Managing Nutrient Cycles to Sustain Soil Fertility in Sub-Saharan Africa

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Improved Food Production by Use of Soil Fertility Amendment Strategies in the Central Highlands of Kenya

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Abstract

Declining soil and crop productivity is a major problem facing smallholder farmers in eastern and central highlands of Kenya. This is caused by continuous cropping without addition of adequate external soil fertility inputs. A multidisciplinary and farmers participatory trial is being implemented in the main maize growing areas of the central highlands of Kenya to address the above problem. The trial is farmer-researcher managed with a general expected output of offering small-scale resource poor farmers feasible soil management techniques for combating soil nutrient depletion. Results for the two seasons reported here indicate that the general maize performance may be improved by combining fast decomposing plant biomass (e.g. *Tithonia diversifolia*) and half the recommended rate of nitrogen fertilizer.

Key words: biomass transfer, nitrogen replenishment, N leaching, maize yield

Introduction

One of the challenges facing Kenya today is the production of adequate food to feed the rapidly growing population and in particular, the inhabitants of the densely populated highlands of central Kenya with over 500 persons km^{-2} (Government of Kenya, 1994). The soils in this area are deep, well drained, weathered humic nitisols with moderate to high inherent fertility (Jaetzold and schmidt, 1983). Over time, the soil fertility has declined due to continuous cropping with little nutrient replenishment (Ikombo, 1984) and crop yield decline has been a major problem facing smallholder farmers in the area. Though high yielding maize varieties have been developed with yield potentials of 7-12 Mg ha^{-1}, maize yields at the farm level hardly exceed 1.5 Mg ha^{-1} (Wokabi, 1994). The use of inorganic fertilizers is generally low, less than 20 kg N and 10 kg P ha^{-1} (Muriithi *et al.*, 1994). The amount is inadequate to meet the crop nutritional requirements for optimum crop yields at the farm level. Due to the high cost of inorganic fertilizers and low prices of farm produce, over 80% of the farmers use farmyard manure (FYM) to improve soil fertility and crop productivity (Maize Data Base Project, 1993). The usefulness of FYM is limited mainly due to its variability and often-low nutrient contents and also the large quantities (5–10 Mg ha^{-1}) needed to supply adequate nutrients (Kihanda, 1996; Nzuma *et al.*, 1998).

Surveys carried out in the area indicate that farmers are fully aware of the declining soil fertility (as expressed by declining crop yields), but in most cases they do not have readily available resources to replenish it (Muriithi *et al.*, 1994). Research work by Mugendi *et al.* (1999); Mutuo *et al.* (1998) and Nziguheba *et al.* (1998) reported positive results from use of tithonia, calliandra and leucaena biomass for soil fertility improvement. These biomass are therefore supplementary components in soil fertility improvement and needs to be evaluated on-farm by farmers and other stakeholders in agricultural production processes. The information reported herein is from a participatory on-farm trial conducted in the predominantly maize growing zones (UM2– UM3) of Meru South District. The aim of the evaluation is to provide a menu (demonstration) on integrated soil fertility management strategies for increased agricultural production by smallholder farmers in Central highlands of Kenya. This project sought to i) integrate nutrient management practices that will arrest the current nutrient depletion and increase food production, and ii) encourage farmers to adopt improved nutrient management practices.

Materials and Methods

Experimental site

The study was carried in Meru South District. According to Jaetzold *et al.* (1983), the area is in upper midlands 2 and 3 (UM2-UM3). Coffee and dairy are the main Land Use Systems (LUS) with an altitude of approximately 1500 m above sea level, annual mean temperature of about 20^0 C and annual rainfall of about 1200 mm. 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. About 65% of the rains come during the long rainy season. The main food crop is maize.

Experimental layout

The experiment was established in March 2000 on a farm with poor and impoverished soils and laid out as a randomized complete block design (RCBD) with 3 replicates. The plot sizes were 6 m x 4.5 m. The test crop, maize, (*Zea mays* L, var. H513) was planted at a spacing of 0.75 m and 0.25 m inter- and intra-row, respectively. Three (3) seeds were sown and thinned at four weeks later to 2 plants per hole to give an approximate population of 53,300 plants ha^{-1}. Nine external soil fertility amendment inputs (Table 41.1) were applied to give an equivalent of 60 kg N ha^{-1}. The tenth was an absolute control (no external input) representing farmers on the lower end of resource endowment.

Organic materials were applied and incorporated into the soil to a depth of 15 cm during land preparation just before the onset of the rains. Nutrients compositions of the applied organic inputs are represented in Table 41.2. The inorganic source of N and P was the compound fertilizer (23:23:0) that was applied during maize sowing. All the agronomic procedures for maize production were appropriately followed after planting. The plots were hand weeded twice, four weeks after planting and at maize flowering. Stalk borers were controlled by use of borericide (Buldock dust) four weeks after the crop emergence. During the first season a general P deficiency was noted, thus a uniform top dressing for P, as TSP, was carried out in the second season.

