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Evaluation of organic and inorganic amendments on nutrient uptake, phosphorus use efficiency and yield of maize in Kisii County, Kenya

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Soil phosphorous and nitrogen are the major constraints to maize production in Nyanza Province of Kenya. The yields are typical of low input systems ranging below 1.0 t ha^{-1} against a potential of 5.0 t ha^{-1} per season. This study was conducted at Bototo, Kisii County in Nyanza Province, Kenya, during the long and short rains seasons in 2007. The aim was to determine the effects of phosphatic fertilizers and manure on nutrient uptake, nutrient use efficiency, maize yields and soil nutrients content at harvest. A Randomized Complete Block Design (RCBD) was used with the farms as blocks. Maize H614 hybrid was sown at a spacing of 0.75 × 0.60 m. The plot sizes were 3.75 m by 4.8 m. All plots were top dressed with Calcium ammonium nitrate (CAN) fertilizer at a uniform rate of 30 kg N ha^{-1}. Diammonium Phosphate (DAP), Minjingu Rock Phosphate (MRP) and Triple Super Phosphate (TSP) fertilizers were applied at a rate of 60 kg ha^{-1} P_2O_5 (P) and farmyard manure (FYM) at 10 t ha^{-1}. One rate of P at 60 kg ha^{-1} was applied on all the phosphorus fertilizers and a no P treatment (check) plus lime only treatment was included in determining the effects due to the applied P in the acidic soils. Complete soil chemical analysis was done in all the plots at the planting time. There was significant ($p \leq 0.01$) crop growth vigour, grain yield, total dry matter, harvest index, nutrient uptake and removal by the crop, available soil P, agronomic phosphorus use efficiency (APUE), physiological P use efficiency (PPUE) due to fertilizers and manure application, with a corresponding reduction in the total soil N, P, K, Ca and Mg. Phosphate fertilizers and manure applications are essential to improve maize yields and nutrient P use efficiency.

Key words: Soils, fertilizer use efficiency, nutrient uptake, lime, maize yield.

INTRODUCTION

Appropriate fertilizer use leads to increased crop yields and high crop recovery of applied nutrients. Some elements may be hazardous to the environment if not used in various forms such as nitrates and phosphates (Buresh et al., 1997). Efficient fertilization is therefore important in ensuring crops attain maturity within specific

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growing seasons (Lelei et al., 2006).

Soil reaction products have made agronomic evaluation of P fertilizers complicated due to range in characteristics of those materials coupled with the complex nature of fertilizers. Effectiveness of P sources therefore depends on the chemical and physical properties, rate and method of application, soil and climatic conditions and the crop species grown (Mokwunye and Bationo, 2002).

Over the recent years, there has been increased use of fertilizers mainly to improve crop production thus increase the economic returns, for example, Diammonium Phosphate (DAP), Triple Super Phosphate (TSP) and Minjingu Rock Phosphate (MRP) fertilizers (Negassa, et al., 2005). Several drawbacks have been reported while using Diammonium Phosphate where young crops have shown injury due to wrong application (Okalebo, 1997). Diammonium Phosphate has also been shown to lower the availability of the soil magnesium, calcium and potassium ions forming insoluble compounds (Opalla et al., 2013). This study was done to establish the influence of phosphorus application rate in different types of fertilizers and manure on growth and yields of maize, in order to allocate appropriate fertilizers and manure to suit varying agricultural conditions in the long and short rains planting seasons.

Maize nutrient (nitrogen, phosphorus, potassium, calcium and magnesium) uptake, use efficiency and yields in Nyanza Province of Kenya have been on the decline (Opalla et al., 2013; Negassa et al., 2005). This may be associated with lack of suitable fertilizer application rates and soil acidity since the current research recommendations, to specific areas in Kisii, Kenya were developed more than two decades ago (FURP, 1994). The extent of nutrient depletion is unknown and phosphate fertilizer and manure application by farmers is not commensurate with the plant requirements and / or nutrient levels in the soil. Twenty years have elapsed since the last country wide fertilizer use recommendation was carried out including Kisii County; during this period a decline of maize yields have been realized (Smalling et al., 1997). Maize is a major food crop for the community within Kisii County of Kenya. This has raised concerns about food insecurity. One of thecauses of food insecurity in the study area is soil acidity which affects crop production, especially maize. There was therefore need to determine the nutrient use efficiencies of phosphate fertilizers and manure and their effects in acidic soils of smallholder mixed farms. There was necessity to develop appropriate recommendations on application rates of fertilizer and manure that can be used by smallholder farmers in acidic soils in Bototo, Kisii County in Kenya. The study was conducted during the long and short rains planting seasons in 2007.

