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Maize Response to Micro Dose Inorganic Inputs on an Acid Smallholder Farm in Kenyan Lower Midland

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ABSTRACT

The study determined nitrogen, phosphorus fertilizers and lime micro doses effects on soil chemistry and maize performance on an acid soil smallholder farm. Treatments were micro doses (50% of recommendations) of N (0 and 37.5 kg N ha^{-1}), P (0 and 13 kg P ha^{-1}) fertilizers and lime (0 and 2.26 tons lime ha^{-1}). Nitrogen, P-fertilizers and lime significantly ($p<0.05$) increased soil N, P and pH. Agronomic N-fertilizer use efficiency were 29 and 35 kg ha^{-1} kg^{-1} N-fertilizer due to 37.5 kg N and 37.5 kg N+2.26 tons lime ha^{-1}, respectively. Grain agronomic P-fertilizer use efficiency was 24 and 30 kg ha^{-1} kg^{-1} P-fertilizer due to 13 kg P and 13 kg P+2.26 tons lime ha^{-1}, respectively. N-fertilizer recovery were 47 and 50% due to 37.5 kg N and 37.5 kg N+2.26 tons lime ha^{-1}, respectively and P-fertilizer recovery efficiency were 14 and 16% due to 13 kg P and 13 kg P+2.26 tons lime ha^{-1}, respectively. Grain yield increments were 72, 27 and 12% due to 37.5 kg N, 13 kg P and 2.26 tons lime ha^{-1}, respectively. Therefore, N-, P-fertilizers and lime micro doses can improve maize grain yield on acid nutrient deficient smallholder farms.

Key Words: Micro dose, Fertilizers, Lime, and Efficiency.

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INTRODUCTION

In sub-Saharan African (SSA) smallholder farms (SHF), maize grain yields are very low, frequently less than 1.0 tons ha^{-1} year^{-1} (Sanchez et al., 1997). The low maize grain yields are attributed mainly to acid infertile soils, especially in high rainfall agricultural potential areas (Kanyanjua et al., 2002). On average SSA looses 22 Kg N, 2.5 kg P and 15 kg K ha^{-1} year^{-1} (Smalings et al., 1997). However, on average the annual fertilizer use in Africa is only about 17 kg ha^{-1} year^{-1} including N, P and K fertilizers (International Fertilizer Industry Association, 2006). Out of this the continent uses only about 5 kg P ha^{-1} year^{-1} (International Fertilizer Industry Association, 2009). These rates are much lower than nutrient losses from the soil and cannot therefore replenish soil fertility.

The recommended fertilizer rates for crop production in Africa are aimed at high crop yields but do not take into consideration the constraints faced by smallholder farmers (Twomlow et al., 2010). Due to high costs of the inorganic inputs and lack of credit most smallholder farmers seldom use the recommended fertilizer rates to replenish soil fertility (Okalebo et al., 2006). This has made it necessary to find alternative soil fertility replenishment interventions tailored towards improving crop productivity among these cadres of farmers (Nziguheba, 2007). Inorganic inputs micro dose which involves use of small and affordable rates at planting and top-dressing is such a technology. It involves use of $^{1}/_{3}$ to ½ of the recommended inorganic inputs (International Crop Research Institute for the Semi-Arid Tropics (ICRISAT), 2008). Use of micro dose rate of fertilizers have increased crop yield by 50 to 100% in semi-arid areas of Zimbabwe using mainly N fertilizers and very little research has been conducted in the medium to high potential agricultural areas with acid soils (ICRISAT, 2008; Kisinyo et al., 2015). There is need therefore to evaluate the effect of micro dose inorganic farm inputs on high rainfall lower midlands such as these found in Kenya with nutrient deficient acid soils. The objectives of this study were therefore to determine the effect of micro doses of N, P fertilizers and lime on (i) soil chemical properties and (ii) maize performance on a smallholder farmer's field Kenyan Midland acid soil.

