

Effects of agricultural lime and phosphorus application to sugarcane (*Saccharum officinarum* L.) growth, yield and quality

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ABSTRACT

Effects of agricultural lime (L), phosphorus (P) and their interaction on sugarcane growth, yield and quality were determined in field experiments conducted between 2009 and 2011 in the Mumias sugar zone (MSZ) of western Kenya. Treatments consisted of two levels of L at 0 and 3 tons/ha and five rates of P at 0, 46, 92, 138 and 184 kg/ha P₂O₅ laid out in randomized complete block design and replicated three times. Emergence, tillering, stalk population, height, inter-node length, millable cane, sugar cane and sugar yields were significantly ($p < 0.05$) high with L and with P application. Sugarcane yield was increased 28.1-45.2 % with increase in P in limed compared with 19.0 – 19.8 % in un-limed treatments. Although incremental levels of P improved the sugarcane growth and quality parameters, there were no differences among P levels beyond 92 kg/ha P₂O₅. While higher value cost ratios (VCR) were observed in un-limed treatments, net returns (NR) were higher in the limed treatments. It is suggested that the inclusion of agricultural lime in the fertilizer regime in MSZ is necessary and cost effective. Where agricultural lime is applied the recommended P dose of 92 kg/ha P₂O₅ be reduced to 46 kg/ha P₂O₅

Keywords: Agricultural lime, Agronomic efficiency, Mumias sugar zone, Sugarcane, Phosphorus

INTRODUCTION

Sugarcane fertilization in Kenyan plantations over the last 40 years is largely concentrated on nitrogen (N) and phosphorus (P). Sources, amounts and methods of fertilizer application largely remain the same with N source being Urea and P source as diammonium phosphate (DAP). These fertilizers are acidifying and could have contributed to the observed decline in soil pH, a factor linked to declining sugarcane yields in the main production zone of Mumias in western Kenya that accounts for 50-60 % of national sugar production (Kenya Sugar research foundation (KESREF), 2006). Growing of sugarcane on the same land over the years is a common practice in the MSZ. There are no well-defined breaks, rotations or fallow periods between the previous crop and re-plant (Wawire et al., 2007). These practices coupled with the current fertilizer regimes are thought to have resulted in the observed yield decline from a high of 110 t/ha in 1997 to a low of only 51 t/ha (Kenya Sugar Board, 2013). According to Jaetzold et al. (2005), the MSZ has mainly acrisols which are acidic soils with low base status thus indicating low fertility.

Under soil acid conditions availability of the major plant nutrients N, P and potassium (K), as well as calcium (Ca) and magnesium (Mg), show a marked

reduction (NETAFIM, 2008). The onset of aluminum (Al³⁺) ions toxicity, as a result of the low pH, leads to rapid inhibition of sugarcane root growth due to impediment of both cell division and elongation, leading to reduced volume of soil explored by root system and direct influence of Ca and P uptake across cell membrane of damaged roots (Wong and Swift, 2003). Adverse effects of acidification lead to decreased water and nutrient retention capacity in soils and reduced biotic activity (Kinraide, 2003). Acidification of MSZ soils is therefore a chemical constraint, which demands special crop management practices in sugarcane such as use of agricultural lime and organic manures. However, there is paucity of information on the effects of liming of sugarcane on acidic acrisols in the MSZ.

Liming can mitigate the effects of P fixation by Al and (iron) Fe oxides at low pH thus making the P available to sugarcane plants (NETAFIM, 2008). Singha (2006) reported that liming of sugarcane at 2 tons/ha on a clay loam with pH 4.8 significantly increased the cane yields by 5.2 to 16.9% over the un-limed control. Liming slightly improved the quality of juice by increasing the sucrose and decreasing the glucose content of cane juice due to enhanced maturity. Residual effects of liming on the

cane yield and quality of juice in ratoon sugarcane crop were also significant together with improved availability of N, P and K status of the soil. Leong (1980) reported that liming of sugarcane on acid and lateritic latosols increased cane tonnage by about 10 t/ha principally through increases in the production of millable stalks as well as increases in stalk length and internode number. Whether inclusion of liming in the fertilization regime would lead to increased sugar cane yield and quality in MSZ has not been determined. The objective of this study was, therefore, to determine the effects of liming, P application and their interaction on sugarcane growth, yield and quality in MSZ.

