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Residual effects of lime and phosphorus applications on soil and maize (*Zea mays L.*) performance in a Kenyan highlands acid soil

Kisinyo Peter [a*], Gudu Samuel [a], Othieno Caleb [a], Okalebo John [a], Ochuodho Julius [a], Agalo Joyce[b], Ng'etich Wilson[a], Opala Peter[a], Maghanga Justin[a], Osiyo Richard[a] and Ligeyo Dickson[c]

[a] Moi University, Chepkoilel Campus, P. O. Box 1125-30100, Eldoret, Kenya.
[b] Moi University, Directorate Open and Distant Learning, P. O. Box 3900-30100, Eldoret, Kenya.
[c] Kenya Agricultural Research Institute (KARI), Kitale, P. O. Box 405-302000, Kitale, Kenya.

[*]Author for correspondence and reprint requests

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In acid and phosphorus (P) deficient soils, lime and P-fertilizers increases crop yields. Residual effects of lime and P-fertilizer on soil pH, P availability, nutrient utilizations and maize yields was conducted at Kuinet (0° 35'N & 35° 18'E), Kenya. Treatments were: lime (0, 2, 4 and 6 tons/ha) containing 21% calcium oxide and P-fertilizer (0, 26 and 52 kg/ha), applied once in the year 2005 to monitor residual effects up to 2007. Each treatment received 75 kg N/ha except control. Kuinet soil was acidic (pH 4.8 & 39.4% aluminum), low in P (4.4 mg P/kg soil) and nitrogen (0.23%). Maintaining soil pH $\geq$ 5.5 with 2 tons lime required reapplication every 2 years, while maintaining soil P $\geq$10 mg P/kg soil required reapplication every one and three years for the 26 & 52 kg P/ha, respectively. Lime increased grain yield increased by 10, 31and 28% for 2, 4, 6 tons lime/ha and P fertilizer by 28 and 44% for 26 and 52 kg P/ha, respectively. Correlations between soil pH & P availability was poor (R^2 = 0.142), while between soil available P & grain yield was weak (R^2 = 0.341). Grain yield increased with soil P availability up to about 20 mg P/kg and thereafter the yield remained almost constant. Correlation between grain P & yield (R^2 = 0.829) was highly significant ($p \leq 0.001$). Soil acidity, N and P deficiencies limit maize production in Kuinet and similar soils in Kenyan highlands.

Key words: Soil acidity, Aluminum toxicity, Lime, Phosphorus, Residual effects, Maize

Introduction

The importance of maize (corn) as a staple food crop in East Africa (Kenya, Uganda, and Tanzania) is well documented and highlighted elsewhere (Obura, *et al*., 2001; Gudu *et al.,* 2005). In the recent years, maize grain yields per ha in Kenya, particularly in the main maize producing area in the west of Rift Valley highlands, have been on the decline (Nekesa *et al.,* 1999; Ayaga, 2003), a worrying trend to farmers and the nation, as a whole. The low maize yields are due to uneven rainfall distribution, pests and diseases, use of low quality seed, socio-economic problems, infertile and acid soils.

Soil acidity is a widespread limitation to crop production in many parts of the world including sub-Saharan Africa (SSA) (van Straaten, 2002). Acid soils occupy about 40% (4 billion ha) of the world soils (von Uexkull and Mutert, 1995) and 29% of the total land area in SSA (Eswaran *et al*., 1997). In Kenya acid soils occupy about 13% (7.5 million ha) of the land area (Kanyanjua *et al*., 2002), which because of rain fed agriculture is of major importance. In the Kenyan highlands, particularly west of the Rift Valley-main maize producing areas, high leaching rates due to high rainfall, parent materials of acidic origin and continuous application of acidifying chemical fertilizers such as diammonium phosphate (DAP) or sulphates of ammonium account for soil acidity (Kanyanjua *et al*., 2002; Jaetzold and Schmidt, 1983). High acidity is associated with aluminum (Al), hydrogen (H), iron (Fe) and manganese (Mn) toxicities and corresponding phosphorus (P), molybdenum (Mo) and calcium (Ca), magnesium (Mg) and potassium deficiencies (K) in the soil (Giller and Wilson, 1991; Jorge and Arruda, 1997). Phosphorus deficiency in

