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Maize Response to Organic and Inorganic Soil Amendments Grown Under Tropical Acidic Soil of Kenya

Kisinyo Peter Oloo

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School of Agriculture, Natural Resources and Environmental Studies, Rongo University College, P. O. Box 103-40404, Rongo, Kenya.E-mail: kisinyopeter@yahoo.com or dean-agriculture@ruc.ac.ke

ABSTRACT

The one year field study evaluated the effectiveness of cattle manure (CM), nitrogen (N) and phosphorus (P) fertilizers on some soil chemical properties and maize *(Zea mays L.)* grain yield in Migori County, Kenya. CM was alkaline and of good quality, likely to increase soil pH and mineralize to release N and P to soil solution. The soil was acidic (pH = 5.5), had low Ca, N, P and C. CM increased soil pH by 9 to 15%, P by 7 to 9%, N by 17 to 60% and C by 22 to 36% while the inorganic fertilizers reduced soil pH by 4 to 6%. N and P fertilizer increased soil N by 50 to 120% and P by 7 to 14%. Grain yield increased by 36, 108, 157, 189 and 203% due to 2 tons CM, 26 kg P+75 kg, 2 tons CM 26 kg P+75 kg N, 52 kg P+75 kg N and 2 tons CM+52 kg P+75 kg ha^{-1}, respectively. Organic and inorganic materials have the potential to increase maize grain yield on tropical acid soils with low N, P and organic matter such as reported in this study. 2 tons CM+52 kg P+75 kg N ha^{-1} was most suitable for soil fertility replenishment necessary for high maize grain yield.

Key words: Soil, Cattle Manure, Phosphorus, Nitrogen and Maize.

INTRODUCTION

The major constraints limiting crop production in medium to high agricultural potential areas in tropical Africa are soil acidity, deficiencies of nitrogen (N), phosphorus (P) and low soil organic matter (SOM) (Buresh et al., 1997; Kanyanjua et al., 2002; Kisinyo, 2011; Opala et al., 2015). These soils have high aluminium (Al), hydrogen (H), iron (Fe) and manganese (Mn) toxicities with deficiencies of P, molybdenum (Mo), calcium (Ca), magnesium (Mg) and potassium (K) (Sánchez et al., 1997). Like many tropical African soils, Kenya acid soils have low levels of base cations with high of H^+, Fe^{3+} and Al^{3+} levels due to leaching of base cations by high rainfall (Sánchez et al., 1997; Kisinyo et al., 2013; Obura, 2008;). Among the Kenyan smallholder farmers, soil available P are extremely low due to its fixation by Fe^{3+} and Al^{3+} ions and because of their inability to use adequate P fertilizers to replenish soil P removed through crop harvests due to lack of credit and high fertilizer costs by (Obura et al., 2001; Okalebo et al., 2006; Kisinyo, 2011). Tropical African low soil N is because of its leaching by high rainfall, high rate of organic matter decomposition and inadequate use of N fertilizers by smallholder farmers to replenish soil N removed through crop harvests (Okalebo et al., 1997; 2006). Low SOM in many tropical African areas are due to high rate of organic matter decomposition, inadequate organic material amounts for its replenishment, removal and burning residues after crop harvests (Okalebo et al., 1997; Sánchez et al., 1997).

In tropical lands soil acidity reduce maize and other cereal grain yields by nearly 10% while in Kenya low N and P reduce maize grain yield by about 30 and 28%, respectively (Ligeyo, 2007; Sierra et al., 2003). Although maize is the staple food grain yield is very low (< 1.0 ton ha^{-1}) against a potential of 4 tons ha^{-1} under good husbandry. Therefore, there is need to investigate the effect of the organic and inorganic materials on maize grain production on infertile soils of Kenya. This study evaluated the effectiveness of cattle manure, N and P fertilizers on some soil chemical properties and maize grain yield in tropical soil of Migori County, Kenya.

MATERIALS AND METHODS

Site Description

The study was conducted on a small holder farmer's field

Table 1.Chemical composition of cattle manure.

MC (%)	% N	% C	% P	% Ca	% Mg	% K	pH	% Lignin	% Polyphenol
30	1.72	35	0.37	0.12	0.5	2.4	7.4	20	0.81

MC= Moisture content.