Table 41.1: Experimental treatments indicating the different soil applied fertility amendment inputs at Chuka, Kenya

Treatment. No.	Treatment
1	Cattle manure
2	*Tithonia diversifolia*
3	*Calliandra calothyrsus*
4	*Leucaena leucocephala*
5	Cattle manure + 30 kg N and 30 kg P ha^{-1}
6	Tithonia + 30 kg N and 30 kg P ha^{-1}
7	Calliandra +30 kg N and 30 kg P ha^{-1}
8	Leucaena + 30 kg N and 30 kg P ha^{-1}
9	60 kg N and 60 kg P ha^{-1}
10	Absolute control (no inputs)

Table 41.2: Nutrient composition (%) of organic materials inputs applied in the Soil at Chuka, during season 1 and 2

Treatment	N	P	Ca	Mg	K	Ash
Cattle manure	1.4	0.2	1.0	0.4	1.8	46.1
Tithonia	3.0	0.2	2.2	0.6	2.9	13.2
Calliandra	3.3	0.2	0.9	0.4	1.1	5.8
Leucaena	3.8	0.2	1.4	0.4	1.8	8.7

Sampling and analyses

Maize was harvested at maturity from a net area of 21.0 m^2. This was after leaving out one row on each side of the plot and the first and the last plants of each row in order to minimize the edge effect. At the end of the second season soil samples were taken with an Alderman auger. The soils were sampled from three different depths: 0-30, 30-100 and 100-150 cm. One sub-sample of each soil sample was dried at 105^0 C for 48 hours in order to determine gravimetric water content.

For determination of ammonium and nitrate, about 20 g of field moist soil was extracted with 100 ml 2 *M* KCl by shaking for one hour at 150 reciprocation per minute and subsequent gravity filtering with prewashed whatman paper. Soil water content was determined on the stored field moist soil at the time of extraction in order to calculate the dry weight of extracted soil. Ammonium in the extract was determined by a calorimetric method (Anderson and Ingram, 1993) and nitrate was determined by cadmium reduction (ICRAF, 1995). Biophysical data was statistically analyzed using Genstat program (1995).

Results and Discussions

Maize grain yield

The average maize grain yield across the treatments was 0.9 Mg ha^{-1} (Table 41.3) during the first season. Application of recommended inorganic fertilizer (60 kg N and P ha^{-1}) gave the highest maize grain yield with an average of 1.6 Mg ha^{-1}. Average maize grain yield from calliandra was lowest (0.2 Mg ha^{-1}) and was worse than the control. The maize yields in this season (long rains) were not significantly different. The average maize grain yield was against the expected grain yield of greater than 6 Mg ha^{-1} (*Var.* H513) for the area. The low maize grain yield in calliandra treatment could be attributed to the lower rate of decomposition and mineralization due to the high polyphenol and lignin content of calliandra, which could have resulted to net immobilization of nutrients. The low soil moisture content resulting from the low rainfall (126 mm received in the first 20 days of the season) during this season could have exacerbated the situation. The higher maize grain yield with the inorganic fertilizer could be due to the readily available N compared to the N from organic inputs which must first decompose and mineralize before the N is available to the plant. Rains that stopped very early in the season could have meant that the organics did not have sufficient water (moisture) to decompose and mineralize and even if they did, water was not available for the mineralized nutrients to be taken up by the plants.

Table 41.3: Maize yields under different soil fertility amendment inputs in Chuka during season 1 and 2

Treatment	1st season Grain wt (Mg ha^{-1})	2nd season Grain wt (Mg ha^{-1})
Cattle manure	0.7	5.0
Tithonia	0.8	5.9
Calliandra	0.2	4.0
Leucaena	0.9	5.1
Cattle manure + 30 kg N & P ha^{-1}	1.4	5.7
Tithonia + 30 kg N & P ha^{-1}	1.5	6.2
Calliandra + 30 kg N & P ha^{-1}	1.1	4.7
Leucaena + 30 kg N & P ha^{-1}	1.0	5.1
60 kg N & P ha^{-1}	1.6	5.4
Control	0.3	3.1
Mean	0.9	5.0
SED	0.7	1.2

The average maize grain yield across all the treatments during the second season was 5.0 Mg ha^{-1}. During this season tithonia with 30 kg N and P ha^{-1}gave the highest maize grain yield of 6.2 Mg ha^{-1}. The control had the lowest maize grain yield (3.1 Mg ha^{-1}). The maize grain yields in the second season were significantly different ($P<0.05$) between the treatments. The better performance of tithonia during this season could be attributed to the faster release of N and P from the leaf biomass (Gachengo *et al.*, 1999). The integration of tithonia and mineral fertilizer had higher maize grain yields than the recommended rate of mineral fertilizer; this could have been as a result of the provision of additional benefits (besides N and P) by the tithonia (organic).

