluded that differences in nutrient release by the organic-mineral N soil amendments can alter net rate of nutrient uptake during crop growth and therefore assist in synchronization of nutrient release and uptake by the growing crop.

Keywords: N accumulation**,** maize grain yields, Calliandra, soil fertility.

INTRODUCTION

Increasing agricultural productivity per unit of land has remained a major challenge in farming systems of sub-Saharan Africa. In the central highlands of Kenya, the situation has been accentuated by the mounting population growth and gross nutrient mining with low levels of nutrient inputs (Stoorvogel and Smaling, 1990). The use of mineral fertilizers on staple food crops of maize (*Zea mays* L.) and beans (*Phaseolus vulgaris* L.) has generally been restricted to only a few farmers endowed with resources, such as cattle and land (Shepherd and Soule, 1998) and with high off-farm income (Niang et al., 1998). The majority of the smallholder farmers, on the other hand have lacked the financial resources to purchase sufficient fertilizers to replace the soil nutrients exported with harvested crop products. The situation is further aggravated by the fact that even the farmers using the mineral N inputs hardly use the recommended rates (60 kg N ha^{-1}) with most of them applying less than 20 kg N ha^{-1}(Adiel, 2004).

Combinations of organic-mineral N sources have increasingly received recognition as integral and indispensable components of sustainable soil fertility management (Palm et al., 2001; Vanlauwe et al., 2002; Mugendi et al., 2007). Although significant advances have been made on their influence on the soil chemical and physical properties (Palm et al., 1997; Jama et al., 2000; Vanlauwe et al., 2001), there is need to understand and improve their efficiency in agricultural systems. The benefits of such work are likely to firstly be reduced losses of fertilizers to the environment and the potential

*Corresponding author. E-mail: emutegi@cgiar.org or mutegiedwin@yahoo.com.

Table 1. Average nutrient composition (%) of organic materials applied in the soil during the 2005 short and 2006 long rains at Mucwa, Meru South District, Kenya.

Treatment	N(%)	P(%)	K (%)	Mg(%)	Ca(%)	Ash
Tithonia	3.0	0.2	2.0	0.7	1.6	13.2
Manure	1.0	0.3	0.9	0.4	1.4	46.1
Calliandra	3.3	0.2	1.1	0.4	0.9	5.8
SED	0.72	0.03	0.34	0.10	0.21	12.39

environmental damage with which that may be associated and secondly, increased efficiency with which organic and mineral N sources are recovered by crops providing the potential for greater economic efficiency. This study therefore aimed at evaluating maize grain yields and N uptake under different soil N organic and mineral N amendments in order to achieve better synchrony between plant uptake and nutrient release while avoiding excess nutrient loss from the farming systems.

MATERIALS AND METHODS

Site description

The study was conducted in Mucwa sub location, Chuka Division, in Meru South District. According to Jaetzold et al. (2006) the area is in upper midland 2 and 3 (UM2 and UM3) with an altitude of approximately 1373 m above sea level. This is a predominantly maize growing zone in the central highlands of Kenya. It experiences bimodal rains which range from 1200 to 1500 mm and mean temperature of about 20°C annually. The long rains (LR) are from March to June, and the short rains are from October to December. The predominant soil types are humic nitisols, which are deep, well weathered, with moderate to high inherent fertility (Jaetzold et al., 2006).

Experimental design and management

The experiment was laid out during the 2004 short rain season in a public land (at Mungoni primary school, Meru South District, Kenya) and was thus accessible to all farmers as a demonstration site. The results from maize grain yields presented herein are for the 2005 SR and 2006 LR seasons. However, the initial soil chemical properties (2004 SR) were compared with those observed at the end of 2006 LR season in order to determine if any changes in soil properties took place as a result of treatment application over the two year period. The plots were laid out as a randomized complete block design (RCBD) with 3 replicates. The plots were measuring 6 x 4.5 m with 1 m and 1.5 m pathways. The test crop was maize (*Zea mays* L, var. H513) planted at a spacing of 0.75 and 0.5 m inter- and intra-row, respectively. Three (3) seeds were sown per hole and thinned four weeks later to two (2) plants.