SSA soils is due to inherent low soil P, high P fixation by Al and Fe oxides (Buresh *et al*., 1997), and also due to insufficient fertilizers used to replace P removed in harvested plant products or correct inherent low P (Obura *et al*., 2001). High P fixation in acid soils makes it difficult for plants to utilize the added P fertilizer with high efficiency. Soil acidity constraints reduce grain yield by about 10% of the maize growing areas in tropical developing countries (Sierra *et al*., 2003). In acid soils of the western Kenya region, Al toxicity and P deficiency (normaly below the critical level of 10 mg /kg soil Olsen P) reduce maize grain yield by about 16 % and 28 %, respectively (Landon, 1991; Ligeyo *et al*., 2006).

In acid soils and P deficient tropical soils where the plant capacity to scavenge the native or use added P with high efficiency is critical (Swift *et al.,* 1994), correcting soil acidity and P fertilizer addition is important. Lime is widely known as the most effective way of correcting soil acidity. Its direct effect is soil pH increase (The *et al*., 2006), reduces of Al, H, Mn, and Fe ions toxicities and increases availabilities of P, Mg, Ca and Mo ions in acid soils (Kamprath 1984; Kanyanjua *et al,* 2002; Moody *et al*., 1998). Reduction in soil exchangeable Al and Fe results in less P fixation thus making the native and applied P fertilizers available for plant uptake. Therefore, in P fixing acid soils, combined lime and P application is necessary for increased availability of the applied P for plant uptake. Although not permanent, the effect of lime lasts longer than other the soil amendments such as organic and inorganic materials. Lime residual effect depends on how Ca^{2+} and Mg^{2+} ions are being displaced by residual acidity (Al^{3+} and H^{+} ions) (Sanchez, 1976). Large lime rates normally have longer term residual effect than lower ones, but may also lead to negative effects (Abruna *et al*., 1964). The objective of the study reported herein aimed at monitoring the residual effects of lime and P fertilizer applied on some soil chemical properties, nutrient uptake and maize production in a Kenyan acid soil.

Materials and methods

Soil and site description: The study was conducted on a smallholder farm (SHF) at Kuinet area (00^{o} 37'N & 35^{0} 18'E) in Uasin Gishu District, located about 12 km North of Eldoret Town in the Rift Valley Province, Kenya. The district has a unimodial rainfall distribution pattern with an average annual of 900 – 1100 mm, relative altitude of 1500– 2100 m a.s.l and mean annual temperature of 22^{o}C. Low temperatures within the district make crops take longer period to mature; therefore there is only one cropping season per year (Jaetzold and Schmidt, 1983). Soil type is a rhodic Ferralsols (FAO/UNESCO, 1991).

Soil sampling: Prior to treatments, surface 0 - 20 cm depth soil samples were randomly take with a soil auger at the experimental site and thoroughly mixed together to make a composite sample for site characterization. After the treatments, composite samples were taken from each plot at the sample depth at planting, thereafter about every two months and during harvesting to monitor changes in the sol pH and P availability.

Experimental design and treatments: Treatments were lime at 0, 2, 4 and 6 tons lime/ha (equivalent to 0, 0.42, 0.84 and 1.26 tons calcium oxide (CaO)/ha, respectively) and P at 0, 26 and 52 kg P /ha as triple supper phosphate (TSP) in a 4 x 3 factorial combination in a randomized complete block design (RCBD) replicated three times. Liming material was obtained from Koru in Kisumu district, Kenya which contains about 21% CaO.

Field Procedures: Plots of 4.5 m by 5.0 m were demarcated and the treatment combinations evenly broadcast and thoroughly mixed with the soil prior to planting during the long rain (LR) in the year 2005.