MATERIALS AND METHODS:

Experimental site and plant material

The study was conducted during 2009 through 2011 in the MSZ (0°21'N and 34° 30'E at 1314 m above sea level) on the Mumias sugar company owned Nucleus estate (fields A 28 and E 35). The MSZ receives bi-modal rainfall ranging from 1500-2000 mm per annum with long rains peaking in April-May and short rains in September-October each year. The dominant soil type in the zone is orthic Acrisol (60%) followed by Ferralsol, Nitosol, Cambisol and Planosol (40%) (Jaetzold et al., 2005).

Predominantly grown sugarcane variety CO 945 was used. The variety was bred in Coimbatore, India from a cross between variety POJ 2878 and variety CO 617 (Jagathesan and Nyang'au, 1990). Its growth habit is erect with rhizomatous tillers. The cane stalks are greenish yellow with a pinkish tinge. Variety CO 945 is a medium maturing sugarcane cultivar harvested between 17 and 20 months (KESREF, 2004).

Experimental design and treatments

Treatments included two levels of agricultural lime (0 and 3 t/ha) and five rates of P (0, 46, 92, 138 and 184 Kg/ha P₂O₅) laid out in a randomized complete block design (RCBD) consisting of a 2 x 5 factorial arrangement with three replications. Each plot measured 9 m x 10 m. Sugarcane budded setts (of 3-eye) were laid in 0.15 m deep rows that were spaced 1.5 m apart. Recommended agronomic practices of weed management, top dressing with N, pest and disease observation were carried out as per the local recommendations (KESREF, 2006). Basal P fertilizer at 92 kg P₂O₅/ha was supplied by DAP while recommended N was top dressed as Urea. The N applied as top dress in the treatments was adjusted based on N provided by DAP at the different rates of P such that all plots receiving the treatment had uniform total of 128 kg/ha N.

Data collection

Data was collected on emergence, tillering, foliar N, P and K content, stalk height, inter-node length and number of millable stalks, sugarcane yield, sugar yield, juice quality and fibre content.

Emergence and tillering

A physical count of emerged shoots was done at 60 days after planting. Emergence was calculated as the highest number of emerged shoots expressed as a percentage (%) of the expected, as:

Emergency = (Number of emerged shoots/ No. of expected shoots) X 100.

Tillering was determined from 9 months after planting. A physical count of the total number of shoots in the net plot was done and extrapolated to establish the number of tillers/ha.

Foliar sampling and analysis

Nutrient uptake by the plants was monitored monthly from 9 months after planting from the four net rows. At sampling time, the 3rd leaf below the top visible dew lap (TVD) or spindle was taken. Ten leaves per row were collected making 40 leaves per plot. The centre of gravity of each bundle of leaves was determined by placing it on a specifically constructed table. The bundle was chopped with a sharp knife at the fulcrum and at 20 cm of the remainder towards the tip. Midribs of the sub sample were removed before determining the sample weight. Samples were then dried in the oven (model BR 6000 Binder World) at 80°C for 24 hours. Dry leaves were ground in an apex cutter and the sample weighed and placed in a clean dry polythene bag ready for analysis. Foliar N, P and K were analyzed by Kjeldahl, Molybdenum blue and Flame photometry methods (Okalebo et al., 2002). Foliar block digester (model DK 42/26 Velp Scientifica) was used to process respectively the samples that were analyzed in the semi auto nitrogen distillation (model unit UDK 132 Velp Scientifica). Flame photometer (model BWB-XP from BWB Technologies Ltd) and Atomic Absorption Spectrophotometer (model AA-7000, Shimadzu) were used for P and K determination.

Stalk height, inter-node length and number of millable stalks

Stalk height and inter-node length were recorded on 20 plants in the net plot at harvest. A physical count of all stalks in the net plot was done and extrapolated to establish the number of millable stalks population per ha.

Sugarcane yield, sugar yield, juice quality and fibre content

Sugar cane yield at harvest was determined by weighing all the stalks from the net plots. A tripod stand and calibrated suspension balance (Salter

