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Effects of lime and fertilizer on soil properties and maize yields in acid soils of Western Kenya

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Many soils in Western Kenya are acidic and deficient in nitrogen and phosphorus. Acidity hinders crop responses to fertilizers applied to remedy nutrient deficiencies. The common liming materials used to ameliorate acidity are Calcium Oxide (CaO) and Calcium Carbonate ($CaCO_3$) in powdery formulations. Broadcasting these materials by hand followed by incorporation is recommended on smallholder farms to enhance their effectiveness but this is laborious. Granular lime which is easier to handle was recently introduced but there is little information on its effectiveness. This study therefore tested the effects of $CaCO_3$, CaO and granulated lime, applied alone or in combination with fertilizer (Diammonium phosphate (DAP) + calcium ammonium nitrate (CAN)), on maize yield for three seasons, 2015 long rains (LR), 2015 short rains (SR) and 2016 LR at four sites: Butere, Emuhaya, Mumias and Kakamega North in Western Kenya. $CaCO_3$ and CaO were applied at 2 t ha^{-1} once in the 2015 LR while granular lime was applied at a ratio of 1:1 with DAP per season. There was no significant effect of lime type on maize yields. Maize did not respond to lime without fertilizer. Application of lime, irrespective of the type, with fertilizer, did not give yields that were significantly different from those of fertilizers alone except at Butere in the 2015 LR when application of CaO and $CaCO_3$ with fertilizer significantly out yielded those with fertilizer applied alone. Similar results were obtained with granular lime in the 2015 SR at Emuhaya. It was concluded that except for Butere, where maize did not respond to fertilizer alone, the other sites are not sufficiently acid to permit the solubility of Al to toxic levels for maize. More attention should therefore be focused on N and P replenishment at these sites than liming. At Butere, soil acidity is a problem and lime should be applied together with fertilizers.

Key words: Aluminum toxicity, lime, maize, nitrogen, phosphorus.

INTRODUCTION

Acid soils are widespread in Western Kenya and cover a large area of arable land (Kanyanjua, 2002; Kisinyo et al., 2015). In these acidic conditions, there is a complex interaction of growth-limiting factors. Plant growth may be

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restricted by one or more of the following: Al or Mn toxicity; Ca, Mg, P, or Mo deficiency; and reduced mineralization, nitrification, nodulation, and mycorrhizal infection (Fageria and Baligar, 2003; Dinkecha and Tsegaye, 2017). In addition, these soils, consisting of mainly the Acrisols, Nitisols and Ferralsols are highly weathered, with widespread N and P deficiencies. Smithson and Sanchez (2000) estimated that 80% of the soils across farms are severely N and P deficient. Under these conditions, yield of maize, the staple food crop is very low, averaging 1.0 t ha^{-1} against a potential of about 6 t ha^{-1} if the soils were well managed by replenishing the essential nutrients (Ojiem et al., 2004). Efforts to ameliorate the deleterious effects of soil acidity must therefore be accompanied by measures to replenish soil N and P. Use of inorganic fertilizers is recognized as an effective way for overcoming nitrogen and phosphorus deficiencies. However, in acid soils, response to fertilizers may not occur because of constraints imposed by soil acidity. Liming is the most dominant and most effective practice to control soil acidity (Fageria and Baligar, 2008; Goulding, 2016). Most plants grow well at soil pH range of 5.5 to 6.5 and liming is aimed to maintain the pH at this range. Liming increases soil pH, Ca concentration, cation exchange capacity (CEC) and base saturation, simultaneously lowering the Al concentration and increasing P availability (Jafer and Hailu, 2017). All these chemical changes, provided they are within a favorable range, improve grain yields and crop sustainability (Merino-Gergichevich et al., 2010; Nduwumuremyi, 2013). Currently, a variety of liming materials are available to farmers in Western Kenya. These materials differ in place of origin, amount of neutralizing power, and nutrients or other elements associated with the liming agent. These characteristics may influence the effectiveness of the liming material (Brady and Weil, 2002). The common liming materials on the Kenyan market are calcium oxide (CaO) and ground limestone composed mostly of calcium carbonate ($CaCO_3$), both of which are in powdery. This formulation increases surface area for quicker reaction with the soils (Bhargava and Subramanian, 2017). For maximum effectiveness, lime should be uniformly spread and incorporated into the soil. Incorporation can be achieved through disking or harrowing followed by rolling but these implementations are not usually available on smallholder farms. Spreading lime by hand is therefore common on smallholder farms but this is laborious and normally not recommended when the weather is windy. To overcome these challenges, granular lime was recently introduced to the Kenyan market (by MEA Ltd, a fertilizer blending Company in Kenya). Granular lime offers some advantages in handling over $CaCO_3$ and CaO. It spreads more uniformly, and it can be blended with fertilizers at low rates for row application (Warncke and Pierce, 1997). Granular lime is however more expensive than $CaCO_3$ and CaO and there is therefore need to determine whether granular lime is more effective than $CaCO_3$ and CaO in order to make it cost effective. The objectives of this study were to evaluate effects of lime types (calcium oxide, calcium carbonate and granular lime) applied alone or in combination with fertilizers containing N and P on maize yields, and assess effects of the three different lime types on soil properties