In addition, all the treatments received a blanket application of 75 kg N/ha (Fertilizer Use Recommendation Project (FURP), 1987) as calcium ammonium nitrate (CAN) in split applications of 30 and 45 kg N/ha, at planting and when plants were at knee height, respectively, except the absolute control plots. Two seeds of maize hybrid variety H 614D was planted per hill at a spacing of 75 and 30 cm between and within rows , respectively which were thinned to one per hill, two weeks post-emergence thus giving a plant population of 44,444/ha. At physiological maturity, only the central rows in each plot were harvested leaving out the guard rows and plants at the end of each row to avoid edge effects. Stover and grain samples were taken for yields and P uptake determination according to procedures outlined in Okalebo *et al*. (2002).

In the years 2006 and 2007, all the plots except control received 75 kg N/ha as CAN as described above without any lime or P to monitor their residual effects on soil pH, P availability, nutrient use efficiency and maize yields. To avoid contamination by inputs from the demarcated neighboring plots, each plot was tilled separately using a hoe. Harvesting was carried out as described above.

Laboratory analysis: All the soil samples were air–dried soil and sieved through 2 mm mesh. Characterization samples were analyzed for pH (Soil: H_20; 1:2.5), texture (hydrometer method), total carbon (C) %, (Walkley - Black method), total N (%), and Olsen available P, exchangeable bases, acidity and Al. Samples taken after the treatments were analyzed for soil pH and P availability. Grain samples were air-dried, ground and sieved through No. 20 mesh screen for content P analysis (Okalebo *et al,* 2002).

Statistical analysis: All the generated data: maize yield, soil pH, P availability, plant N and P contents were subjected to analysis of variance (ANOVA) with the General Linear Model (GLM) using General Statistics(GenStat) (Buysse, 2006). Means were separated using pooled least significant difference (lsd) whenever treatments effects were significant at ($p<0.05$).

Results

Kuinet soil is strongly acidic, high in Al, low in organic matter, deficient in N and P. The effective cation exchange capacity (ECEC) is also low (Table 1).

Table 1: Some physical and chemical characteristics of Kuinet soil in January 2005 before treatments

pH	Total N (%)	C (%)	Olsen-P (mg/kg)	Exch. Cations (Cmol/kg)				ECEC (Cmol/kg)	Al saturation (%)	% Clay	% Silt	% Sand	Textural Class
				K	Mg	Ca	Al						
4.8	0.23	1.3	4.4	0.5	0.6	2.4	2.3	5.8	39.4	46	38	36	Clay loam

Effect of lime on soil pH and P availability during the cropping sequence

Soil samples taken at different times from the initial time of treatments revealed that soil pH generally increased with rates of lime to maximum for each rate in about 180 days and then continued on a declining trend for the rest of the cropping seasons (Fig.1). In the control plots it slightly declined from a pH 4.8 at planting to pH 4.71 in day 975. With 2 tons application it declined from a maximum of pH 6.22 in day 180 to 5.09 in day 975, 4 tones from pH 6.76 in day 180 to 5.69 in day 975 and 6 tons from pH 7.22 in day 180 to 5.89 in day 975. Therefore, to maintain soil pH ≥ 5.5 to control Al toxicity with 2 tons lime/ha, re-application is necessary every 2 years in Kuinet. However, with 4 and 6 tons lime/ha re-application was not necessary within three years cropping period.

Soil extractable P due to lime alone increased with lime rates to maximum for each rate in about 60 days (Fig. 2). Then followed by a rapid decline in all treated plots such that in less than 180 days, it was dropped below the critical (≥10 mg P/kg) level and continued to decline throughout the three years of cropping.