Seven external soil fertility amendment inputs were applied to give an equivalent amount of the recommended rate (60 kg N ha^{-1}) of nitrogen to meet maize nutrient requirements for an optimum crop production in the area. The eighth treatment was fertilizer at half the recommended rate (30 kg N ha^{-1}) to mimic the sub-optimal rates currently applied by some farmers in the region. The ninth treatment was fertilizer at 90 kg N ha^{-1} which is above the recommended rate. The tenth treatment was absolute control (no soil fertility enhancement input) representing farmers on the lower end of resource endowment. Calcium Ammonium Nitrate (CAN) was the source of mineral N fertilizer and one-third was applied 4 weeks after planting (WAP) and the other two-thirds was applied 8 WAP. To prevent phosphorous deficiencies confounding N response, all plots received P application at 60 kg P ha^{-1}. The average nutrient composition of the organic inputs that were incorporated in the two seasons is shown in Table 1.

Sampling and analysis

At maturity, maize was harvested and the fresh weight of both grain and stover taken. The maize was then air-dried and the dry weight taken and expressed on a 12.5% water content basis. Treatment effects on maize yields and N uptake were subjected to analysis of variance (ANOVA) using Genstat programme version 7.1. Nitrogen uptake by maize crop was then determined by multiplying the grain and stover yields with the N concentration in the specific components. Treatment means found to be significantly different from each other were separated by Least Significant Differences (LSD) at $p < 0.05$.

RESULTS AND DISCUSSIONS

The results for nitrogen concentrations and uptake in maize plant tissue during the 2005 SR are presented in Table 2. These results revealed that the magnitude of plant nitrogen uptake was significantly affected ($p < 0.05$) by soil N amendments.

It was observed that sole manure treatment gave the highest N (1.8%) concentration in maize grain while sole manure, manure + 30 kg N ha^{-1} and fertilizer (90 kg N ha^{-1}) gave the highest N (0.7%) concentration in maize stover during the 2005 SR season. Fertilizer at 60 kg N ha^{-1} recorded the lowest N (1.2%) concentration in the maize grain while the control had the lowest N (0.4%) concentration in maize stover. The concentration of N in different parts of the maize crop varied, the grain being higher, followed by the stover. Sole application of calliandra gave the highest N uptake (170.8 kg N ha^{-1}) while the control gave lowest (49.3 kg N ha^{-1}). Maize from plots treated with fertilizer at 90 kg N ha^{-1} and sole manure had 151.9 kg N ha^{-1} and 150.9 kg N ha^{-1} total N uptake while those with fertilizer at recommended rate had 123.8 kg N ha^{-1} during the 2005 SR season. Maize from plots treated with sole tithonia biomass accumulated 131.2 kg N ha^{-1} which was comparable to maize from plots treated with tithonia + half recommended rate,

Table 2. Nitrogen accumulation and uptake by maize at harvest during the 2005 SR at Mucwa, Meru south district, Kenya.

Treatment	Nitrogen uptake	% N concentration	
	(Kg N/ha)	Grain	Stover
Manure	150.9 [b]	1.8 [a]	0.7 [a]
Tithonia	131.2 [c]	1.4 [d]	0.6 [b]
Calliandra	170.8 [a]	1.6 [b]	0.6 [b]
Manure+ 30 kg N ha^{-1}	123.4 [c]	1.4 [d]	0.7 [a]
Tithonia + 30 kg N ha^{-1}	127.4 [cd]	1.5 [c]	0.5 [c]
Calliandra + 30kg N ha^{-1}	117.2 [d]	1.6 [b]	0.6 [b]
Fertilizer (30 kg N ha^{-1})	79.6 [e]	1.2 [f]	0.5 [c]
Fertilizer (60 kg N ha^{-1})	123.8 [cd]	1.4 [d]	0.6 [b]
Fertilizer (90 kg N ha^{-1})	151.9 [b]	1.6 [b]	0.7 [a]
Control	49.3 [f]	1.3 [e]	0.4 [d]

Means with same letter in each column are not statistically different at $p < 0.05$

manure + half the recommended rate and 60 kg N ha^{-1}(127.4, 123.4 kg N ha^{-1} and 123.8 kg N ha^{-1} respectively). 30 kg N ha^{-1} treatment allowed an uptake of only 79.6 kg N ha^{-1}.