model 10X Avery) were used. The weight (kg) realized was extrapolated to determine the cane yield in t/ha. Sugarcane quality parameters at harvest were determined from four stalks per net plot. Each stalk was chopped into three equal portions i.e. top, middle and bottom. The sub samples were chopped into smaller pieces and shredded in a Jeffco cutter machine (model WD02 Jefress Engineering Pty Ltd). Juice extraction was done in the disintegrator machine (model WD02 Jefress Engineering Pty Ltd). A shredded sample of 1000 g was put in the cold digester with 2 litres of water and left to run for 20 minutes. The sample was sieved and 150 ml put in a conical flask. One gram of Lead sub acetate was added for clarification before filtration. From the sieved and digested juice, Brix (total dissoluble solids) was determined directly from the Refractometer (model Abbemat-WR Anton Paaroptotec GmbH). From the clarified juice, Pol (apparent sucrose) was read on a Polarimeter (model AA-5 Optical Activity Ltd). A crushed and sieved cane sample of 100 g was placed in an oven (model BR 6000 Binder world) at 105°C for 4 hours then re-weighed for moisture determination. From Brix, Pol reading and moisture % calculations, sugarcane juice quality (Pol %), fibre % and sugar yield per ha were derived according to the South African Sugar Technologists Association (SASTA) (Schoonees-Muir et al., 2009).

Agronomic efficiency

Agronomic efficiencies (AE) for P application to limed and un-limed plots were evaluated from the yield increase as a result of P fertilization per unit of fertilizer P applied (Singh et al., 2008).

Economic evaluation

The costs and returns of sugarcane yield of the treatments were recorded. Cost-benefit analysis was done using Gross returns (GR), Net returns (NR) and Value cost ratios (VCR) as described by Shehu et al. (2010).

Data analyses

The data collected were subjected to analysis of variance using GenStat Release 13.2 (PC/Windows 7) Copyright 2010, VSN International Limited, and means compared by Fischer's Least Significant Difference (LSD) procedure at 5 % level of significance (Steel and Torrie, 1987).

RESULTS:

Soil characterization and rainfall

Soil analysis results from the experimental sites indicated low pH (5.0), total N (0.075) %, P (15.7 ppm), K (0.35 m.e), and low organic carbon (1.05 %), while Mg (2.70%), Ca/Mg (2:28) and CEC

contents (14.15 %) were higher than the recommended values for sugarcane ((Bureau of Sugarcane Experimental Stations (BSES), 1994). Soil texture was sandy clay and sandy clay loam with high bulk density. The short rains (season 1(S1)) were lower (3088.9 mm) than the long rains (season 2 (S2)) (3246.4 mm).

Sugarcane emergence

Sugarcane emergence (%) was affected by the L×P interaction. Generally, higher cane emergence was observed in treatments that received 46 kg/ha P₂O₅ in both un-limed and limed plots in season 1. In season 2, increase in P applied led to increase in sugarcane emergence (Table 1).

Tillering

The L × P interaction significantly ($p \leq 0.05$) affected tillering. In season 1, tiller numbers generally increased with increase in P, however, the increase was not pronounced in limed plots. In season 2, in un-limed plots, tillering increased with increase in P application up to 92 kg/ha P₂O₅, but leveled off with further increase in P. In limed plots, P application beyond 138 kg/ha P₂O₅ decreased tillering relative to the control (Table 1).

Foliar N content

In both seasons, L, P, and L X P had no significant ($p \leq 0.05$) effect on foliar-N content. In season 2, however, L×P interaction significantly affected foliar-N content. Generally in un-limed plots, foliar N was high in P treated plots compared to control (Table 2).

Foliar P content

The L, or P or the L×P interaction did not affect foliar P content in season 1. However in season 2 in un-limed plots, foliar P content was highest in P treated plots compared to control, it did not differ among the P treatments (Table 2).

Foliar K content

Neither P application nor L had significant ($p \leq 0.05$) effect on foliar K content in season 1. In season 2, foliar K content was high in treatments that received 92 and 184 kg/ha P₂O₅ but was low in the control, 46 and 138 kg/ha P₂O₅ treatments (Table 3). Generally limed plots had high foliar K content.

Stalk height

The L×P interaction significantly ($p \leq 0.05$) affected stalk height in both seasons. In season 1, stalk height increased with increase in P application to 138 kg/ha P₂O₅, then decreased thereafter (Table 4). In season 2, stalk height increased with increase in P application. Generally, limed cane had higher stalk heights.