MATERIALS AND METHODS

Site Characteristics

A field experiment was established on a smallholder farmer's field in lower midland 3 located at Sega (0º 14'N and 34º 13'E) in Siaya County, Kenya with an acid soil. The site is at an elevation of 1340 m above sea level with an average annual rainfall of 1545 mm per year with bimodal distribution pattern, long rains from March to July and the short rainy season from September to December. The mean annual temperature is 16 to 28.5ºC (Jaetzold and Schmidt, 1983). The soil type at the site has been classified as Orthic Ferralsol (FAO, 1988).

Soil Sampling

Prior to inorganic inputs applications, nine sub-soil samples were taken in March 2008 with a soil auger at the 0 to 20 cm soil depths in a zig - zag manner. They were thoroughly mixed and about 1.0 kg composite sample sent to the laboratory for determination of the initial soil properties of the site. Soil samples were also taken in the same manner at the rhizopshere at different interval during the cropping period (Okalebo et al., 2002).

Experimental Design, Layout and Management

The study was conducted during the long and short rains, the year 2008. The experiment was a 2 × 2 × 2 split-split plot laid out in randomized complete block design with N (0 and 37.5 kg N ha^{-1}) as the main plot, P (0 and 13 kg P ha^{-1}) as the sub-plot and lime (0 and 2.26 tons ha^{-1}) as sub-sub plot. 37.5 kg N and 13 kg P ha^{-1} are half the recommended N and P fertilizer rates for maize production in Kenya (Kenya Agricultural Research Institute, 1994) while 2.26 tons lime ha^{-1} is the half the calculated lime requirement (Kisinyo, 2011). Liming material containing 21% calcium oxide was used. The nitrogen and phosphorous fertilizers were provided as calcium ammonium nitrate (CAN) and triple superphosphate (TSP), respectively. Plots measuring 3.5 by 3 m were demarcated after ploughing to the appropriate tilts in March, the year 2008 long rain season. Each plot was separated from the next by a spacing of 1 m. Lime was applied only once in the long rains season by evenly broadcast and thoroughly mixing it with the soil, 30 days prior to planting. This was to allow for adequate time for it to react with the soil. Phosphate and nitrogen fertilizers were spot applied into the planting holes and thoroughly mixed with soil at the time of planting in each season. Nitrogen was split-applied with 30% applied at planting and the rest as top-dress at six weeks later. Two seeds of maize hybrid 513 were planted per hill at a spacing of 75 by 25 cm and were thinned to one plant per hill two weeks post-emergence. Maize was managed using the recommended agronomic practices for the area and harvested at physiological maturity.

Determination of Crop Response to Nitrogen, Phosphate Fertilizers and Lime

The grain yield was computed using the following formulae:

$$\text{Yield plot}^{-1} = \frac{(\text{Total fresh weigh} \times \text{Sample dry weight})}{\text{Sample fresh weigh}} \quad (1)$$

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

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

Determination of Grain Fertilizer Nutrient Use Efficiency

The agronomic nutrient use efficiency (ANUE) is the amount of harvestable product for example, kg of cereal kg^{-1} of applied nutrient. This is a classical method of evaluating fertilizer use and is defined by the following equation:

$$\text{ANUE} = \frac{(YT - Yo)}{T} \quad (3)$$

Where YT = crop yield (kg ha^{-1}) due to fertilizer application, Yo = crop yield (kg ha^{-1}) in the control plot and T = the rate of fertilizer applied (kg ha^{-1}). It can be increased with fertilizer additions or soil amendment practices that affect recovery efficiency (Dobermann, 2005). Nutrient recovery efficiency reflects the ability of plants to acquire applied nutrient from the soil. It measures the total amount of fertilizer recovered/absorbed by plant per the total kgs applied. It is determined by the following formula:-

$$\text{Nutrient recovery efficiency (\%)} = \frac{(NT - No)}{T} \times 100 \quad (4)$$

Where NT = nutrient uptake in treated plots (kg ha^{-1}), No = nutrient uptake in control plots (kg/ha) and T = rate of the nutrient applied (kg ha^{-1}) (Dobermann, 2005).