(1^o04'S and 34^o47'E) in tropical Migori County, Kenya. The site is 1500 m above sea level with mean annual temperature of 14 to 22^oC. It has mean annual rainfall of 1200 mm with bimodal distribution pattern with long rains from March to June (336 mm) and short ones from September to December (204 mm) (Sombroek et al., 1982; Jaetzold and Schmidt, 1983; Migori Monthly Climate Average, Kenya, 2016;). Farmers in the study area plant maize mainly during the long rains and maize or tobacco during the short rains. The study site has orthic Ferralsol soil classification (FAO, 1988).

Soil Sampling

Before inorganic and organic materials applications, nine sub-soil samples were taken with a soil auger from the top (0 to 20 cm) soil depth in a zig - zag manner from the experimental site in March, 2014. They were thoroughly mixed and about 1.0 kg composite sample packed in a polythene bag, properly labeled and taken to the laboratory for both physical and chemical analyses. Samples were also taken from each plot during harvesting as described above to determine some chemical changes due to treatments applications.

Preparation of Organic Materials

Completely decomposed cattle manure was collected from the farmer's cattle yard, air-dried and a sub-sample sent to the laboratory for analysis. Table 1 shows the composition of cattle manure used in this study. It had an alkaline pH (pH = 7.4) likely to ameliorate soil acidity. The manure had a C: N ration of 19.6 and a C: P ration of 94.6. It had high lignin (> 15%) level and low polyphenol (<4%). The material is of good quality and is therefore expected to readily release N and P into the soil solution (Palm et al., 2001; Okalebo et al., 2002).

Experimental Design and Field Layout

The treatments were laid out in randomized complete block design replicated three times. The treatment combinations were used:

1. Control
2. 2 tons Cattle Manure ha^{-1}
3. 26 kg P + 75 kg N ha^{-1}
4. 2 tons Cattle Manure + 26 kg P + 75 kg N ha^{-1}
5. 52kg P + 75 kg N ha^{-1}
6. 2 tons Cattle Manure + 52kg P + 75 kg N ha^{-1}

The recommender fertilizer rates for maize production in Kenya are 26 kg P and 75 kg N ha^{-1} (Kenya Agricultural Research Institute, 1994). 2 tons cattle manure provided 7.4 kg P+ 34.4 kg N ha^{-1}. Where 2 tons CM + 26 kg P + 75 kg N ha^{-1} was applied, CM supplied 7.4 kg P + 34.4 kg N ha^{-1} while triple super phosphate (TSP) provided 18.6 kg P N ha^{-1} and ammonium nitrate (CAN) provided 40.6 kg N ha^{-1} . With application of 2 tons CM + 52kg P + 75 kg N ha^{-1}, cattle manure provided 7.4 kg P + 34.4 kg N ha^{-1} , TSP provided 34.4 kg P ha^{-1} and calcium CAN provided 40.6 kg N ha^{-1}.

Field Procedures and Data Collection

After ploughing and harrowing, plots of 4 m by 3 m were demarcated and each plot was separated from each other with a guard row between of 1.0 m apart. Planting holes were made at a spacing of 75 cm between rows and 25 cm within rows. Cattle manure and P fertilizer was broadcast and mixed well with the soils before planting. Nitrogen fertilizer was applied at 30 and 45 kg N ha^{-1} at planting and top-dressing, respectively. Two seeds of maize hybrid (H520) were planted per hole at a spacing of 25 cm within rows and 75 cm between rows. Plots were weeded using a hand hoe while pest and disease management were carried out when necessary. Maize was harvested at physiological maturity, leaving out guard rows and plants at the end of each plot to avoid edge effects. Cobs were separated from the stover and their fresh weight recorded. Eight representative cobs were randomly taken per plot and their fresh weights recorded. The samples were air-dried to a constant weight, shelled and grain weight per plot recorded. The grain yield was calculated using the following formulae:

$$\text{Yield (kg) per plot} = \frac{\text{Total Fresh Weigh (kg) x Sample Dry Weight (kg)}}{\text{Sample Fresh Weight (kg)}} \quad (1)$$

$$\text{Yield (kg ha}^{-1}\text{)} = \frac{\text{Yield per plot x 10,000 m}^2}{\text{Effective Area (m}^2\text{)}} \quad (2)$$

Where effective area is part of the plot harvested which is less the guard row and plants at the end of each row.

Laboratory Analyses

The soil samples were air-dried and the ones taken before treatment applications were analyzed for texture, pH (1: 2.5; soil: water), Olsen P, exchangeable bases (Ca^{2+}, Mg^{2+}, K^+ and Na^+), organic carbon (%C) and total N (%N). The samples taken after treatment applications

Table 2. Initial soil chemical and physical characteristics of the study site.