MATERIALS AND METHODS

Study sites

The study was conducted in 4 sub-counties in Western Kenya: Kakamega North, Mumias, Butere and Emuhaya for three consecutive seasons, 2015 long rains (LR), 2015 short rains (SR), and 2016 LR. Mumias has an average temperature of 21.6°C with an average annual of rainfall 1743 mm. The average temperature in Emuhaya is 20.5°C with an average annual rainfall of 1860 mm. The average temperature and annual rainfall in Butere is 21.3°C and 1830 mm, respectively. The temperature in Kakamega averages 20.4°C. The annual average rainfall at this site is 1971 mm. The rainfall at all these sites is distributed over two main cropping seasons, the long rainy season from March to July and the short rainy season from September to December. The soils in Mumias and Butere are Acrisols with a clay loam texture while those at Emuhaya and Kakamega North are Nitisols with a loamy texture. The sites were selected on the basis of having a soil pH of less than 5.5. Farming in the region is largely undertaken by smallholder farmers, practicing a mixture of cash crops and livestock enterprises. Maize and beans are the most common food crops grown in the area mainly as intercrops with little or no fertilizer and lime inputs.

Soil sampling and analysis

Soils from the study sites were sampled before the onset of the trials and characterized for relevant chemical properties using standard methods (Anderson and Ingram, 1993; Okalebo et al., 2002). The pH of soil samples was measured from a soil suspension solution prepared with 1:2.5 soil: water ratios using conventional glass electrode meter. Exchangeable acidity was extracted using unbuffered 1M KCl. Further, 25 ml of 1M KCl was added to 10 g of air-dry soil and shaken for 10 min on a reciprocal shaker and then allowed to stand for 30 min. The contents were filtered and the soil leached with 5 successive 25 ml aliquots of 1M KCl. The filtrate was titrated with 0.1M NaOH to determine the exchangeable acidity (H^+ and Al^{3+}) in the extract. The basic cations (Ca, Mg and K) were extracted using ammonium acetate at soil pH 7. Exchangeable Ca and Mg in the extract were determined using atomic absorption spectrophotometry, and exchangeable K by flame photometry. Organic C was determined by Walkley and Black sulphuric acid-dichromate digestion followed by back titration with ferrous ammonium sulphate. Total N and P were determined by digesting 0.3 g of the soil/OM sample in a mixture of Se, $LiSO_4$, H_2O_2 and concentrated H_2SO_4. The N and P contents in the digests were determined calorimetrically. Available P was determined by the Mehlich double acid method. A 2.5 g of air-dried soil sample was weighed into a 100 ml shaking bottle and 20 ml of the extracting solution (a mixture of 0.05 M HCl and 0.0125 M H_2SO_4) added. The mixture was shaken for 5 min and filtered through a Whatman No. 42 filter paper. A 5 ml of the extract was transferred to a 25 ml flask and diluted to the mark. Phosphorus concentration in the filtrate was determined calorimetrically by the ascorbic method at 880 nm using a spectrophotometer. Soils were again sampled at the end of the 2015 SR and 2016 LR seasons and analyzed for pH and exchangeable acidity only. However, this time

Table 1. Initial soil properties at the study sites.

Parameter	Sites			
	Butere	Emuhaya	Kakamega North	Mumias
pH	5.21	5.48	5.04	5.01
Exchangeable acidity (me/100 g)	0.40	0.10	0.30	0.30
Total N (g kg^{-1})	1.50	1.30	1.10	1.50
Organic C (g kg^{-1})	14.3	12.90	11.00	14.70
Available P (ppm)	5.00	10.00	10.00	15.00
Ca (Cmol/kg)	1.20	1.20	0.16	1.50
Mg (Cmol/kg)	1.90	2.09	1.10	1.29
K (Cmol/kg)	0.14	0.10	0.16	0.26

only one farm was sampled per site.