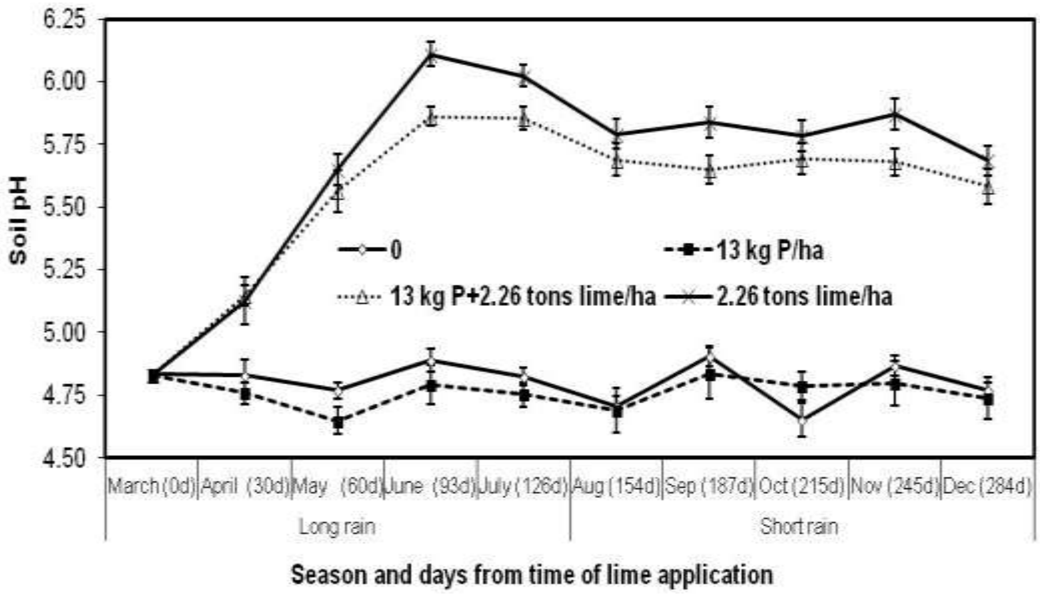

Figure 1. Effect of lime on soil pH, d=days from time of lime application and error bars indicates standard error of means (s.e.d).

Laboratory Analyses

Soil samples were air-dried and the ones taken before treatment applications were analyzed for texture, pH(1: 2.5; soil: water), bicarbonate extractable P, exchangeable bases (Ca^{2+}, Mg^{2+}, K^{+} and Na^{+}), Al^{3+}, organic carbon (%C) and total N (%N). Samples taken after treatment applications were analyzed for pH, total N and available P. The grain samples were analyzed for P and N contents. Detailed procedures for soil chemical and plant analyses are described by Okalebo et al. (2002).

Statistical Analysis

Maize yield data was subjected to analysis of variance (ANOVA) with the split-split plot design 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 $p \leq 0.05$).

RESULTS AND DISCUSSION

Soil Characteristics

Table 1 shows initial soil characteristics of the study site. The soil was moderately acidic, low in organic C (< 2%), N (<0.25%), P (<10 mg kg^{-1}), Ca (< 4 cmol kg^{-1}) and K < 0.5 cmol kg^{-1} with high Al saturation (> 20%) (Kanyanjua et al., 2002; Landon, 1991). Low nutrient acid soils such as reported in this study are characteristics of highly weathered soils found in tropical areas (Sanchez et al., 1997). As a result, such soils are not able to support healthy plant growth.

Effect of Lime and Phosphate Fertilizer on Soil pH

Figure 1 shows the effect of lime on soil pH. Lime took about 93 days to reach the highest peak of pH values of 6.1 and 5.7 where 2.26 tons lime and 13 kg P+2.26 tons lime ha^{-1}, respectively were applied. Thereafter, the effect of lime began to decline for the rest of cropping seasons however, it remained above the critical level of pH 5.5 below which liming is necessary throughout the cropping period. Therefore, it was not necessary to re-apply it during this cropping period. Lime has been reported to increase and maintain higher soil pH on acid soils for a long period which is attributed to its slow reactivity to release Ca^{2+} and/or Mg^{2+} ions (Kisinyo et al., 2014; The et al., 2006). Therefore, unlike other inorganic inputs, lime does not require application each cropping season. Unlike lime, P fertilizer reduced soil pH. This was because during TSP dissolution, there was release of phosphoric acid into the soil solution leading to acidification.