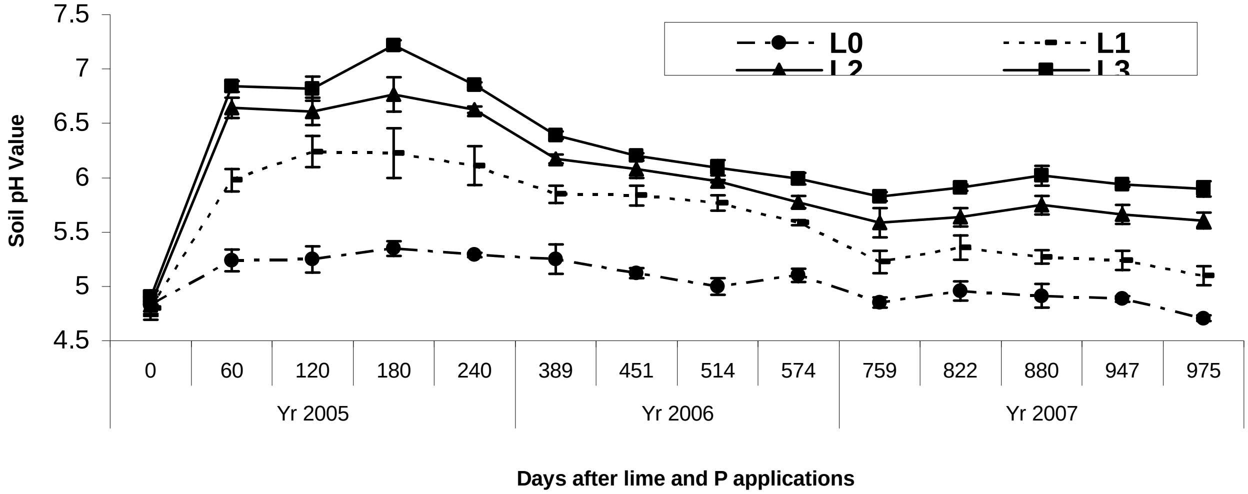

Figure 1: Residual effect of lime on soil pH after the initial lime and P application in 2005, *L0 = Control, L1 = 2 tons, L2 = 4 tons, L3= 6 tons lime/ha*

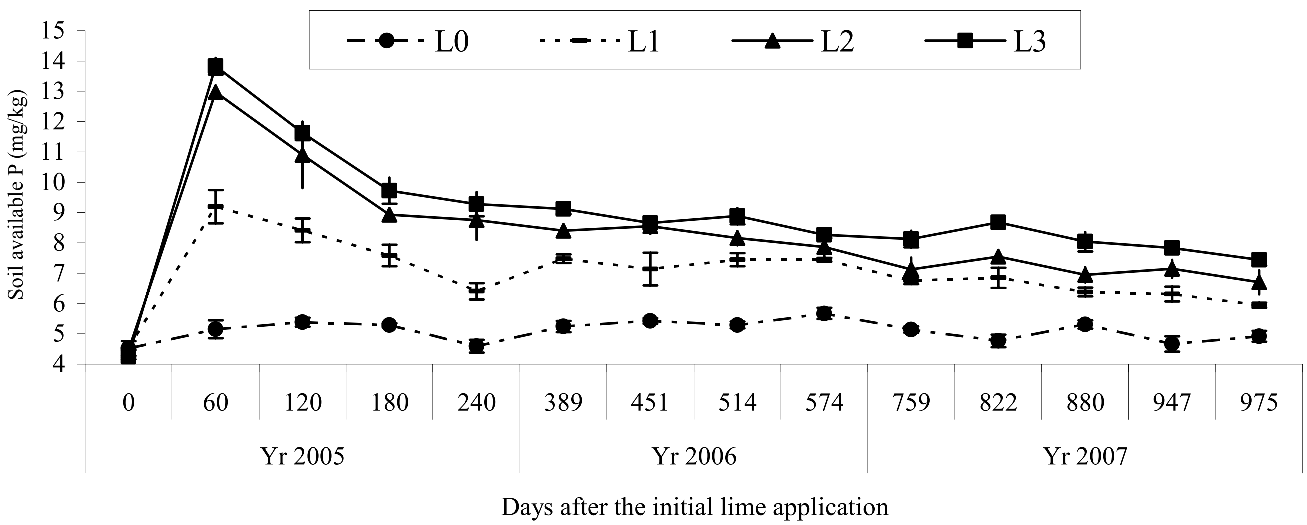

Figure 2: Residual effect of lime alone on soil available P after the initial lime and P application in 2005

Effect of phosphorus application on soil P availability during the cropping sequence

Soil P availability increased with rates of P fertilizer to maximum in 60 days and thereafter continued to decline during the cropping period (Fig. 3). The two P rates i.e. 26 and 52 Kg P/ha increased soil P to highest levels of about 16 and 23 mg P/kg, respectively. Where 26 kg P/ha was applied, available P declined below the critical level in less than 240 days. However, with 52 kg P/ha application, P availability was still above the critical level except in t day 975 which makes it necessary to monitor the trend during the subsequent years to determine when to reapply the fertilizer. TSP is very soluble therefore rapidly released P into the soil therefore increasing solution P within a very short period.