		Emergence (%)						Number of tillers/ha (000)					
	Treatment	Phosphorus application (P ₂ O ₅ (kg/ha))						Phosphorus application (P ₂ O ₅ (kg/ha))					
		0	46	92	138	184	Mean	0	46	92	138	184	Mean
S1	UL	76.1	86.6	73.5	76.3	82.0	78.9	40.17	47.33	44.50	57.11	71.28	52.08
	L	76.6	85.5	74.2	80.4	76.6	78.7	56.67	60.85	60.78	66.56	65.44	62.06
	Mean	76.4	86.0	73.9	78.3	79.3		48.42	54.09	52.64	61.83	68.36	
	LSD _{0.05}	(L) = 4.38 ^{ns} , (P) = 6.92*, (L×P) = 9.79*, CV = 7.2 %						(L) = 2.58**, (P) = 4.09**, (L×P) = 5.78***, CV = 5.9 %					
S2	UL	47.33	52.67	54.00	60.33	70.00	56.87	117.49	123.09	130.58	127.75	120.22	123.83
	L	47.00	46.67	47.33	62.67	76.33	56.00	130.08	135.81	126.99	125.80	121.33	128.00
	Mean	47.17	49.67	50.67	61.50	73.17		123.78	129.45	128.79	126.77	120.78	
	LSD _{0.05}	(L) = 3.78 ^{ns} , (P) = 5.97*, (L×P) = 8.45*, CV = 7.2 %						(L) = 3.58*, (P) = 5.66*, (L×P) = 8.00*, CV = 3.7 %					

UL = Un-limed, L = Limed (3t (P₂O₅/ha), S1 = Season 1 and S2 = Season 2), *P < 0.05, ** P < 0.01; *** p < 0.001; ns - not significant at (p<0.05) using Fischer's Least Significant Difference (LSD) procedure at 5 % level; L - agricultural lime; P - phosphorus; L×P - interaction of lime and phosphorus; CV - coefficient of variation

		Foliar N (%) content						Foliar P (%)					
	Treatment	Phosphorus application (P ₂ O ₅ (kg/ha))						Phosphorus application (P ₂ O ₅ (kg/ha))					
		0	46	92	138	184	Mean	0	46	92	138	184	Mean
S1	UL	1.67	1.70	1.65	1.75	1.76	1.71	1.85	1.73	2.15	2.27	2.26	2.05
	L	1.78	1.85	1.87	1.90	1.92	1.86	1.96	2.25	2.21	2.43	2.69	2.41
	Mean	1.73	1.78	1.76	1.83	1.84		1.91	1.99	2.18	2.35	2.48	
	LSD _{0.05}	(L) = 0.17 ^{ns} , (P) = 0.30 ^{ns} , (L×P) = 0.38 ^{ns} CV = 12.2 %						(L) = 0.29*, (P) = 0.45*, (L×P) = 0.64*, CV = 16.7 %					
S2	UL	0.17	0.19	0.18	0.19	0.19	0.18	0.08	0.11	0.10	0.09	0.13	0.10
	L	0.19	0.19	0.18	0.19	0.18	0.19	0.10	0.12	0.10	0.11	0.11	0.11
	Mean	0.18	0.19	0.18	0.19	0.19		0.09	0.11	0.10	0.10	0.12	
	LSD _{0.05}	(L) = 0.01 ^{ns} , (P) = 0.02 ^{ns} , (L×P) = 0.03 ^{ns} , CV = 8.1 %						(L) = 0.01 ^{ns} , (P) = 0.02*, (L×P) = 0.03 ^{ns} , CV = 8.1 %					

UL = Un-limed, L = Limed (3t (P₂O₅/ha), S1 = Season 1 and S2 = Season 2), *P < 0.05, ** P < 0.01; *** p < 0.001; ns - not significant at (p<0.05) using Fischer's Least Significant Difference (LSD) procedure at 5 % level; L - agricultural lime; P - phosphorus; L×P - interaction of lime and phosphorus; CV - coefficient of variation

S1	Treatment	Phosphorus application (P ₂ O ₅ (kg/ha))					
		0	46	92	138	184	Mean
	UL	0.40	0.44	0.39	0.51	0.59	0.47
	L	0.50	0.49	0.53	0.55	0.65	0.54
	Mean	0.45	0.47	0.46	0.53	0.53	
	LSD _{0.05}	(L) = 0.10 ^{ns} , (P) = 0.15 ^{ns} , (L×P) = 0.22 ^{ns} , CV = 25.3 %					
S2	Treatment	0	46	92	138	184	Mean
	UL	0.69	0.76	1.25	0.52	1.30	0.90
	L	0.74	0.90	1.68	0.84	1.71	1.17
	Mean	0.72	0.83	1.47	0.68	1.51	
	LSD _{0.05}	(L) = 0.03**, (P) = 0.05**, (L×P) = 0.07**, CV = 4.3 %					