Effect of Lime and Phosphate Fertilizer on Soil Available Phosphorus

Figure 2 shows the effect of lime and P fertilizer on soil available P. Both lime and P fertilizer increased soil available P and maintained it higher than the control throughout the cropping period. The effect of both lime and P fertilizer on soil available P were below the critical of 10 mg kg^{-1} necessary for healthy plant growth (Olsen

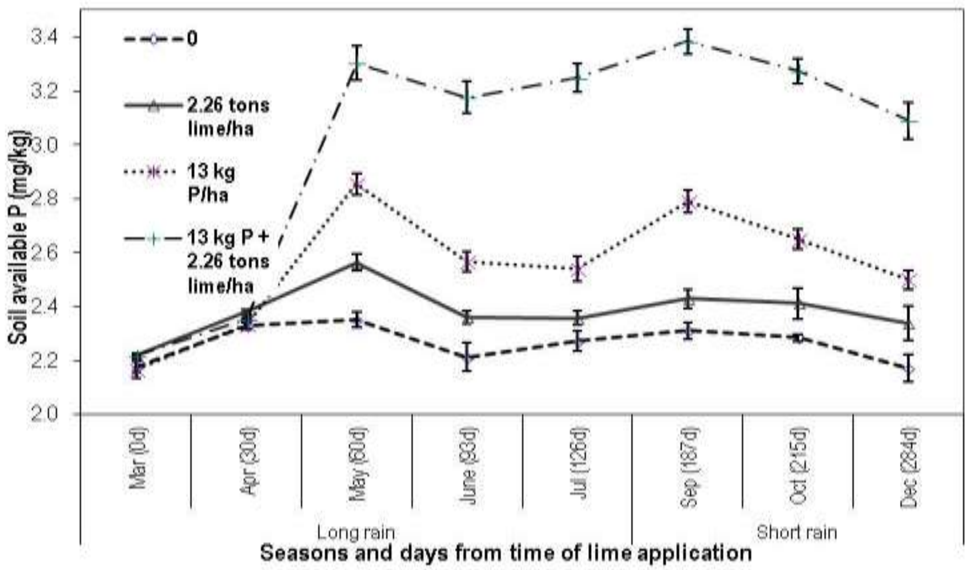

Figure 2. Effect of P fertilizer and lime on soil available P during the cropping period; d=days from time of lime application and error bars indicates s.e.d.