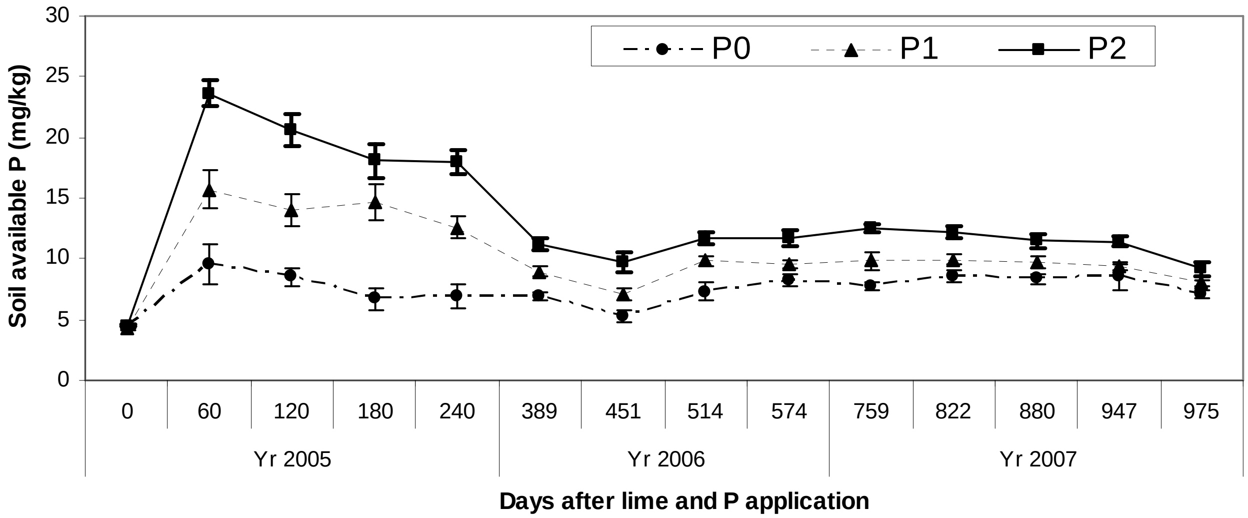

Figure 3: Residual effect of P on soil available P after initial lime and P application in 2005 during the cropping sequence, *P0 = Control, P1 = 26 kg P, P2 = 52 kg P as TSP/ha,*

Effect of lime and phosphorus on maize yield

Both lime and P had significant ($p \leq 0.05$) effect on grain yield throughout the three year maize cropping period, however their interaction was only significant during the year of treatments in 2005) (Table 2). The two P rates i.e. 26 and 52 kg P/ha increased average grain yield over the three years by about 28 and 44%, respectively. P fertilizer had significant ($p \leq 0.05$) effect on grain yield in years 2005 and 2006 only but not 2007. In day 389 during the year 2006, where 26 kg P/ha was applied the available P was already below the critical level and grain yield was no significantly ($p = 0.05$) different from control in 2007. The three lime rates i.e. 2, 4 and 6 tons/ha increased average grain yield over the three years by 10, 31 and 28%, respectively. In the year 2005, 52 kg P/ha plus 4 lime/ha produced the highest grain yield of 6.52 ton/ha. However in 2006 & 2007, the highest grain yields were obtained with 52 kg P/ha plus 6 tons lime/ha.