UL = Un-limed, L = Limed (3t (P₂O₅/ha), S1 = Season 1 and S2 = Season 2), *significant ** highly significant; *** very highly significant, ns - not significant at (p<0.05) using Fischer's Least Significant Difference (LSD) procedure at 5 % level; L - agricultural lime; P - phosphorus; L×P - interaction of lime and phosphorus; CV - coefficient of variation

Inter-node length

Sugarcane that received P generally had longer internodes than canes not treated with P in both un-limed and limed plots in season 1. However, inter-node length did not differ among P treated plots; except 46 kg/ha P₂O₅ in the limed plots which had the highest inter-node length. The same pattern was observed in season 2 except that P application did not increase inter-node length in limed plots. Inter-node length was higher in season 2 crop than in season 1 (Table 4).

Number of millable stalks

Number of millable stalks was affected by the L×P interaction in both seasons (Fig 1). In season 1, the P treated canes had higher stalk numbers relative to the control in un-limed treatment. There was no difference in number of millable stalks among the P treated stalks. In the limed plots, stalk numbers were less with P application of 92 kg/ha P₂O₅ and above. In season 2, number of millable stalks increased with P application of 92 kg/ha P₂O₅ and above relative to the control in the un-limed plots. In the limed plots, number of millable stalks increased with P application of 46 kg/ha P₂O₅ and above relative to the control. Generally, limed plots had more millable stalks than the un-limed. Season 2 crop had higher high number of millable stalks than those of season 1.

Sugarcane yield

Sugarcane yields increased significantly ($p \leq 0.05$) with P application relative to the control in season 1; however, there were no differences among sugarcane treated with 46-184 kg/ha P₂O₅ (Fig 2). In season 2, sugarcane yields generally increased with increase in P to 138 kg/ha P₂O₅ in un-limed plots. In the limed plots, sugarcane yields increased with increase in P application. Generally, limed plots had higher sugarcane yields.

Sugarcane juice quality (Pol %)

In season 1, Pol % was high only with P application of 184 kg/ha P₂O₅ in un-limed and at 138 kg/ha P₂O₅ in limed plots. The control treatment had significantly high Pol % relative to 46 kg/ha P₂O₅. In season 2, L, P rate and L×P interaction had no significant effect on Pol %. Generally, Pol % was high in un-limed plots (Table 5).

Fibre %

The L×P interaction had a significant effect on fibre content in both seasons. Application of P did not increase fibre % in un-limed plots but did so relative to the control in limed plots. However, liming had an inconsistent effect on fibre % cane. In season 2, there was a drop in fibre content with P application relative

to the control in un-limed plots while the converse was true in the limed plots (Table 5).

Sugar yield

In both seasons, the P treated plots had more sugar yield than the control (Fig 3). There was no difference in sugar yield among P treated plots. In season 2, sugar yield increased with increase in P to 92 Kg/ha (P₂O₅) and decreased thereafter. Generally sugar yield was higher in limed than un-limed plots.

Since the trends of results for AE and economic evaluation were similar, only those of season 2 are presented.

Agronomic efficiency of liming and P application

Higher AE were observed at the lower P levels of 46 and 92 kg/ha P₂O₅ but decreased with increase in P application in both seasons (Table 6). Generally, AEs were greater in plots that received lime than those that were un-limed.

Economic evaluation of sugarcane

Value cost ratio decreased with increase in P application to un-limed and limed plots in both seasons (Table 7). However, NR was highest in treatments of P at 46 and 92 kg/ha P₂O₅ in both seasons. Generally, NR was higher in the limed treatments than the un-limed.

DISCUSSION:

Emergence, tillering, millable stalk number, height and inter-node length

Results obtained from this study indicated that liming and P application had a positive effect on sugarcane growth and yield parameters. It would be argued that P availability was enhanced by application of higher doses of P or use of agricultural lime. This result corroborated the findings of other studies which indicate that plant growth benefits from the application of P fertilizers because it increases the rate of P diffusion to roots and promotes root growth into unexploited soil (Kelly et al., 2005). Malavolta (1994) and Omollo and Abayo (2011) indicated that the role of P in sugarcane is to stimulate early root formation and development. Being essential for productive growth, P firstly works on roots to provide a bigger root mass, but it is equally important in providing stronger stalk development, more tillers and quicker canopy closure as may have occurred in this study. Poor P supply reduces tillering, intermodal length and root area. Liming is known to mitigate the effects of P fixation by Al and Fe oxides at low pH thus making the P available to sugarcane plants (NETAFIM, 2008). In the current study liming appeared to unlock the