The relatively better N uptake from sole calliandra treatment could be attributed to slow decomposition of biomass from the previous seasons resulting to residual effects. Lehmann et al. (1995) reported that only 52% of calliandra N is released by the time of the maximum N demand by maize.

Treatments that received sole organics or a combination of sole organics with mineral N amendments produced maize stover biomass that consistently showed higher total N uptake and higher N concentrations than treatments that received mineral N treatments which is an indication that there was less N loss from the soil-plant system. This may be attributed to slow release of N from sole organics and that the pattern of release more closely approximated the demand of the maize plant. These results corroborates with observations made by Kulasooriya et al. (1988) who were comparing urea and Azolla as sources of N in rice systems. Addition of mineral N sources might have also resulted to release of N too fast and too early in the season before the maize crop developed an extensive root system to take it up. Such available N in the soil is subject to loss through leaching, volatilization and de-nitrification or it may be immobilized into forms not readily available to plants.

Maize grain yields

The second objective of this study was to determine the effects of organic and mineral N sources on maize grain yields. Table 3 shows grain yields obtained during the two seasons (2005 SR and 2006 LR)

During the first season (2005 SR), sole calliandra treatment gave the highest maize grain yield of 4.8 t ha^{-1}, followed by tithonia + 30 kg N ha^{-1} and 90 kg N ha^{-1}(3.6 t ha^{-1}). The control gave the lowest maize grain yield across the treatments with 1.6 t ha^{-1} followed closely by fertilizer at 30 kg N ha^{-1} (1.8 t ha^{-1}). The yields obtained from fertilizer at 60 kg N ha^{-1} were not significantly different from the 90 kg N ha^{-1} (3.0 t ha^{-1} and 3.6 t ha^{-1} respectively).

The results obtained during the 2006 LR season revealed that maize grain yield was between 0.4 t ha^{-1} and 4.2 t ha^{-1}, which was against the expected grain yield of greater than 6 t ha^{-1} (*Var*. H 513) for the area. During this season, calliandra treatment gave the highest grain yield of 4.2 t ha^{-1}, while the control and application of 30 kg N ha^{-1} gave the lowest maize grain yield (0.4 t ha^{-1}). Sole tithonia and tithonia + 30 kg N ha^{-1} gave significantly higher yields than all the other treatments (except in sole calliandra treatment). The yields obtained from application of 60 kg N ha^{-1} were not significantly different from those obtained in 90 kg N ha^{-1} treatment. Sole organics and integration of sole organics with 30 kg N ha^{-1} had higher yields than the recommended rate of mineral fertilizer (60 kg N ha^{-1}). The application of organic alone or in combination with mineral fertilizers led to increased maize yield compared to the control.

The higher maize grain yields obtained during the 2005 SR season from mineral fertilizer at 90 kg N ha^{-1} and 60 kg N ha^{-1} (though not significantly different from sole tithonia, sole manure and Tithonia + 30 kg Nha^{-1}) could be attributed to nutrients being readily available from the mineral fertilizers as compared to nutrients from organic residues which must first undergo decomposition before

Table 3. Maize grain yield (t ha^{-1}) during the 2005 SR and 2006 LR at Mucwa, Meru, South District, Kenya.