MATERIALS AND METHODS

Field experiment was conducted at an on–farm site in Bototo at an altitude of 1590 masl, 34°44'E and 0° 39'S and 1200 to 2100 mm rainfall. The site is located in upper midland zones (UM_1) with agro climatic conditions suitable for maize, tea, coffee and sweet potatoes production (Jaetzold et al., 2007). Maize is the leading food crop in the region and was planted twice a year, during the long rains March to July 2007 and short rains August to December 2007. The upper midlands (UM_1) lie between 1500 and 1900 m above sea level. It is warm and humid with annual mean temperature of 18 to 25.5°C and a mean minimum temperature of 11 to 14°C. The annual average precipitation is greater than 80% of the potential evaporation (E_0).

The soils are mollic Nitisols or sandy loam Nitisols with moderately high fertility (Jaetzold et al., 2007). Maize is planted twice annually (March to July) and (August to December). The experimental design was Randomized Complete Block Design (RCBD) with selected farms as blocks (ten men and ten women). The sites were chosen randomly based on being dominated by acidic soils and having agro-ecological similarities. The previous cropping history and management showed that the performance was poor. The treatments were:

i). No phosphorus fertilizer used at planting -Control
ii). Lime only- 250 kg ha^{-1} $CaCO_3$
iii). Diammonium Phosphate (DAP)- 60 kg ha^{-1} P_2O_5
iv). Minjingu Rock Phosphate (MRP)- 60 kg ha^{-1} P_2O_5
v). Triple Super Phosphate (TSP) - 60 kg ha^{-1} $P_2O_5P_2$
vi). Farm Yard Manure (FYM) -10 t ha^{-1}
vii). ½ FYM + ½ DAP - 5 t ha^{-1} FYM + 30 kg ha^{-1} P_2O_5

The nutritional status of FYM was analysed and found to be relatively the same for all the farms.

Land preparation was done prior to the start of the rains (the long rains March to July 2007 and short rains August to December 2007), ploughed and harrowed twice using oxen to obtain a fine tilth seedbed. There were seven plots per block each measuring 3.75 m wide by 4.80 m long giving plot area of 18 m^2. Lime was applied in one of the seven plots per block at the rate of 250 kg ha^{-1} $CaCO_3$ two weeks before sowing. Each plot consisted of 5 rows each with 8 hills. Maize hybrid H614 was the test crop in Bototo, chosen on the basis of being a suitable variety for the study area (Jaetzold et al., 2006).

At the onset of rains (the long rains March to July 2007 and short rains August to December 2007), three seeds were sown per hill. Fertilizers were applied at time of planting along the furrows and mixed with soil to avoid direct contact with the seeds to avoid scotching. All plots were uniformly top dressed with CAN fertilizer at a rate of 30 kg N ha^{-1} as recommended (FURP, 1994).

Furadan was applied in each planting hole at the rate of 10 kg ha^{-1} to protect the seeds and seedlings against soil borne pests after which the seeds were placed and covered with a small quantity of soil. The crop was protected against maize stalk borer *(Busseola fusca)* by application of Kombat (Carbaryl), a commercial insecticide, applied to the maize funnels at 4 weeks after planting at the rate of 4 kg ha^{-1}. Weeding was done twice after crop germination, one month after planting, then two months respectively.

Gladiator was applied in each trial site to prevent termite damage. Whenever a termite attack was visible, insecticide (Gladiator 4TC, liquid, active ingredient 480 gl À1 chlorpyrifos) was applied at the base of the maize plants to control this damage. The crop was harvested at physiological maturity from a net harvest area of 18 m^2 and threshed by hand. All ears affected by pests or rotten were excluded in yield measurements. All the consumable grains per plot were weighed and then sub–sampled. The maize stover was cut at about 5 cm above the ground level, weighed and sub-sampled for dry matter determination.