Table 4: Effects of agricultural lime and phosphorus application on stalk height (cm) of sugarcane and inter-node length (cm) of sugarcane

		Stalk height (cm)						Inter-node length (cm) of sugarcane					
Treatment		Phosphorus application (P ₂ O ₅ (kg/ha))						Phosphorus application (P ₂ O ₅ (kg/ha))					
		0	46	92	138	184	Mean	0	46	92	138	184	Mean
S1	UL	93.47	102.73	108.03	111.87	102.17	103.65	5.57	6.21	6.18	6.51	6.32	6.16
	L	105.93	107.93	109.57	112.37	103.57	107.87	6.24	7.38	6.61	6.69	6.44	6.67
	Mean	99.70	105.33	108.80	112.12	102.87		6.05	6.79	6.39	6.60	6.38	
	LSD _{0.05}	(L) = 2.36*, (P) = 3.73***, (L×P) = 5.27***, CV = 2.9 %						(L) = 0.19***, (P) = 0.30***, (L×P) = 0.43***, CV = 3.8%					
S2	UL	205.10	226.80	233.37	236.30	247.73	229.86	8.47	9.63	9.37	9.60	9.23	9.26
	L	241.83	246.60	254.73	251.17	256.77	248.22	9.80	9.97	9.67	9.20	9.63	9.65
	Mean	223.47	236.70	243.74	238.73	252.25		9.13	9.80	9.52	9.40	9.43	
	LSD _{0.05}	(L) = 3.46***, (P) = 5.46***, (L×P) = 7.73***, CV = 1.9 %						(L) = 0.28**, (P) = 0.43*, (L×P) = 0.62**, CV = 3.8 %					

UL = Un-limed, L = Limed (3t (P₂O₅/ha), S1 = Season 1 and S2 = Season 2), *P < 0.05, ** P < 0.01; *** p < 0.001; ns - not significant at (p<0.05) using Fischer's Least Significant Difference (LSD) procedure at 5 % level; L - agricultural lime; P – phosphorus; L×P – interaction of lime and phosphorus; CV – coefficient of variation

Table 5: Effects of agricultural lime and phosphorus application on juice quality (Pol %) and fibre (%) content of sugarcane

		Juice quality (Pol % of cane) of sugarcane						Fibre (%)					
Treatment		Phosphorus application (P ₂ O ₅ (kg/ha))						Phosphorus application (P ₂ O ₅ (kg/ha))					
		0	46	92	138	184	Mean	0	46	92	138	184	Mean
S1	UL	13.56	13.11	13.34	13.64	13.86	13.50	17.67	16.86	17.93	17.72	16.80	17.40
	L	13.83	13.53	13.79	14.12	13.59	13.77	16.96	17.70	17.15	17.36	17.09	17.25
	Mean	13.70	13.32	13.56	13.88	13.73		17.31	17.28	17.54	17.54	16.95	
	LSD _{0.05}	(L) = 0.12*, (P) = 0.19***, (L×P) = 0.27***, CV = 1.2%						(L) = 0.13**, (P) = 0.21***, (L×P) = 0.29***, CV = 1.0 %					
S2	UL	12.11	11.85	11.94	11.95	12.25	12.02	17.15	16.70	16.36	16.36	16.07	16.53
	L	12.57	12.43	12.38	11.87	11.90	12.23	16.66	17.02	16.83	17.40	17.80	17.14
	Mean	12.34	12.14	12.16	11.91	12.08		16.91	16.86	16.59	16.88	16.94	
	LSD _{0.05}	(L) = 0.02 ^{ns} , (P) = 0.04 ^{ns} , (L×P) = 0.80 ^{ns} , CV = 0.5%						(L) = 0.43***, (P) = 0.10 ^{ns} , (L×P) = 0.14***, CV = 2.4 %					

UL = Un-limed, L = Limed (3t (P₂O₅/ha), S1 = Season 1 and S2 = Season 2), *P < 0.05, ** P < 0.01; *** p < 0.001; ns - not significant at (p<0.05) using Fischer's Least Significant Difference (LSD) procedure at 5 % level; L - agricultural lime; P – phosphorus; L×P – interaction of lime and phosphorus; CV – coefficient of variation