Experimental design and agronomic procedures

This trial was established on farmers' fields in each of the sites. A randomized complete block design was used with each farm treated as a replicate. Six replications were used per site (sub-county). The eight treatments consisted of three types of lime, applied alone or with fertilizers (Diammonium phosphate (DAP) and calcium ammonium nitrate (CAN). In addition, a treatment consisting of fertilizer alone (DAPS + CAN) and a control with no fertilizer or lime input was included. A summary of the treatments is as follows: Control (No lime, No fertilizer); 2 tons ha^{-1} $CaCO_3$; 2 tons ha^{-1} CaO; 2 tons ha^{-1} $CaCO_3$+26 kg P+60 kg N; 2 tons ha^{-1} CaO ha^{-1}+26 kg P+60 kg N; DAP 26 kg P (DAP) + 60 kg N (CAN); Granulated lime (only); and Granulated lime + fertilizer.

The liming materials were burnt lime material with 92.5% calcium carbonate ($CaCO_3$) equivalent, and CaO from Homa Lime Company Limited and granulated lime (64% $CaCO_3$, 2.5% MgO and trace elements) from MEA Ltd. The $CaCO_3$ and CaO were applied once at the recommended rate of 2 tons ha^{-1} in the first season (2015 LR) only while granular lime was applied in each season starting with the 2015 SR. The granular lime was applied as a blend with basal fertilizer (DAP), where applicable, in the ratio 1:1. DAP was applied every season (where applicable) at the recommended rate (26 kg P ha^{-1}) and CAN top dressed at 60 kg Nha^{-1} (where applicable) every season. After ploughing, plots of 4.5 m by 5.0 m were demarcated and guard rows between them maintained at 1.0 m apart. Two lime types ($CaCO_3$ and CaO) was evenly broadcasted by hand and thoroughly mixed with the soil using a hoe, in appropriate plots, at least 30 days before planting to allow for adequate reaction time with the soil. Planting was done at the onset of rainy season using recommended agronomic practices. Maize hybrid H 520, a variety recommended in the study areas was planted at a spacing of 25 cm by 75 cm, within and between rows, respectively. One and two seeds were sown in alternate holes and thinned to one per hill, 2 weeks post-emergence. Hand weeding and management of pests and diseases was carried out when necessary. To avoid contamination of inputs from the neighboring plots, each plot was individually tilled using a hoe. Harvesting was done at the end of each season and grain yield determined.

Data analysis

All the data collected was subjected to analysis of variance (ANOVA) using the General Linear Model (GLM) of the SAS statistical software (version 9.2). Means were separated by least significance difference of means (LSD) at the $p < 0.05$ level of significance.

RESULTS AND DISCUSSION

Initial soil properties

The initial soil properties at the study sites are shown in Table 1. The soil pH ranged from 5.01 (Mumias) to 5.48 (Emuhaya) and would be rated as moderately acidic and therefore likely to encounter challenges associated with acidic soils such as Al toxicity, deficiencies of bases and available P, which are encountered at soil pH <5.5. However, all the sites were low in exchangeable acidity suggesting that Al toxicity may not be a serious problem. The soil available P at all the sites was <20 ppm, which is considered the critical value of available P for maize using the Mehlich method that was used in this study (Landon, 1991). Hence, P deficiency is likely to limit maize yields at these sites. In addition, N was also deficient at all the sites (<0.2%). The low levels of soil N and available P at these sites is consistent with other reported studies in the area and is partly attributed to mining of soil P and N through crop harvest on small-holder farms where the recommended N and P fertilizer rates to replenish the removed nutrients through crop harvests are rarely applied (Smaling et al., 1993; Okalebo et al., 2006). The sites were low in organic Carbon (C) (<2%) indicating low levels of organic matter (Landon, 1991). Exchangeable bases (Ca, Mg and K) were also generally low as would be expected of acid soils because of leaching (Obiri-Nyarko, 2012).

Effect of treatments on soil pH and exchangeable acidity

All treatments with lime application generally increased the soil pH when compared with control in both 2015 and 2016 cropping seasons (Table 2) as expected. However, only granulated lime applied without fertilizer attained

Table 2. Effect of lime and fertilizer on soil pH.