Data collected included planting date, emergence date at principal growth stage (0) (germination), code 00 (dry seed), code

09 (emergence), stand count at 21 days after emergence (DAE), scores for crop growth vigor on a scale of 1 to 7 at 21 DAE according to BBCH scale at principal growth stage 3 (stem elongation), code 33 (3 nodes detectable) on a rating scale of 1-7 (1- least vigorous, 7- most vigorous) based on the length of the maize plant, plant stand count at harvest (Lancashire et al., 1991). Common diseases (bacterial diseases, fungal diseases, nematodes, parasitic and viral diseases), flowering date, harvesting date, and yield per plot converted to t ha $^{-1}$. Data was collected in a net plot of 18 m^2.

Crop harvest data included field grain, cob and stover weights recorded. Field grain moisture content was recorded using a grain moisture tester (model DjGMTS. N. 0528.).

Sub-samples of grain, cobs and stover were then taken for oven drying and subsequent dry matter yield determination. The grain yield (adjusted to 15% moisture content), total above ground dry matter yield, harvest index, and total nutrient uptake and phosphorus use efficiency was calculated using the following formulae:

(i) Grain yield (at 15% moisture) = GW × (100 – MCA) / 100 – MCD
(ii) Total dry matter yield (kg ha^{-1}) = GY + SY +CY
(iii) Harvest index = GY / Total dry matter yield
(iv) Total nutrient uptake = (NCG X GY) + (NCS X SY) + (NCC X CY)

Where: *GY, SY* and *CY* are grain, stover, and cob dry matter yields respectively; *GW, MCA* and *MCD* are fresh grain weight, moisture content of fresh grain and moisture content of grains at 15% moisture respectively; *NCG, NCS* and *NCC* are nutrient (N, P, K, Ca, and Mg) concentrations in grain, stover and cob respectively.

Nutrient phosphorus use efficiency was calculated using the following formulae:

(v) Agronomic P use efficiency = $\frac{Y_f - Y_O}{P}$

(vi) Physiological P use efficiency = $\frac{Y_f - Y_O}{P_{uf} - P_{uo}}$

Where: Y_f, and Y_o are yields of fertilized and unfertilized crops respectively; *P* is the rate of fertilizer P applied, P_{uf} and P_{uo} are P uptake in fertilized and unfertilized crops respectively.

The changes in soil nutrient contents at harvest were determined by difference method:

(vii) Change in soil nutrient content = $P_x – P_o$.

Where: *Px* is the nutrient content for a given fertilizer application rate.*Po* is the nutrient content for the check (zero) fertilizer treatment (Sigunga et al., 2002).

At the start of the experiment, soil samples were randomly collected from 5 spots in a zigzag pattern at a depth of 0 to 30 cm at each experimental farm using a 5-cm diameter auger. The samples were used to assess initial soil fertility status. The soil samples were mixed to obtain a composite sample. About 3 kg sub–samples were obtained from the composite sample, air–dried in a well-ventilated room for three days and ground to pass through 2-mm sieve. The soil samples were analyzed for pH 1:2.5 soil: solution (H_2O and 0.01 M $CaCl_2$), extractable P, %P, %N, texture, organic carbon, exchangeable acidity, cation exchange capacity (CEC), and exchangeable bases. At crop harvesting, composite soil samples were collected per plot at 3 spots per row, to assess changes in soil chemical properties with respect to the fertilizer treatments applied. The samples were analyzed for extractable P, %N, %P, %K, and %Ca contents (Okalebo et al., 2002).

Plant samples were separated into stover, cob, and grain. The stover was chopped using a chaff cutter. The stovers, cobs, and grains were sub-sampled, weighed, and oven–dried to a constant weight at 70°C for 48 h for determination of the above ground dry matter yield. The dried plant material was ground using Cromption Willey mill to pass through a 2 mm sieve and sub-sampled for total N, P, K, Ca and Mg determination.

Data analyses

Data on growth vigor, grain yield, total dry matter yield, harvest index, nutrient (N, P, K, Ca, and Mg) uptake, phosphorus use efficiency, soil nutrient contents (extractable P, %P, %N, %K, % Ca at harvest, were subjected to the General Linear Model (GLM). Twenty farms serving as blocks/replicates in the GLM and mean at p = 0.001 using Tukeys. Correlation analysis was carried out to estimate the relationship between the variables such as grain yield, total dry matter yield, harvest index and nitrogen uptake, phosphorus uptake, calcium uptake, magnesium uptake, phosphorus PAUE, PPUE, extractable phosphorus, total soil phosphorus, total soil potassium, total soil calcium, and total soil magnesium. SAS statistical package was used for analysis.