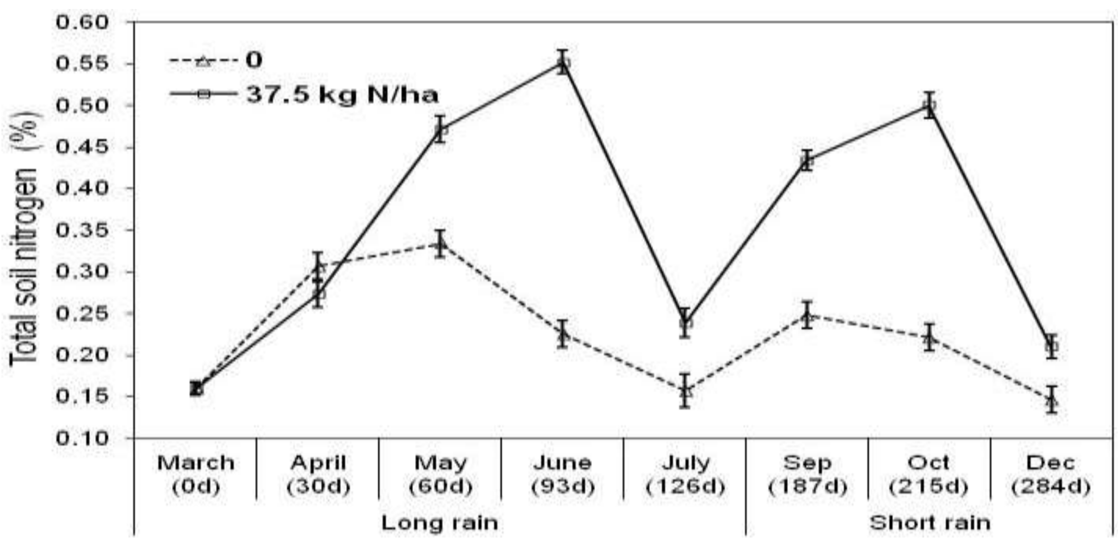

Figure 3. Effect of N fertilizer on soil total N during the cropping period.

et al., 1954). Soil available due to P fertilizer was at its highest peak in just only 30 days after its applications and thereafter there was a general decline for the rest of the season. The rapid increase in soil P was due to fast reactivity of TSP fertilizer to release phosphate ions into the soil solution (Tisdale et al., 1990). In similar tropical acid soils, lime and P fertilizer have been reported to increase and maintain high soil available P above the control for a longer period (Halvin et al., 2006; Weisz et al., 2003). Lime increased soil available P possibly because of reduction in P sorption thus making both the native and the applied P fertilizer available for plant uptake (Kisinyo et al., 2011; van Straaten, 2002).

Effect of Nitrogen Fertilizer on Soil Nitrate

Figure 3 shows the effect of N fertilizer on soil total N. Soil total N generally increased at the onset of rains that is, from March to May even in plots which did not receive N fertilizer. This was followed by a general decline in all plots up to harvesting time in July. A similar trend of soil N increase was observed during the short rain. The increase in soil N even in plots which did not receive N fertilizer was due to Birch effect. Normally at the onset of rains there is increased microbial activity leading to decomposition of organic matter to release N and accumulation of nitrate ions in surface soils during the dry

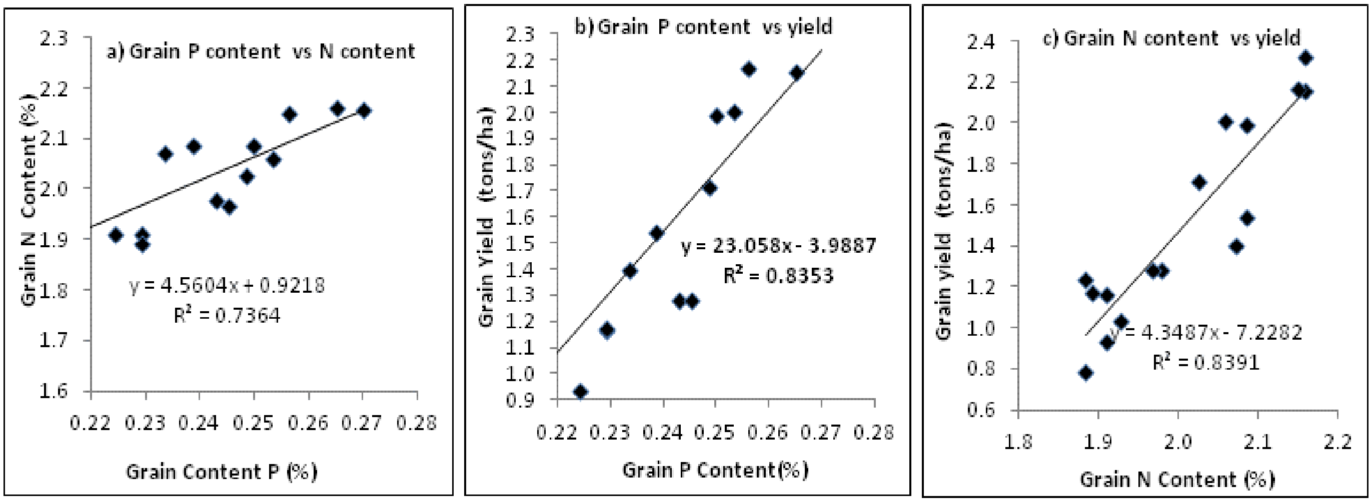

Figure 4. Correlations between grain nutrient contents and between grain nutrient contents and yield.

season making them readily available for plant uptake at the beginning of the cropping season (Tisdale et al., 1990). Nitrogen fertilizer increased soil N very fast because of the rapid solubility of CAN fertilizer. The rapid decrease of soil N was possibly due to its high rate of leaching and volatilization of N fertilizers in humid tropical climates such as reported in this study (Sanchez, 1976). Similar increases and trends of soil N following N fertilizer applications have been reported on N deficient tropical soil such as this (Kisinyo et al., 2015).