Table 2: Effect of lime and P on maize grain yield (tons/ha) year 2005 – 2007 (*$p \leq 0.05$*)

Year	2005				2006				2007			
Lime	P (kg/ha)				P (kg/ha)				P (kg/ha)			
(tons/ha)	0	26	52	Mean	0	26	52	Mean	0	26	52	Mean

0	3.52	4.24	5.48	4.41	1.72	2.65	3.28	2.55	3.07	4.71	5.31	4.36
2	4.13	4.85	5.88	4.95	2.26	2.65	3.41	2.77	3.55	4.93	5.82	4.77
4	4.36	6.39	6.52	5.76	2.52	3.60	3.80	3.30	5.33	5.97	6.27	5.86
6	4.14	5.37	5.97	5.16	2.73	3.67	3.91	3.44	5.53	6.02	6.29	5.95
Mean	4.04	5.21	5.96	5.07	2.31	3.14	3.60	3.01	4.37	5.41	5.92	5.23
Lsd lime	0.25				0.18				0.69			
Lsd P	0.22				0.16				0.59			
Lsd lime x P	0.43				0.31				1.19			

Both lime and P had significant ($p = 0.05$) effect on stover yield throughout the three year cropping period (Table 3). The two P rates i.e. 26 and 52 kg P/ha increased average stover yield over the three years by about 60 and 114%, respectively. The three lime rates i.e. 2, 4 and 6 tons/ha increased average stover yield over the three years by 8, 21 and 26%, respectively. Similar to grain yield in the year, 52 kg P/ha plus 4 lime/ha produced the highest stover yield of 7.38 ton/ha and in the subsequent years 52 kg P/ha plus 6 tons lime/ha produced the highest yields. In the year 2006, both grain and stover yields were lowest due to the drought which occurred during the vegetative growth and grain filling periods in the months of May and September, respectively.

Relationships between soil pH, P availability and P uptake to soil P availability, P uptake and grain yields

There was poor correlation between soil pH and P availability ($R^2 = 0.146$) (Fig. 4a). Soil available P generally increased from an average of 4.4 mg P/ha at pH of 4.8 to a maximum average of 11.7 mg P/kg soil at pH of about 6.0 and thereafter declined continuously towards pH 7.5. Soil analysis at tasseling stage in the three years showed that grain yield increased with soil P availability up to about 20 mg P/kg and thereafter the yield remained almost constant (R2 = 0.341) (Fig. 4b). Grain yield significantly ($p \leq 0.001$) increased linearly with grain P uptake ($R^2 = 0.829$) (Fig. 4c).

Table 3: Effect of lime and P on maize stover yield (tons/ha) year 2005 – 2007 (*p = 0.05)*

Year	2005				2006				2007			
Lime (tons/ha)	P (kg/ha)				P (kg/ha)				P (kg/ha)			
	0	26	52	Mean	0	26	52	Mean	0	26	52	Mean
0	3.32	4.39	4.91	4.21	1.96	3.34	4	3.10	3.68	5.11	6.97	5.25
2	4.01	4.47	4.85	4.44	2.79	4.00	3.24	3.34	3.92	5.5	7.59	5.67
4	4.43	6.34	7.38	6.05	3.43	2.85	4.24	3.51	4.83	6.54	7.73	6.37
6	4.43	5.41	6.88	5.57	3.34	4.62	5.64	4.53	5.28	6.88	7.90	6.69
Mean	4.05	5.15	6.00	5.07	2.88	3.70	4.28	3.62	4.43	6.01	7.55	5.99
Lsd lime	0.52				1.28				0.81			
Lsd P	0.45				1.11				0.70			
Lsd lime x P	0.91				2.22				1.39			