RESULTS

Maize yields

Initial soil analysis indicated that the soils at the site were low in fertility, acidic, with low amounts of total N, organic carbon, and total and extractable phosphorus and exchangeable bases (Table 1).

Visual observations revealed P deficiency symptoms (over-all stunted growth) in the Control plots at early crop growth stages (4 weeks after crop emergence) at the site (Table 2). There were significant difference ($p \leq 0.0001$) crop growth vigour response to the fertilizers and manure. Plants that received fertilizer and manure were more vigorous in growth than those in the control plots. Maize growth vigour varied from 1.15 in the Control plots to 6.95 in the ½ DAP + ½ FYM treatment with a mean of 3.76. The maize growth vigour scores were 5.0, 4.75, 3.95, 2.95 and 1.15 in TSP, FYM, DAP, MRP and lime respectively (Table 2). There were P deficiency symptoms in plants that did not receive P treatments which indicated that P limited crop growth. There was significant difference ($p \leq 0.0001$) effect of fertilizer on grain yield. Grain yield varied from 1722 kg ha^{-1} in the Control plots to 6244 kg ha^{-1} in the ½ DAP + ½ FYM treatment with a mean of 3932 kg ha^{-1}. The grain yields were 4961, 4274, 3995, 3760 and 2569 kg ha^{-1} in TSP, FYM, DAP, MRP and lime respectively. The significant grain yield response to fertilizers and manure application at the site (Table 2) is attributed to the low soil P status of these soils (Table 1). There was significant difference ($p \leq$ 0.0001) effect of fertilizer and manure on total dry matter yield. Total dry matter yield varied from 6.49 t ha^{-1} in the control plot to 16.33 t ha^{-1} in the ½ DAP + ½ FYM treatment with a mean of 11.47 t ha^{-1}. The total dry matter yields were 13.61, 12.32, 11.69, 11.2 and 8.68 in TSP, FYM, DAP, MRP and lime respectively (Table 2). There

Table 1. The initial pH, extractable P, phosphorus, nitrogen, potassium, calcium and magnesium at the start of the experiment at the study site (0 to 30 cm).

Treatment	pH	Extractable P (mg P /kg)	Phosphorus (ppm)	Nitrogen (%)	Potassium (%)	Calcium (%)	Magnesium (%)
½ DAP + ½ FYM	4.3	3.0	16.6	0.11	4.9	1.10	0.85
TSP	4.4	3.1	16.4	0.10	4.8	1.20	0.70
FYM	4.0	3.2	16.4	0.20	5.0	1.10	0.90
DAP	3.9	2.9	16.6	0.10	4.8	1.20	0.90
MRP	4.2	2.9	16.4	0.20	4.7	1.10	0.80
Lime	4.1	3.3	16.8	0.12	5.1	1.12	1.0
Control	4.4	3.0	16.7	0.11	4.9	1.10	0.8
Mean	4.2	3.1	16.5	0.14	4.9	1.13	0.85
COV %	3.3	2.7	8.3	7.3	2.3	6.93	4.2
SE +/ -	0.031	0.019	0.315	0	0.025	0.017	0.008
MSD	0.131	0.079	1.339	0.009	0.105	0.074	0.034

Table 2. Effects of treatments on mean maize growth vigour scores, maize grain yield, total dry matter yield and harvest index at the study site.

Treatment	Maize growth vigour score*	Grain yield (kg/ha)	Total dry matter yield (t/ha)	Harvest Index (HI)
½ DAP + ½ FYM	6.95	6244	16.33	0.37
TSP	5.0	4961	13.61	0.35
FYM	4.75	4274	12.32	0.33
DAP	3.95	3995	11.69	0.33
MRP	2.95	3760	11.2	0.32
Lime	1.55	2569	8.68	0.30
Control	1.15	1722	6.49	0.26
Mean	3.757	3932	11.47	0.321
COV %	20.57	32.52	22.24	10.79
SE + / -	0.1728	285.92	0.571	0.0078
MSD	0.4841	801.02	1.598	0.0217

*Growth vigour ranked on a scale of 1-7 (1-least vigorous, 7 –most vigorous.) according to BBCH scale at principal growth stage 3 (stem elongation), code 33 (3 nodes detectable).

was significant effect of fertilizer and manure on harvest index ($p \leq 0.0001$). The harvest indexes varied from 0.26 in the Control plots to 0.37 in the ½ DAP + ½ FYM treatment with a mean of 0.321. The harvest indexes were 0.35, 0.33, 0.33, 0.32 and 0.30 in TSP, FYM, DAP, MRP and lime respectively (Table 2).