Table 6: Effects of agricultural lime and phosphorus application on sugarcane yield (t/ha) and AE of L, P rates

		Sugarcane yield (t/ha) and AE of L and P rates				Sugar yield (t/ha) and AE of L, P rates			
Treatment	P ₂ O ₅ rate (kg/ha)	Y ¹ (t/ha)	YI (t/ha)	%	AE (kg sugarcane/kg nutrient)	Y ¹ (t/ha)	YI (t/ha)	%	AE (kg sugarcane/kg nutrient)
UL	0	93.6	-	-	-	11.33	-	-	-
	46	115.7	22.1	23.6	480.4	13.71	2.38	21.0	51.7
	92	116.7	23.1	24.7	251.1	13.93	2.60	22.9	28.3
	138	128.2	34.6	37.0	250.7	15.32	3.99	35.2	28.9
	184	125.8	32.2	34.4	175.0	15.41	4.08	36.0	22.2
L	0	110.9	17.3	18.5	-	13.94	2.61	23.0	-
	46	132.8	39.2	41.8	852.2	16.50	5.17	45.6	112.4
	92	135.3	41.7	44.5	453.3	16.75	5.42	47.8	58.9
	138	131.9	38.3	40.9	277.5	15.66	4.33	38.2	31.4
	184	132.7	39.1	41.8	212.5	15.79	4.46	39.4	24.2

UL = Un-limed, L = Limed (3t (P₂O₅/ha), Y = Yield, YI = Yield increase, AE = agronomic efficiency (kg sugarcane/kg nutrient).

Treatment	P ₂ O ₅ rate (kg/ha)	GR (Ksh)	FC (Ksh)	NR (Ksh)	VCR
UL	0	351,000.00	10,952.00	188,192.40	17.2
	46	433,875.00	18,746.00	244,024.30	13.0
	92	437,625.00	26,540.00	239,109.30	9.0
	138	480,750.00	34,334.00	264,423.80	7.7
	184	471,750.00	45,128.00	249,720.20	5.9
L	0	415,875.00	23,357.00	225,594.10	9.7
	46	498,000.00	31,151.00	280,850.20	9.0
	92	507,375.00	38,945.00	280,253.70	7.2
	138	494,625.00	46,739.00	262,671.10	5.6
	184	497,625.00	54,533.00	257,180.30	4.7

UL = Un-limed, L = Limed (3t (P₂O₅/ha), GR= Gross return, FC= Fertilizer cost, NR= Net return, VCR= Value cost ratio. Price of DAP= Ksh 3,897 per 50 kg bag, Price of Urea= Ksh 2,960 per 50 kg bag; Agricultural lime = Ksh 4,135 per ton; Price of sugarcane= Ksh 3,750 per ton

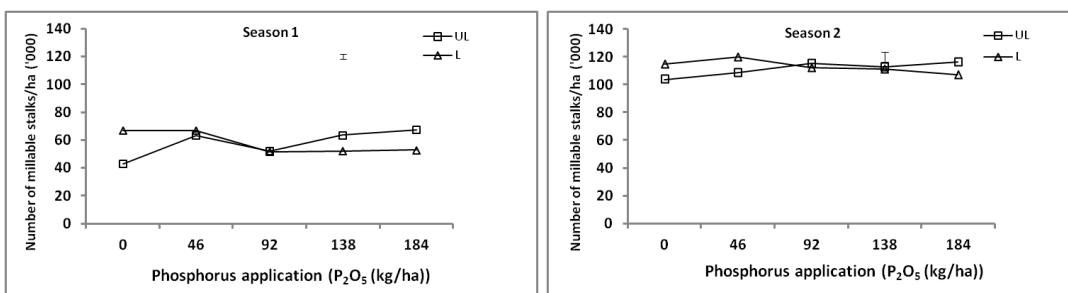


Fig 1. Effects of agricultural lime and phosphorus application on number of millable stalks/ha ('000) of sugarcane. UL = Un-limed and L = Limed treatments. Vertical bars are LSD_(0.05) bars