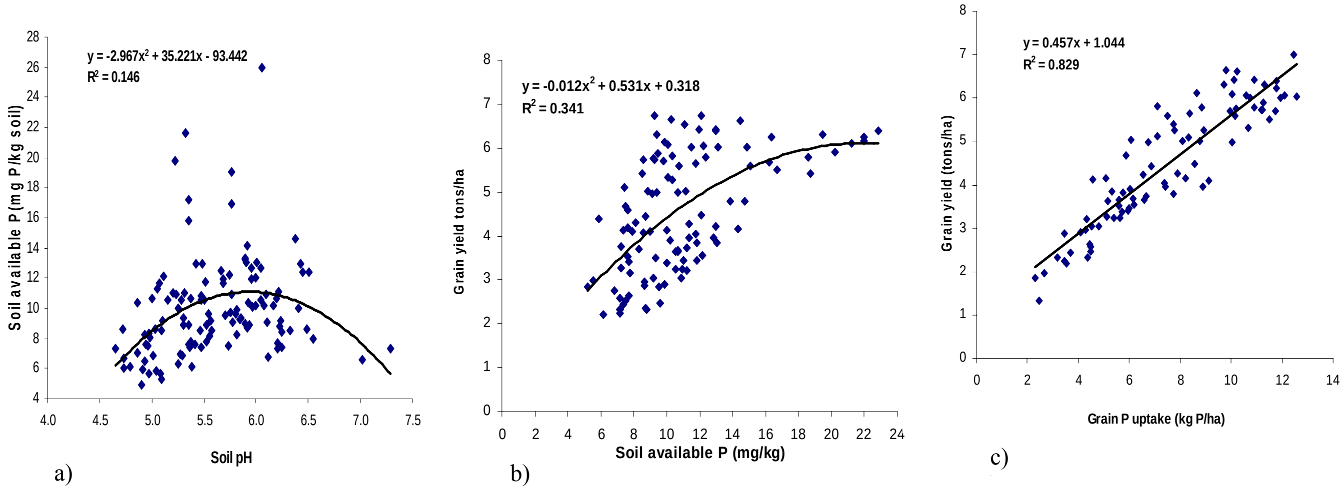

Figure 4: Correlations betweens: a) soil pH and P availability, b) soil P availability and grain yield at tasseling stage and c) grain P uptake and grain yield during the years (2005 – 2007).

Discussion

Strongly acid soils such as those found in Kuinet are common in the Kenyan highlands and many tropical areas. Low ECEC (≤16 cmol/kg) and high Al^{3+}concentration(≈ 39%) such as found in the Kuinet soil (Table 1) is a characteristic of highly weathered soils that have lost most of the basic cations due to leaching from high rainfall. These soils are common in most tropical areas (Landon, 1991; Kanyanjua *et al.*, 2002; van Straiten, 2002). Soils high in exchangeable Al such as this are known for high P sorption which results into P deficiency (Buresh., *et al*, 1997). Also the Kuinet soil was formed from igneous rocks low in P content (Jaetzold and Schmidt, 1983).

The highest soil pH levels due to lime rates were attained in about 180 days while the highest soil P available due treatments were attained in about 60 days. Lime is slow in reacting to release Ca^{2+} and/or Mg^{2+} to displace Al^{3+} and H^+ ions thus increasing soil pH while TSP is very soluble in water thus releasing P into the soil comparably within a shorter time. The rapid decrease in soil P availability in this study was due to decrease in soil pH and increase in Al^{3+}ion concentrations which lead to P fixation as the lime effect diminished with time. It was also due depletion of the native and applied P fertilizer through absorption by plants without any replenishment. Lime has been reported increase soil pH and P availability in acid soils because Ca^{2+} ions in lime displaces Al^{3+}, H^+, Mn^{2+} and Fe^{2+} ions from soil adsorption sites thus increasing soil pH and P availability due to decrease in P sorption (Kanyanjua *et al,* 2002; Moody *et al*., 1998; The *et al*., 2006).

Higher lime rates (4 and 6 ton lime/ha) had longer term residual effects on soil pH, P availability and maize yields compared to the lower rate (2 tons lime/ha). The shorter term residual effect of the lower lime rates observed in this study is because of rapid depletion of Ca^{2+} ions in the material applied. Residual effect of lime normally depends on the amount of Ca^{2+} and Mg^{2+} ions remaining in the liming material that can still displace residual soil acidity (Al^{3+} and H^+ ions) (Sanchez, 1976). During the year of application (2005), lime at 4 tons/ha plus P fertilizer combinations gave the highest maize yields, while in 2006 and 2007, 6 tons lime/ha with various P fertilizer combinations resulted in highest maize yields (Tables 2 & 3). In 2005, 6 ton lime/ha resulted to over liming which raised soil pH to 7.2 which is beyond the optimum range (pH 6.5 - 7.O) suitable for maize production (Arnon, 1972). Liming to neutralize the entire exchangeable Al or eliminate Mn toxicity (over liming) can be as detrimental as low pH. It may increase soil pH to levels that cause mineral deficiencies and toxicities (Tisdale *et al.,* 1990). Higher P fertilizer rate (52 kg P/ha) had longer term residual on soil P availability and maize yield than the lower one (26 kg P/ha) in Kuinet (Tables 2 & 3). This is because higher P rates have the capacity to satisfy soil P fixation capacity and also to remain in the soil solution for a longer period than the lower ones.