Nutrient uptake

Fertilizer and manure application had significant ($p \leq 0.0001$) effect on nutrient uptake. Nitrogen uptake varied from 21.1 kg ha^{-1} N in the Control plot to 67.8 kg ha^{-1} N in the ½ DAP + ½ FYM plot with a mean of 49.83 kg ha^{-1} N. Nitrogen uptake correlated positively ($p \leq 0.0001$, r = 0.84) with total dry matter yield. There was significant P uptake response to the fertilizers and manure (Table 3). The P uptake varied with the fertilizers and manure from 18.3 kg ha^{-1} P in the control plots to 63.5 kg ha^{-1} P in the ½ DAP + ½ FYM plots with a mean of 47.4 kg ha^{-1} P. Phosphorus uptake correlated positively ($p \leq 0.0001$, r = 0.72) with grain yield and total dry matter yield. Potassium uptake increased significantly due to the fertilizers and manure (Table 3). K uptake varied from 46.7 kg ha^{-1} K in the control plots to 105.1 kg ha^{-1} K in the ½ DAP + ½ FYM plots with a mean of 77.3 kg ha^{-1} K. Calcium uptake increased significantly due to the fertilizers and manure (Table 3). Ca uptake varied from 3.34 kg ha^{-1} Ca in the control plots to 8.25 kg ha^{-1} Ca in the ½ DAP + ½ FYM plots with a mean of 5.78kg ha^{-1} Ca. Magnesium uptake increased significantly ($p \leq 0.0001$, r = 0.77) due to fertilizers and manure (Table 3).

Table 3. Nutrient uptake by the maize plants at physiological maturity.

Treatment	Nitrogen uptake (kg ha^{-1} N)	Phosphorus uptake kg ha^{-1} P	Potassium uptake (kg ha^{-1} K)	Calcium uptake (kg ha^{-1} Ca)	Magnesium uptake (kg ha^{-1} Mg)
½ DAP + ½ FYM	67.8	63.5	105.1	8.25	4.12
TSP	47.8	43.3	82.9	5.06	2.99
FYM	67.3	59.6	80.6	8.17	3.49
DAP	56.3	51.6	86.0	6.74	3.98
MRP	50.8	56.8	80.2	6.33	3.44
Lime	37.7	38.4	59.5	3.56	2.69
Control	21.1	18.3	46.7	3.34	1.9
Mean	49.83	47.35	77.27	5.78	3.23
COV %	7.68	11.35	8.85	8.36	12.89
SE +/ -	0.856	1.202	1.530	0.108	0.093
MSD	2.398	3.367	4.287	0.303	0.261

Table 4. Phosphorus agronomic use efficiency and physiological use efficiency.

Treatment	Phosphorus agronomic use efficiency (kg grain/kg P applied)	Phosphorus physiological use efficiency (kg grain/kg P taken up)
½ DAP + ½ FYM	29	39
TSP	24	42
FYM	42	36
DAP	43	38
MRP	21	29
Lime	-	35
Control	-	29
Mean	31.85	35.53
COV %	6.80	6.02
SE +/ -	0.485	0.478
MSD	1.365	1.74

Mg uptake varied from 1.9 kg ha^{-1} Mg in the control plots to 4.12 kg ha^{-1} Mg in the ½ DAP + ½ FYM plots with a mean of 3.23 kg ha^{-1} Mg. There were significant ($P \leq 0.0001$) treatment effects on nutrient uptake which indicates significant N responses to fertilizers and manure (Table 3). Nitrogen uptake was highly correlated ($p \leq 0.0001$, $r = 0.84$) with total dry matter yield while phosphorus uptake correlated positively ($p \leq 0.0001$, $r = 0.78$) with grain and total dry matter yields. Lack of significant difference in N content between the control and lime treatments in all the plots was due to the blanket application of the recommended N rate.

Nutrient use efficiency

Fertilizer and manure application had significant difference ($p \leq 0.0001$, $r = 0.61$) effect on PUE. P agronomic use efficiency varied from 21 kg grain per kg P applied in the Minjingu Rock Phosphate plots to 43 kg grain per kg P applied in the DAP plots with a mean of 32 kg grain per kg P applied (Table 4). Control and lime treatments had no applied P and thus no data. Physiological P use efficiency responded significantly to fertilizers and manure (Table 4). Physiological P use efficiency varied from 29 kg grain per kg P taken up in the control and Minjingu Rock Phosphate plots to 42 kg grain per kg P applied in the TSP plots with a mean of 36 kg grain per kg P applied (Table 4).