Treatment	pH 2015	pH 2016	∆ pH	t-value	p-value
Control	4.92	5.21	0.28	-1.65	0.20
$CaCO_3$	5.26	5.53	0.28	-1.55	0.22
$CaCO_3$ + fertilizer	5.35	5.41	0.06	-0.46	0.62
CaO	5.23	5.42	0.19	-3.38	0.04
CaO + fertilizer	5.27	5.49	0.22	-1.85	0.16
DAP + CAN	5.21	5.19	-0.02	-0.13	0.91
Granulated lime	5.46	5.28	0.18	0.76	0.50
Granulated lime + fertilizer	5.45	5.23	0.22	0.94	0.42
LSD (0.05)	0.447	0.307	-	-	-

Note: Fertilizer= (26 kg P (DAP) + 60 kg N (CAN)); CaO=2 tons ha-1 Calcium Oxide; CaCO3=2 tons ha-1 Calcium Carbonate

Table 3. Effect of lime and fertilizer on soil exchangeable acidity (cmol/kg).

Treatment	2016	2017	∆ Exchangeable acidity	t-value	p-value
Control	0.25	0.15	0.10	1.4	0.25
$CaCO_3$	0.13	0.13	0.00	0.0	1.00
$CaCO_3$ + fertilizer	0.10	0.13	-0.03	-0.29	0.79
CaO	0.18	0.15	0.03	1.00	0.39
CaO + fertilizer	0.12	0.13	-0.01	0	1.00
DAP + CAN	0.25	0.15	0.10	1.40	0.25
Granulated lime	0.10	0.18	-0.08	-0.68	0.55
Granulated lime + fertilizer	0.15	0.15	0	0	1.00
LSD (0.05)	0.16	0.16	-	-	-

statistical significance in 2015 and $CaCO_3$ alone in 2016. The rise in pH of soil is associated with the presence of basic cations (Ca^{2+}) and anions (CO_3^{-2}) in lime that are able to exchange H^+ from exchange sites to form H_2O + CO_2. Cations occupy the space left behind by H^+ on the exchange leading to the rise in pH (Fageria et al., 2007). Similar increases in pH have been reported by several authors (Whalen et al., 2002; Moreira and Fageria, 2010; Buni, 2014). None of the treatments raised the pH above the critical level of 5.5 in both years. This indicates that the lime rate that was applied was inadequate to overcome the pH buffering capacity of these soils. The change of pH from 2015 to 2016 was significant only for CaO where the pH increased by 0.19 units. This suggests that the residual effects of the applied liming materials are likely to be low, due to the low rate of lime used in this study. Similar results were reported by Kisinyo et al. (2014) in Western Kenya with the same lime rate of 2 t ha^{-1}. Residual effects, lasting up to four years were however observed at a higher lime rate of 6 t ha^{-1} in the same study. Similarly Quaggio et al. (1995) affirm that the residual effects of liming materials were primarily related to the rates than to the chemical components of liming materials.

The effect of lime types, applied alone or in combination with fertilizer on exchangeable acidity is presented in Table 3. There was no significant effect of treatments on exchangeable acidity likely due to its low levels in these soils and high variability among the sampled sites. Similar results were reported by Opala (2017) on Ferralsols of Maseno. The change of exchangeable acidity from 2015 to 2016 was also not significant for all treatments.

Effect of lime and fertilizer on maize yields

The maize grain yields varied across sites and seasons. The yields in the long rains seasons were generally higher than those in the short rains seasons (Tables 4 and 5). The yield ranged from 1.35 t ha^{-1} (control) at Mumias to 6.15 t ha^{-1} ($CaCO_3$+ fertilizer) at Butere in the 2015 LR and 0.90 t ha^{-1} (granular lime alone) to 7.15 t ha^{-1} (CaO + fertilizer) at Butere in the 2016 LR. In the 2015 SR, the highest yields (4.35 t ha^{-1}) were obtained with granular lime applied with fertilizer at Emuhaya and the lowest was by 0.55 t ha^{-1} (control) at Kakamega North. In general, application of lime without fertilizers containing N and P did not significantly increase yields at all the sites in all the seasons. However, all sites, except Butere responded to application of N and P fertilizers when applied without lime. At Butere, maize responded to

Table 4. Effect of lime and fertilizer inputs on maize yields (t ha^{-1}) at four sites in western Kenya in 2015 rain seasons.