In this study, a combined lime and P fertilizer treatments gave higher soil P availability and maize yields compared to each treatment applied individually. This is because in acid and P deficient soils such as Kuinet, lime reduces soil acidity and P fixation which makes the P fertilizer applied available for plants uptake (The *et al*., 2006). In a similar study, Weisz *et al*. (2003) reported long term residual effect of higher P fertilizer rates on soil P availability and maize grain yield in North Carolina acid soils. Residual effect of P fertilizer can persist for as long as 5 to 10 years or more depending on the initial P rate applied, crop removal and the buffering capacity of the soil for P (Tisdale *et al.,* 1990). Combined lime and TSP fertilizer applications have been reported increase in soil pH, P availability and maize grain yield in tropical acid soils such as in Kuinet (Kisinyo *et al*., 2005; Buresh *et al.,* 1997; The *et al*., 2006).

The poor correlation between soil pH and P availability in this study was because in acid soils, P availability increases in soil pH due to decrease in exchangeable Al^{3+} and Fe^{2+} ions to a maximum range of pH 6.0 – 6.5. However, above pH 7.0 soil P availability decreases because of high exchangeable Ca^{2+} and Mg^{2+} ions that also fixes soil P (Tisdale *et al.,* 1990). Therefore, soil pH alone can not be used to predict P availability, since it also controlled by the amount of P fertilizer applied and the native soil P at any one given time. Grain yield increased with soil available P up to 20 mg P/kg and thereafter the yield remained almost constant at about 6 tons/ha (Fig. 4b). Once the plant can obtain adequate amounts of P from the soil, any increase soil P availability will not necessarily crop production. Similar correlations between soil P availability and maize grain have been reported in Burkina Faso (Bado *et al.,* 2004). The higher correlation between grain P and yield reported in this study is because large amounts of P are deposited in reproductive plant cells. In flowering plants, adequate P is essential for seed and fruit formation, faster grain maturity and the quality cereal straws (Tisdale *et al* 1990). Also high correlation between grain P and N since P uptake enhances N absorption in plants. This is because the functions of both P and N are complementary in plants since they re required for the DNA and RNA formations. Both nutrients are necessary for biomass accumulation and general plant growth (Marshner, 1986; Tisdale *et al*., 1990). Therefore the increased grain yield observed in Kuinet soil due to increase in grain P may have resulted from N uptake also. The low maize yields obtain in the year 2006 compared to the years 2005 and 2007 revealed that apart from infertility constraints, unreliable rainfall is a major factor limiting maize production in Kenyan soils (Ayaga, 2003). Thus, unreliable rainfall, soil acidity, deficiencies of N and P make these soils unable to sustain healthy plant growth which eventually leads to low crop yields.

Conclusion

In acid soil of Kuinet, Al toxicity, low P and N are major constraints to maize yields. Lime and P fertilizer residual effects of on soil pH, P availability and maize yields is dependent on the initial rates applied, whereby higher rates have longer term effects than the lower ones. To maintain of soil pH $\geq$ 5.5 to control Al toxicity when 2 tons lime is applied, re-application is necessary every 2 years in Kuinet, but with higher rates (4 & 6 tons lime/ha) monitoring should continue to establish when to reapply. Over liming to raise soil pH > 7.0, reduces soil P availability and maize yields. Maintaining soil P above the critical level ($\geq$10 mg P/kg soil) where 26 and 52 kg P/ha was applied require reapplication in every one and three years, respectively. In acid, high Al and P deficient soils, lime reduces P fixation thus making the native and applied P fertilizer available for plants. Soil pH alone can not be used to predict P availability since the two are poorly corrected while grain P uptake can be used to predict grain yield since the two are highly correlated. Soil P availability increases grain yield only when it is limiting production, thereafter other factors come into play. Apart from low soil fertility constrains, unreliable rainfall limits maize production in the tropical areas.

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