Effects of treatments on soil nutrient contents

Fertilizer and manure application had significant difference ($p \leq 0.0001$) effect on soil nutrient contents. Fertilizers and manure application significantly increased the extractable soil P content above the control. Extractable P varied from 3.5 mg P/kg in the farmyard manure plots to 7.6 mg P/kg in the Minjingu Rock Phosphate plots with a mean of 5.43 mg P/kg (Table 5).

Table 5. Final pH, extractable P, phosphorus, nitrogen, potassium, calcium and magnesium.

Treatment	pH	Extractable P (mg P /kg)	Phosphorus (ppm)	Nitrogen (%)	Potassium (%)	Calcium (%)	Magnesium (%)
½ DAP + ½ FYM	5.1	6.8	2.2	0.01	2.02	0.0023	0.035
TSP	5.0	5.9	2.6	0.01	2.15	0.0027	0.024
FYM	5.1	3.5	2.4	0.01	2.96	0.0020	0.027
DAP	5.0	4.7	2.3	0.01	2.27	0.0024	0.024
MRP	5.4	7.6	2.3	0.01	2.87	0.0028	0.029
Lime	5.4	5.6	2.3	0.01	2.88	0.0029	0.022
Control	4.5	3.6	2.4	0.01	2.88	0.0022	0.020
Mean	5.1	5.4	2.35	0.01	2.56	0.0025	0.026
COV %	3.5	5.4	3.59	0	6.53	5.92	4.93
SE +/ -	0.039	0.065	0.019	0	0.037	0.00003	0.0003
MSD	0.167	0.277	0.080	0	0.159	0.0001	0.001

Total soil P contents were significantly (p≤ 0.0001) different. The total soil P content varied from 2.1% in the control plots to 2.5% in the TSP plots with a mean of 2.2% (Table 5). The fertilizers and manure had no significant effect on total N. The total N % was approximately 0.01. The fertilizers and manure had no effect on the total N % in the soils because a blanket application of 30 kg ha^{-1} N was done so that it was not limiting to the maize germination, growth and yield (Table 5). Total soil potassium (K) significantly (p≤ 0.0001) changed with the different fertilizers and manure applied. The total soil K varied from 2.02% K in the ½ DAP + ½ FYM plots to 12.27 % K in the DAP plots with a mean of 4.09% K (Table 5). Total soil calcium significantly (p≤ 0.0001) differed in the different fertilizers and manure treatments. The total soil Ca varied from 0.002% Ca in the farmyard manure plots to 0.0029% Ca in the lime plots with a mean of 0.0025% Ca (Table 5). Total soil magnesium differed (p≤ 0.0001) in the different fertilizers and manure treatments. The total soil Mg varied from 0.2% Mg in the control plots to 0.035% Mg in the ½ DAP + ½ FYM plots with a mean of 0.026% Mg (Table 5). Fertilizer and manure application had significant difference (p≤ 0.0001) effect on soil nutrient content. Fertilizers and manure application significantly increased the extractable soil P content above the control. The mean values for extractable soil P content was 5.43 mg P/kg. Minjingu Rock Phosphate and the ½ DAP + ½ FYM treatments significantly increased extractable P than the control. The application of lime significantly increased extractable P as compared to the control (Table 5). Total soil P contents, total soil potassium, total soil calcium and total soil magnesium were significantly different. The mean values for total soil P was 2.2% P, total soil potassium 2.63% K, total soil calcium 0.003% Ca and total soil magnesium 0.03% Mg. The fertilizers and manure had no significant effect on total N (Table 5).

The mean value for pH in farmyard manure at Bototo was 8.6. The mean values for N, P, Ca, Mg, K and C in farmyard manure were 11.6, 2.2, 8.8, 2.6, 7.8 and 116 g kg^{-1}. Nutrient analysis of the manures show that for example 5 t ha^{-1} cattle manure can supply approximately 58 kg N, 11 kg P, 39 kg K, 44 kg Ca, and 13 kg Mg ha^{-1}, however these potential values, particularly for N, K, Ca and Mg vary across farms.