Treatment	2005 SR	2006 LR
Calliandra	4.8 [a]	4.2 [a]
Tithonia	3.1 [bcd]	3.4 [b]
Manure	3.5 [bc]	2.4 [d]
Tithonia + 30 kg N ha^{-1}	3.6 [b]	3.2 [bc]
Calliandra + 30 kg N ha^{-1}	2.9 [d]	2.5 [cd]
Manure + 30 kg N ha^{-1}	2.9 [d]	3.0 [b]
Fertilizer (90 kg N ha^{-1})	3.6 [b]	2.3 [c]
Fertilizer (60 kg N ha^{-1})	3.0 [bc]	2.0 [de]
Fertilizer 30 kg N ha^{-1})	1.8 [e]	0.4 [f]
Control	1.6 [e]	0.4 [f]

Means with same letter in each column are not statistically different at $p < 0.05$

they are available for crop uptake. The split application of mineral N could have also resulted to minimal leaching losses and better synchrony of nutrient availability to maize crop demand. Kimetu et al. (2004) suggested that split N application should be implemented so as to increase plant N uptake and decrease potential for N losses. Another aspect that contributed to high maize yields during the 2005 SR season was the even distribution of rainfall throughout during the first three months of the cropping season. This promoted rapid growth since the soil moisture deficits were eliminated. The lower yield obtained from fertilizer at 30 kg N ha^{-1} in comparison to the 60 kg N ha^{-1} is probably because the N supplied was not enough to meet the maize crop demand since the recommended mineral N application rate for the area is 60 kg N ha^{-1} (KARI, 1994).

Lower moisture regimes characterized the 2006 long rains cropping season with 79% of the rainfall being received within the first 40 days of the season. This may in part have been responsible for the suppressed performance of maize crop during the 2006 LR period. The low moisture regimes in the soil could also have meant that most of the organic materials did not fully decompose in time, thus N was not fully released in time, and if it was, water was not available for the mineralized nutrients to be taken up by the crop. Soil moisture content influences N mineralization and availability and subsequent maize growth and uptake (Vanlauwe et al., 2002). Myers et al. (1994) noted that variability in climatic factors such as rainfall and temperature make the synchrony between nutrient release from tree litter and crop uptake an elusive goal to achieve in practical terms. Insufficient moisture has also been reported to limit the response of crops to nutrients (Jama et al., 1997). During this season, the better performance in sole tithonia and tithonia + 30 kg N ha^{-1} is possibly due to high release of N through mineralization and this synchronized to plant uptake (Chesson, 1997). Palm and Rowland (1997) noted that the overall secondary compounds (lignins and polyphenols) in tithonia are low compared with foliage herbaceous plants. Tithonia contains 80% water that further contributes to rapid decomposition (Ayuke et al., 2004).

The relatively better performance from sole organics and integration of sole organics with 30 kg N ha^{-1} in comparison to sole mineral N sources could be due to provision of additional benefits (besides N) by the organic inputs to the soil chemical and physical properties that in turn influence nutrient acquisition and plant growth (Palm et al., 1997). Principal among these is the soil moisture holding capacity and provision of other macro-nutrients like calcium and magnesium (Wallace, 1996; Mutuo, 2000). Higher maize yields with organic and/or a combination of organics with mineral fertilizer has been reported elsewhere. For instance, research work by Mugendi et al. (2007) and Mucheru-Muna et al. (2007) have demonstrated that higher yields can be obtained when sole organics or their combinations with mineral fertilizer have been incorporated in comparison to sole mineral fertilizer treatment. Kapkiyai et al. (1998) and Vanlauwe et al. (2002) reported that a combination of organic and mineral nutrient sources has been shown to result into synergy and improved synchronization of nutrient release and uptake by plants leading to higher yields. More so, addition of green manure and animal waste helps to reduce the total concentration of Al in the soils and thus reduce Al phototoxicity and increase crop growth (Asghar and Kanehiro, 1980; Hue, 1992). Another likely cause for the observed higher yields in the organic and/or mixed treatments was reduced water stress compared with sole mineral fertilizer treatments due to the presence of organic materials. The organic residues improve water holding capacity and moisture retention.

Conclusion

It is concluded that differences in nutrient release by the organic-mineral N soil amendments can alter net rate of nutrient uptake during crop growth. The organic-mineral N soil amendments may assist in synchronization of nutrient release and uptake by the growing crop. This study has further confirmed that sole organics or their integrations with mineral fertilizers can be an alternative to the limited use of fertilizers amongst the small scale farmers in the central highlands of Kenya.

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