Relationships between Grain P and N, Grain P and Yield and Grain N and Yield

There were very high correlations between grain P and N (r = 0.86), grain P and yield (r = 0.91) and grain N and yield (r = 0.92) (Figure 4). The very high correlation between P and N is because the two nutrients have synergistic effects. Both P and N are required for vital processes such as photosynthesis and protein synthesis (Tisdale et al., 1990). The high correlation between grain P and yield was because P is important for root growth and development. It is also essential for photosynthesis necessary for biomass accumulation and grain production. Phosphorus necessary for flowering and grain formation in plants (Neil, 1991). High correlations such reported this study between plant P uptake and yield parameters have been reported in crop species in acid tropical soils (Gudu et al., 2009). Very high positive correlation between grain N uptake and yield was because N is essential for dark green coloration necessary for photosynthesis and vegetative growth. Nitrogen deficiency leads to stunted growth that eventual results to low grain yields (Marshner, 1986; Sanginga and Woomer, 2009). Therefore, P uptake can be used to predict N uptake while grain P and N uptakes can be used to predict grain yield.

Effect of Nitrogen, Phosphorus Fertilizer and Lime on Grain Nutrient Use Efficiency and Yield

Figure 5 presents agronomic P and N fertilizers use efficiencies. The mean grain agronomic P use efficiency were 24 and 30 kg ha^{-1} kg^{-1} P fertilizer due to 13 kg P and 13 kg P + 2.26 tons lime ha^{-1}, respectively and mean agronomic N use efficiency were 29 and 35 kg ha^{-1} kg^{-1} N fertilizer due to 37.5 kg N and 37.5 kg N + 2.26 tons lime ha^{-1}, respectively. Table 2 shows N and P fertilizers recovery efficiencies. The mean N fertilizer recovery efficiency were 47 and 50% due to 37.5 kg N and 37.5 kg N + 2.26 tons lime ha^{-1}, respectively and mean P fertilizer recovery efficiency were 14 and 16% due to 13 kg P and 13 kg P + 2.26 tons lime ha^{-1}, respectively. Plate 1 shows the effects of micro dose N, P fertilizers and lime on maize seedlings growth and maize cobs. Inorganic micro doses enhanced seedling growth which led to production of large cobs compared to the control. Table 3 shows the effect of micro doze rates of N, P fertilizers and lime on grain yield. All the treatments had significant ($p<0.05$) effects on grain yield. A combination of any two or three of them had more effect than any one of them applied alone Mean grain yield increment were 72, 27 and 12% due to 37.5 kg N, 13 kg P and 2.26 tons lime ha^{-1}, respectively.

On a Kenyan acid soil similar recovery efficiencies of 37 and 14% due to micro doses of N and P fertilizers, respectively have been reported. They were higher when the fertilizers were applied together with lime (Kisinyo et al., 2015). On acid soils, fertilizer recoveries and utilizations are normally as low 10 to 20% due to soil acidity related constraints. On tropical acid soils such as reported in this study, P recovery efficiency as low as 10 to 31% due to high P sorption by Al and Fe oxides (Fofana et al., 2007; Keerthisinghe et al., 2001). Similar maize yield increases due to micro doses of fertilizers