Soil pH	% N	Olsen P (mg P kg^{-1})	% C	Exchangeable bases (cmol kg^{-1}) Ca	Mg	K	% Clay	% Silt	% Sand	Textural class
5.5	0.05	6.2	1.88	3.2	0.7	0.7	30	8	62	Sandy loam

Table 3. Effect of treatments on the soil pH, available P, total N and organic carbon.

Parameter	Soil pH		Olsen P (mg kg^{-1})		% N		% C	
Season	LR	SR	LR	SR	LR	SR	LR	SR
Control	5.51±0.04	5.37±0.03	6.30±0.05	5.76±0.03	0.06±0.03	0.05±0.02	1.55±0.07	1.77±0.06
2 tons CM ha^{-1}	6.02±0.02	6.23±0.02	6.44±0.03	6.34±0.04	0.07±0.04	0.08±0.03	2.11±0.05	2.16±0.03
26 kg P + 75 kg N ha^{-1}	5.31±0.01	5.20±0.03	6.39±0.02	6.44±0.05	0.12±0.04	0.11±0.02	1.67±0.04	1.79±0.04
2 tons CM + 26 kg P + 75 kg N ha^{-1}	5.82±0.03	5.80±0.04	6.77±0.05	6.87±0.06	0.13±0.05	0.14±0.02	2.22±0.05	2.19±0.05
52 kg P + 75 kg N ha^{-1}	5.24±0.03	5.13±0.02	6.53±0.04	6.63±0.05	0.09±0.02	0.09±0.04	1.87±0.03	1.82±0.05
2 tons CM + 52 kg P +75 kg N ha^{-1}	5.71±0.02	5.60±0.02	7.21±0.05	7.12±0.02	0.11±0.02	0.10±0.03	2.12±0.06	2.20±0.03
Mean	5.60	5.56	6.61	6.53	0.10	0.10	1.92	1.99
% CV	4.7	5.4	12	14	17	18	7	9
SED (p ≤ 0.05)	0.3	0.2	1.1	1.5	0.03	0.04	0.31	0.42

LR = Long Rain, SR = Short Rain and CM = Cattle Manure containing 34.4 kg N+7.4 kg P ha-1.

were analyzed for pH, Olsen P, %N and %C. Detailed laboratory procedures are outlined in Okalebo et al. (2002). Cattle manure was oven-dried at 70ºC, ground to pass through a 0.5 mm sieve. They were analyzed for pH, nutrient contents (total N, P, K, Ca, and Mg) and %C, lignin and polyphenols according to procedures described by Anderson and Ingram (1993).

Statistical Analysis of Data

Maize grain yield and soil analytical data taken after treatment application were subjected to analysis of variance (ANOVA) using General Statistics (GenStat, 2010). Means were separated using pooled standard error of difference of means (S.E.D) whenever treatment effects were significant at p ≤ 0.05.

RESULTS AND DISCUSSION

Initial Study Site Soil Chemical and Physical Characteristics

Table 2 shows the initial chemical and physical characteristics of the experimental site. The soil was acidic with low N, P, Ca and C levels while the levels of Mg and K were adequate. At soil pH ≤ 5.5, Al^{3+} and Fe^{3+} ions toxicities becomes a problem in acid soils (Sánchez et al., 1997). Soil N (< 0.25%), P (< 10 mg kg^{-1}), C (<4%), Ca (< 4 cmol kg^{-1}), Mg (< 0.5 cmol kg^{-1}) and K (< 0.5 cmol kg^{-1}) levels are classified as low (Landon, 1991; Okalebo et al., 2002). Low soil N in tropical soils such as reported in this study is due to its leaching by high rainfall and insufficient application of N fertilizers (Sánchez et al., 1997; Okalebo et al., 2006;). Low soil available P is probably due to its sorption by Al^{3+} and Fe^{3+} ions common in acid soils with pH ≤ 5.5 such as observed in the current study (Kisinyo et al., 2013; Okalebo et al., 2006). Low C in tropical soils are due to its rapid decomposition due to adequate soil moisture and favourable temperature as well as inadequate SOM use by farmers (Palm et al., 1997). Low Ca reported in this study is a characteristic of tropical soils that have lost most base cations due to leaching by high rainfall (Sánchez et al., 1997). Soils with high proportion of sand such as this are porous and are therefore prone to leaching of nutrients (Landon, 1991). Therefore, soil acidity, low levels of N, P, C and Ca renders this soil unsuitable for healthy maize growth without adequate organic and inorganic inputs.