Treatment	2015 Long rains				2015 Short rains			
	Butere	Emuhaya	Kakamega N	Mumias	Butere	Emuhaya	Kakamega N	Mumias
1. Control	1.73	1.80	2.22	1.35	0.70	1.38	0.55	2.01
2. CaO	2.96	1.64	2.54	2.25	1.55	1.28	0.38	1.72
3. CaO + fertilizer	6.15	4.08	5.26	4.48	2.23	3.48	0.83	3.97
4. $CaCO_3$	2.32	1.54	2.84	1.75	1.5	1.10	0.57	1.12
5. $CaCO_3$ + fertilizer	5.88	4.50	5.52	3.50	2.60	2.35	0.94	4.31
6. Granular lime	-	-	-	-	0.75	1.83	0.66	2.05
7.Granular lime + fertilizer	-	-	-	-	1.65	4.35	0.80	3.31
8. .Fertilizer	1.83	4.20	5.58	3.33	1.75	2.68	0.64	3.89
LSD	1.46	1.92	1.26	1.64	1.57	1.29	0.71	3.20

In the 2015 LR season, granulated lime treatments were not applied in the experiment.

Table 5. Effect of lime and fertilizer inputs on maize yields (t ha^{-1}) at four sites in western Kenya in the 2016 long rains.

Treatment	Sites			
	Butere	Emuhaya	Kakamega N	Mumias
1. Control	1.65	2.05	2.87	1.05
2. CaO	2.15	4.50	2.60	1.90
3. CaO + fertilizer	2.80	7.15	5.77	5.95
4. $CaCO_3$	2.35	2.85	2.47	1.90
5. $CaCO_3$ + fertilizer	2.75	6.80	6.47	5.20
6. Granular lime	0.90	3.90	3.47	1.95
7. Granular lime + fertilizer	3.75	5.55	5.97	4.40
8. Fertilizer	2.15	6.80	6.10	4.65
LSD (0.05)	2.20	2.10	1.91	1.68

fertilizer only in the presence of lime suggesting that soil acidity was a constraint at this site. The response observed with application of the fertilizers (with or without lime) confirms that both N and P are deficient at these sites and fall under the category of responsive soils (Kihara et al., 2016). Similar responses of maize to N and P fertilizers have been reported by several studies in the region (Okalebo et al., 2006; Ademba et al., 2015; Nziguheba et al., 2016; Kihara et al., 2016) Fertilizers containing these nutrients must therefore be applied, the acidity status of the soils notwithstanding. The application of lime, irrespective of the type, with fertilizer, did not give yields that were significantly different from those of fertilizer applied without lime at two sites (Emuhaya and Kakamega North) in all seasons. However, at Butere application of lime in the form of CaO and $CaCO_3$ with fertilizer gave yields that significantly exceeded those with fertilizer (DAP + CAN) applied without lime in the 2015 LR (Table 4). Similar results were observed with granular lime with fertilizer in the 2015 SR at Emuhaya (Table 4). The general lack of significant responses to lime in Kakamega North, Mumias and Emuhaya may be due to the low levels of exchangeable Al in the soils. Aluminum toxicity is therefore not likely to have been a major problem because the exchangeable acidity of the soil was below the critical level for soils to have acidity problem according to Mohammed et al. (2016). Economic considerations may therefore militate against the use of lime at these three sites because the use of lime resulted in extra costs that were not offset by increased yields. In Butere however use of lime in the form of CaO or $CaCO_3$ could be economically feasible and should be preferred to granular lime which was more expensive yet it was not superior in terms of increasing maize yields.

Conclusions and Recommendations

The maize grain yields varied across sites and seasons. There is need therefore to tailor soil fertility management practices to site-specific conditions to sustainably increase crop productivity. There was no significant effect of lime type on maize yields at all the sites. Maize responded to the fertilizers containing N and P but not to application of lime without fertilizer at all sites. Application of lime, irrespective of the type, with fertilizer, did not give yields that were significantly different from those of fertilizers alone at all sites except at Butere in the 2015 long rain season when application of CaO and $CaCO_3$ with fertilizer gave significantly higher yields than those with fertilizer applied alone. Similar results were obtained with granular lime in the 2015 short rain season at Emuhaya. Soils in Mumias, Kakamega North and Emuhaya are either not sufficiently acid to permit the solubility of Al to toxic levels for maize or have inherently low levels of Al and that more attention should be focused on replenishing N and P at these sites. However, in Butere, soil acidity is a problem and lime should be applied together with fertilizers. The type of lime to be used should however be based on economic considerations since all the three types of lime tested were equally effective.

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CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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