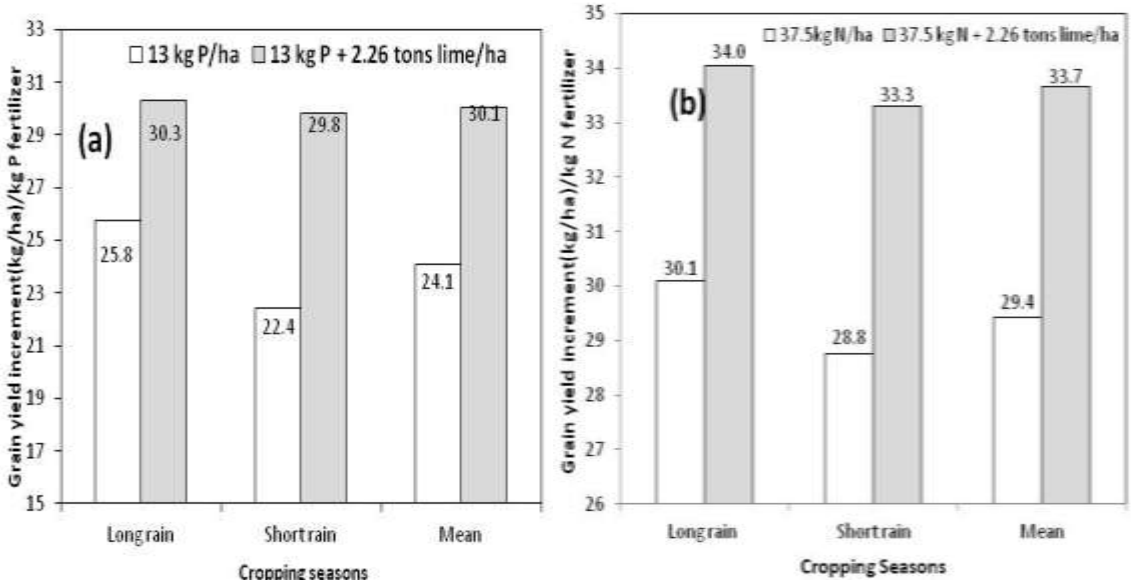

Figure 5. Effect of lime on the agronomic use efficiency; (a) agronomic P use efficiency and (b) agronomic N use efficiency.

Table 1. Initial soil chemical and physical characteristics of the study site.

Parameter	Value
pH – H_2O (soil: water; 1:2.5)	4.84
bicarbonate P (mg/kg)	2.21
N (%)	0.16
C (%)	1.83
Ca (cmol kg^{-1})	2.39
Mg (cmol kg^{-1})	1.93
K (cmol kg^{-1})	0.48
Al (cmol kg^{-1})	1.67
ECEC (cmol kg^{-1})	6.47
% Al saturation	25.8
Specific gravity	2.4
Sand (%)	52
Clay (%)	30
Silt (%)	18
Textural Class	Sandy clay loam

Table 2. Nutrient recovery efficiency (%); LR = long rain and SR = short rain.

Phosphorus Recovery Efficiency				Nitrogen Recovery Efficiency			
	LR	SR	Mean		LR	SR	Mean
13 kg P ha^{-1}	17.8	10.8	14.3	37.5kg N ha^{-1}	47	46	47
13 kg P + 2.26 tons lime ha^{-1}	19.4	12.7	16.1	37.5 kg P ha + 2.26 tons Lime ha^{-1}	51	49	50

and lime rates have been reported in both semi-arid and high rainfall African agricultural areas (ICRISAT, 2008; Kisinyo et al., 2015). Lime increased fertilizers agronomic and recovery efficiencies as well as grain yield because probably it relieved plants of soil acidity related constraints. This likely created a conducive environment for good root development, thus enhancing nutrients uptake and utilization necessary for high grain production such as reported in this study. Amelioration of adverse chemical conditions such as Al toxicity by lime enhances