Effect of Soil Amendments on Soil Properties

Table 3 below shows the effect of treatments on soil pH, available P, total N and C. Soil organic matter increased soil pH while inorganic fertilizers decreased it with CM having significant effect ($P \leq 0.05$) during the second cropping season. Cattle manure increased soil pH by 9 to 15% while the inorganic fertilizers reduced it by 4 to 6% during the cropping seasons. Cattle manure effect on soil pH is consistent with report by Opala et al. (2010; 2013) where application of tithonia and farm yard manure increased soil pH. Increased soil pH reported in this study could be due to higher original pH of the CM, the effect of humic materials and organic acids it contained on the surfaces of sesqioxides by ligands exchange and consequent release of OH^- ion into the soil solution (Hue et al., 1986). Application of the inorganic fertilizers decreased soil pH because of the release of phosphoric acid during TSP dissolution. Both cattle manure and P fertilizer did not have significant

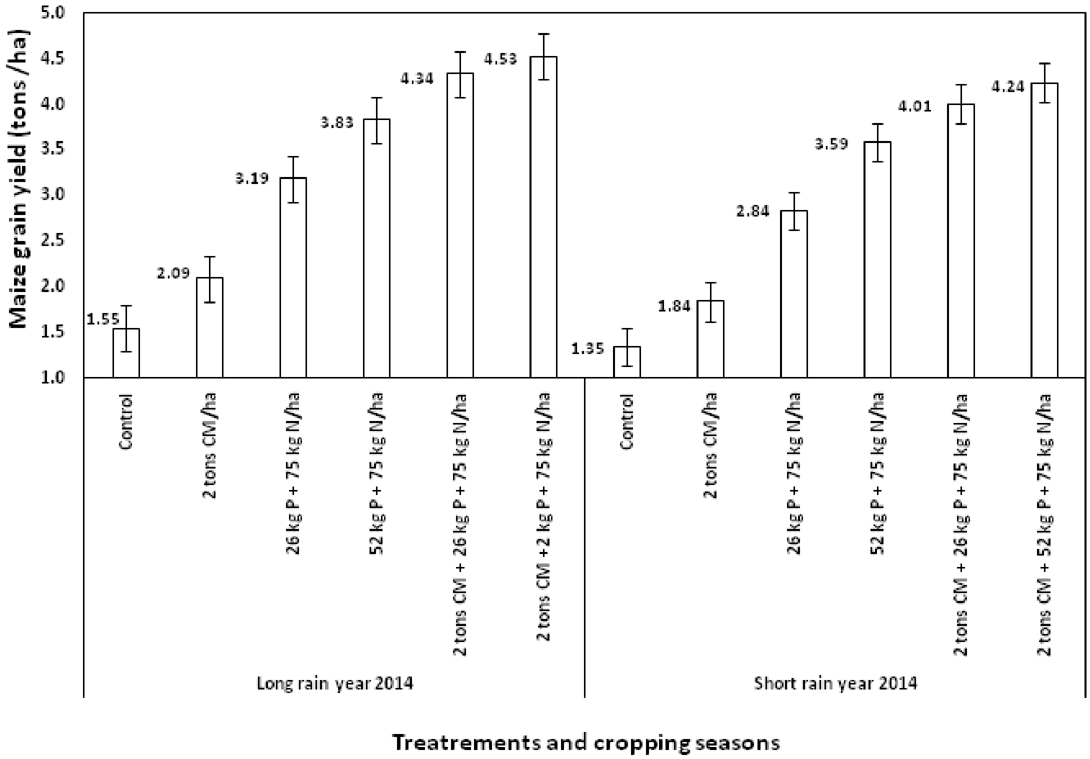

Figure 1. Effect of organic material and inorganic fertilizers on maize grain yield. Error bars indicates S.E.D AND CM = Cattle Manure.

($p \leq 0.05$) effects on soil available P. Cattle manure increased soil P by 7 to 9% and P fertilizer by 7 to 14% during the cropping seasons.