The integration of organic and inorganic nutrient sources of N gave higher maize grain yields as compared to the sole application of organic materials in both seasons. These results concur with results by Gachengo (1996), Kihanda (1996), Mutuo *et al* (1998), Nziguheba *et al.* (1998) and Mugendi *et al.* (1999) on the integration of organic and inorganic soil fertility inputs. Integration of inorganic and organic nutrient inputs can be considered as a better option in increasing fertilizer use efficiency and providing a more balanced supply of nutrients (Donovan and Casey, 1998). 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).

The low maize grain yields in the first season could be associated with the very low precipitation (average 126 mm) with most of it being recorded within the first three weeks of the season. This low precipitation could have reduced the availability of nutrients to the maize plants. However, the second season was characterized by high precipitation (average 698 mm) occurring throughout the season and this could have led to the higher maize grain yield.

Residual Mineral N

Leucaena with 30 kg N and P ha^{-1} had the highest (97.7 kg N ha^{-1}) residual mineral N while recommended level of inorganic fertilizer had the lowest (51.4 kg N ha^{-1}) residual mineral N at 0-30 cm depth. There was a significant difference ($P<0.05$) of mineral residual N between treatments at the end of the second season (Table 41.4). All treatments were higher in residual mineral N than the control with the exception of the recommended level of inorganic fertilizer. This trend could be attributed to the beneficial ability of the soil incorporated biomass to release N gradually (especially in the present scenario where they were soil incorporated when dry) unlike inorganic fertilizers which release N drastically after application making them have a low residual effect. No significant differences were observed for ammonium between the treatments at 0-30 cm depth but significant differences were observed in the other depths. Nitrate concentration was significantly different ($P<0.05$) between the treatments as well as depth. Lower levels of ammonia-N were noted in comparison with nitrate-N in all the treatments. This could be as a result of the rapid conversion of ammonia to nitrate following mineralization of inputs in the soil.

Table 41.4: Treatment effects on soil residual mineral N (kg ha^{-1}) at various soil depths at Chuka at the end of the second season

Treatment	0-30 cm	30-100 cm	100-150 cm
Cattle manure	77.7	143.4	38.2
Tithonia	67.8	282.8	94.2
Calliandra	64.1	-	-
Leucaena	77.5	104.4	43.2
Cattle manure + 30 kg N & P ha^{-1}	64.7	70.6	44.1
Tithonia + 30 kg N & P ha^{-1}	77.7	131.9	84.2
Calliandra + 30 kg N & P ha^{-1}	87.1	-	-
Leucaena + 30 kg N & P ha^{-1}	97.7	207.2	87
60 kg N & P ha^{-1}	51.4	56.4	49.8
Control	51.7	161.5	95.8
Mean	70.8	144.8	67.1
SED	10.6	28.5	15.6

The average concentration of mineral N was highest (144.8 kg N ha^{-1}) in the 30-100 cm soil depth and lowest (67.1 kg N ha^{-1}) in the 100-150 cm soil depth. Mineral N concentration was lower in the 100-150 cm depth in all the treatments. Cattle manure had the least concentration (38.2 kg N ha^{-1}) in the 100-150 cm depth (Table 41.4) while the recommended level of fertilizer had the least concentration in both the 0-30 cm and 30-100 cm depth with 51.4 kg N ha^{-1} and 70.6 kg N ha^{-1} respectively. The mineral N in the 100-150 cm soil depth is below the rooting zone of maize plants and may not be available to the maize plants (Mugendi *et al.*, 2000). It may also not be readily transformed (denitrified or assimilated) because of the limited microbial population and available C at this depth (Paramasivam *et al.*, 1999). This mineral N is therefore prone to leaching into ground water therefore careful management of soil fertility inputs like timely application and split fertilizer application that have been reported to reduce N leaching should be encouraged (Paramasivam *et al.*, 2001).

A bulge in nitrate occurred at 30-100 cm in all the treatments. This concurs with Kindu *et al.* (1997) who reported a bulge in nitrate at 0.3 to

1.5 m soil depth in the maize land use system in Western Kenya. The bulge (accumulation) in nitrate at this depth could be attributed to greater N mineralization compared to plant uptake of top soil N immediately after the onset of the rainy season, subsequent nitrate leaching and then adsorption of nitrate on positively charged soil surfaces. Hartemink *et al.* (1996), also working in the land use systems of western Kenya reported that about 60% of nitrate at 1 to 2 m depth was sorbed on soil surfaces; this sorption of nitrate is known to delay its downward movement resulting in nitrate accumulation in the subsoil (Wong *et al.*, 1987).

Farmers' perception

Two farmers' field days were held during the two seasons. The farmers were impressed with what they saw in the field and they were willing to experiment with these technologies especially with tithonia, which grows locally along the boundaries and roadsides.

Conclusion

The high maize grain yields in the second season demonstrate the positive impact of these technologies in the area. Tithonia with half recommended rate of inorganic fertilizer gave impressive yields and hence the farmers are encouraged to adopt it on their farms to improve their food security. The bulge in nitrate at 30-100 cm depth indicates that there is nitrogen leaching in the soil and this calls for action.

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