DISCUSSION

The study conducted during the long and short rains seasons in 2007 confirmed that the low soil fertility could be attributed to the continuous cropping of land with little or no nutrient returns, thus resulting into low nutrient content and therefore decline in soil fertility (Gudu et al., 2005). The crop response to P fertilizers and manure application in these soils was therefore expected from the initial soil analysis results. The increase in yield is therefore, attributed to the increased available P due to fertilizers and manure application. The significant difference in growth vigour response to fertilizers and manure (Table 2) could be attributed to the fact that maize depends on fertilizer P at its early stages of growth and this might have stimulated root proliferation and acquisition of nutrients for growth.

Acidic soils render P and N unavailable through P fixation and slowing down of nitrification rates, respectively (Gudu et al., 2005). Therefore the control gave lowest yields, probably because of reduced N and P. Combinations involving manure and DAP gave high grain yields. This underlines the importance of FYM and DAP in crop performance and more so for these acidic soils (pH 3 to 6). High yields of maize were observed in TSP plots because it contained Ca (12 to 14%) and hence large doses of P are similar to liming.

The relative difference in nutrient (N, P, K Ca, and Mg) uptake was related to differences in dry matter yield production (Mengel and Kirkby, 2001). The higher nutrient uptake with combined N and P than the sole P application could be attributed to the synergistic N enhancement of P uptake (Negassa et al., 2005).

Mengel and Kirkby (2001) proposed that the decreased efficiency in P uptake following P application was a result of conversion of fertilizer P to relatively insoluble forms. The reductions in total soil P content with application of fertilizers and manures could be attributed to the increased dry matter production and hence higher nutrient P removal by the crop following N application. This may be due to N effect in promoting dry matter production. It could also be attributed to the synergistic interaction between N and P (Brady and Weil, 1984), whereby the availability and P uptake was increased hence the reduction of P in the soil that was observed in this study. The lack of significant change in total soil N with application of fertilizers and manure could be attributed to the blanket application of the recommended rate of N. The reduction in total soil K, Mg and Ca contents with fertilizers and manure applications could be attributed to the increased crop nutrient removal following fertilizer N and P application. The results agree with Smalling et al. (1997) that increased fertilizer N and P application could result in deficiency of other nutrients (such as K, Ca, Mg and Zn) due to rapid crop removal. The low Ca and Mg uptake could be related to their relatively low levels in these soils: 0.003 and 0.03% respectively. The gradual net depletion of soil cations if not compensated by fertilizer and manure inputs, would eventually affect crop yields.

Crop responses to decomposed or non-decomposed manure application may be due to increases in soil pH, N, P, Cations such as Ca and Mg or to physical effects of addition soil organic matter on water filtration and retention. However the responses to cattle manure application are highly variable due to differences in the chemical composition of the manures. Poor storage conditions may result in ammonia losses through volatilization and leaching of nitrates. A survey in Bototo, Kisii County, Kenya to determine how livestock and manure management practices (stocking rate, feeding, collection, composition and storage) affect the quality of the manure for crop production indicated that collecting boma manure and just heaping it on the soil surface resulted in very low quality manure (KARI, 1991). The differences in organic C and N could be due to cattle diets, method of collection, storage, and degree of decomposition of the manure.

CONCLUSIONS AND RECOMMENDATIONS

The study conducted at Bototo, Kisii County in Nyanza Province, Kenya, during the long and short rains seasons in 2007 showed that farmers should use phosphate fertilizers and manure when planting. Phosphate fertilizers and manure application significantly ($p \leq 0.0001$) increased maize grain and dry matter yields. ½ FYM + ½ DAP application makes N and P nutrients readily available from the fertilizers used and manure and effectively regulate the soil acidity. Farmers should apply ½ DAP + ½ FYM because this makes N and P available to the maize crop and regulates the soil acidity. Investigations should be done on the effectiveness of manure to binding Fe and Al ions in acid soils. Fertilizers and manure are essential to improve maize yields, nutrients uptake, nutrients use efficiency and soil nutrient contents. Soils in the site were low in fertility, acidic (pH 3 to 6), thus, low amounts of total N, organic carbon, total and extractable phosphorus and exchangeable bases.The soils require phosphate fertilizers and farmyard manure. Further long-term studies in these soils to investigate the effects of fertilizer use nutrient balance, as a basis for fertilizer formulations and recommendation is necessary.

Conflict of Interests

The authors have not declared any conflict of interests.

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