The slight increase on soil available P due to CM was due to its low P content and possible desorption of fixed P. Previously, researchers have reported increased soil P availability due to organic matter ability to reduce P sorption on acid soils (Whalen and Chang, 2002; Opala et al., 2010). Application of P fertilizer increased available P due to increase on solution P. Similar increase on soil available P on tropical soils have been reported (Nziguheba et al., 2000; Kisinyo et al., 2014; Opala et al., 2015). Combined application of the inorganic P and CM increased soil available P more than where either of them was applied alone. Similar results were reported by Opala et al. (2010). This was because organic material reduced soil P sorption making both the soil native P and the applied P fertilizer available for plant uptake (Nziguheba et al., 2000; Opala et al., 2010). Cattle manure increase soil N however the effect was not significant ($p \leq 0.05$) due to its low N content. CAN increase soil N due to increase in soil solution N however the effect was not significant ($p \leq 0.05$) due to possible leaching of NO_3^- down the soil profile. Cattle manure increased soil N by 17 to 60% and N fertilizer by 50 to 120%. Similar increase on soil N levels due to inorganic N fertilizer application has been reported elsewhere on tropical soils (Kisinyo et al., 2015, 2014; Opala et al., 2015). Cattle manure increased soil C by 22 to 36% but the effect was insignificant ($P \leq 0.05$) due to rapid organic matter decomposition in tropical soils such as reported in this study. The current study confirms earlier research in tropical soils where addition of organic materials increased SOM (Kipkiyai, 1996; Palm et al., 1997; Opala et al., 2015).

Effect of Organic and Inorganic Materials on Maize Grain Yield

Figure 1 shows the effect of treatments on maize grain yield. Treatment effectiveness on grain yield increment followed the increasing order of control < cattle manure < inorganic fertilizers < cattle manure + inorganic fertilizers. All treatments had significant ($p \leq 0.05$) on grain yield over and above the control. Grain yield increments were: 36,108, 157, 189 and 203% due to 2.0 tons cattle manure, 26 kg P + 75 kg N, 52 kg P + 75 kg N, 2.0 tons cattle manure+ 26 kg P + 75 kg N and 2.0 tons cattle manure+ 52 kg P + 75 kg N ha^{-1}, respectively. Cattle manure alone was inferior to the inorganic fertilizers (CAN and TSP) due to its low nutrient levels (N and P). Where cattle manure was applied grain yield increase probably due its ability to increase soil pH and reduction P sorption therefore making soil P available for plant uptake. Crop yield responses such as reported in this study due to use organic materials have been reported by several authors (Murgwira and Murwira, 1997; Sánchez et al., 1997; Opala et al., 2015). Application of the inorganic fertilizers increase grain yield because CAN supplied the necessary N while TSP supplied P required by plants for health growth. In plants, N is essential for vegetative growth while P is necessary for root development, root growth, healthy plant growth and high grain production (Tisdale et al., 1990; Sanginga and Woomer, 2009).

In Kenyan soils, Kisinyo et al. (2014) reported grain yield increments above the absolute control of 139% as a result of 26 kg P + 75 kg N ha^{-1} and 231% due 52 kg P + 75 kg N ha^{-1}. Combined application of both the inorganic and organic materials increased grain yield more than where either of them was applied alone in the current study. Combined application of organic and inorganic materials has been severally reported to increase crop yields than either of them alone (Goyal et al., 1992; Kifuko et al., 2007; Opala et al., 2010). Therefore, both organic and inorganic materials have the potential to increase maize grain yield on nutrient deficient acid soils such as reported in this study. However, there have been conflicting results on combined use of the organic and inorganic materials due to the low quality of some organic materials and the quantities applied. Most organic materials particularly of cereal straws are low in nutrients (Palm et al., 1997).

CONCLUSION

The soil in the study area was found to be acidic, had low N, P, Ca and C. Cattle manure increased soil pH by 9 to 15%, available P by 7 to 9%, N by 17 to 60% and C by 22 to 36%. The inorganic fertilizers reduced soil pH by 4 to 6% during the cropping seasons since TSP fertilizer acidifies the during its phosphoric acid dissolution. TSP fertilizer increased soil P by 7 to14% while N fertilizer increase soil N by 50 to 120%. A combination of both organic and inorganic materials had more effect on soil N and P compared to where either of them alone was applied. Grain yield increments were: 36,108, 157, 189 and 203% due to 2.0 tons cattle manure, 26 kg P + 75 kg N, 52 kg P + 75 kg N, 2.0 tons cattle manure+ 26 kg P + 75 kg N and 2.0 tons cattle manure + 52 kg P + 75 kg N ha^{-1}, respectively. Cattle manure and inorganic fertilizers (N and P) have the potential to increase soil pH, C, N, available P and maize grain yield on infertile acid soils such as reported in this study. Given the extent of soil acidification and low nutrient status, a combination of 2.0 tons cattle manure + 52 kg P + 75 kg N ha^{-1} is best for soil fertility replenishment suitable for maize grain yield.

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