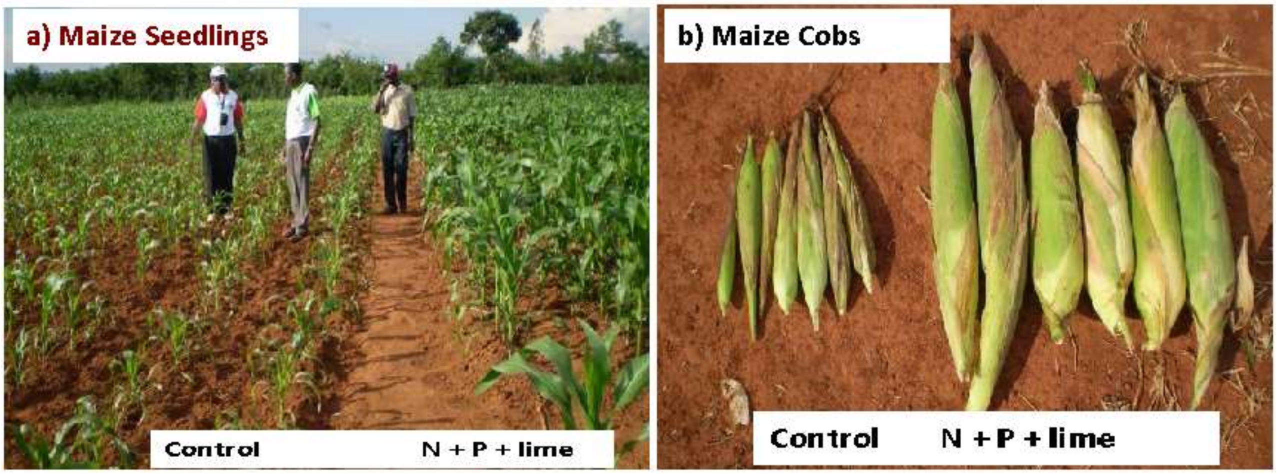

Plate 1. Effect of micro dose N, P fertilizers and lime on maize performance during the long rain cropping season.

Table 3. Effect of micro dose N, P fertilizers and lime of maize grain yield (tons ha^{-1}); L = lime, t = tons and ns=not significant.

Seasons		**Long rain**				**Short rain**			
N Kg ha^{-1}	**P kg ha^{-1}**	**Control**	**2.26 t lime ha^{-1}**	**Mean for P**	**Mean for N**	**Control**	**2.26 t lime ha^{-1}**	**Mean for P**	**Mean for N**
0	0	1.032	1.231	1.132	1.177	0.783	0.935	0.859	1.044
	13	1.162	1.283	1.223		1.174	1.284	1.229	
37.5	0	1.712	2.004	1.858	1.964	1.398	1.540	1.469	1.856
	13	1.986	2.154	2.070		2.167	2.317	2.242	
Mean for Lime		1.473	1.668			1.381	1.519		
CV%		6.9				7.8			
SED (0.05) N		0.014				0.030			
SED (0.05) P		0.010				0.014			
SED (0.05) L		0.013				0.014			
SED (0.05) N x P		0.012				0.024			
SED (0.05) N x L		0.016				0.025			
SED (0.05) P x L		0.017				ns			
SED(0.05) NxPxL		ns				ns			

the capture and utilization of nutrients by plants (Baligar et al., 2001). Therefore, on acid and nutrient deficient (N and P) soils such as this, combined application of micro doses of N, P fertilizers and lime are important for healthy plant growth and nutrient utilization necessary for high grain yield.

CONCLUSION

The study site soil was acidic with low nutrient levels which makes it unable to sustain high crop production. Lime maintained soil pH above the critical pH of 5.5 below which lime application is necessary throughout the cropping period. TSP fertilizer increased soil available P but not to the critical level of 10 mg P kg^{-1} necessary for health growth due to its sorption by Al. High correlation between grain P and N uptakes is an indication that P uptake can be used to predict N uptake and vice-versa. Both grain N and P contents can be used to predict grain yield because of the high correlations between these fertilizer nutrients and grain yield. Lime enhanced N and P fertilizers utilization efficiencies which led to higher grain yields compared to either of them alone. Mean grain yield increment were 72, 27 and 12% due to 37.5 kg N, 13 kg P and 2.26 tons lime ha-1, respectively. Therefore, micro doses of N, P fertilizers and lime have the potential to improve maize grain yield on acid nutrient deficient smallholder farms.

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