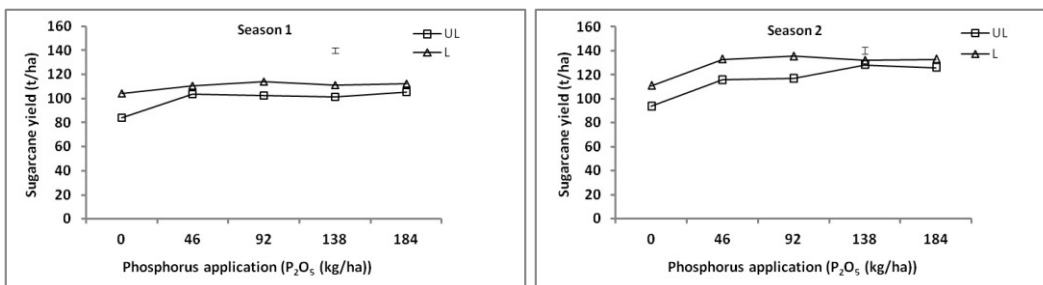


Fig 2. Effects of agricultural lime and phosphorus application on sugarcane yield (t/ha). UL = Un-limed and L = Limed treatments. Vertical bars are LSD_(0.05) bars

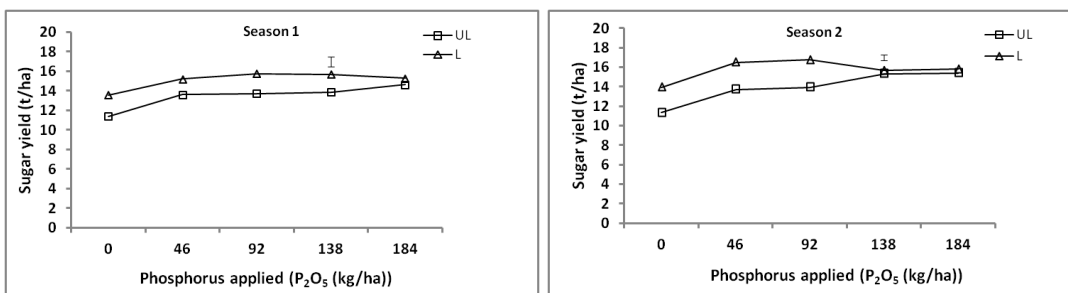


Fig 3. Effects of agricultural lime and phosphorus application on sugar yield (t/ha). UL = Un-limed and L = Limed treatments. Vertical bars are LSD_(0.05) bars

fixed P hence the requirement of only 46 kg/ha P₂O₅ to obtain response in sugarcane growth.

Sugarcane and sugar yields

Results of this study showed that sugarcane yield increased significantly ($p \leq 0.05$) with agricultural lime and P application. Yield increase of up to 15.9 % was obtained with inclusion of agricultural lime along with the current fertilizer recommendation. With liming, the P requirement could be minimized to only 46-92 kg/ha P₂O₅. The yield increase due to liming was clearly due to increased tillering, number of millable stalks, increased stalk height and intermodal length. Liming appears to have improved the available N, P and K status of the soil hence the utilization of the nutrients for plant growth. Our results agree with findings of Leong (1980) study, where liming of sugarcane on acid latosols and lateritic latosols increased cane tonnage by about 10 t/ha principally through increases in the production of millable stalks as well as increases in stalk length and internode number; and of Singha (2006) who reported that agricultural lime applied on a clay loam soil with pH 4.8 significantly increased sugarcane yield by 5.2 to 16.9% over the control.

Sugar cane yields were higher in season 2 (the long rains) due to the slightly above normal rains recorded in the growth period of the crop compared to that of season 1. According to Mutanda (1990), MSZ sugarcane yields for plant crops are largely related to climatic factors especially rainfall. Environmental processes (rainfall, radiation, temperatures) enhance biomass accumulation and improve the cane and sugar yields.

Sugar yields were higher in limed and P treated plots in this study. Most of the time the application of P, while increasing yield and tons of sucrose per hectare, did not affect Pol % cane significantly. Therefore, the increase in sugar yield per ha was largely due to the higher sugarcane yields realized. The results of this study contrasted with those of Leong (1980) indicating that liming at 2.5 t/ha caused a drop in the sucrose percentage, thereby lowering the cane commercial sugar.

Juice quality and fibre content

In this study, application of lime had no effect on the quality of juice. Generally, Pol % cane was higher in season 1 compared with season 2 because the latter received higher rainfall in the crop growth period. Stressed plants are known to have high sugar concentrations (KESREF, 2006) hence the observed high Pol % in season 1 sugar cane. Our findings agree with those of Meyer (1976) who reported in one trial on a high N mineralizing soil, that lime treatments significantly depressed sucrose % cane from an average of 13.4 % in the control to 12.4 % in

the lime treatment. The decline was accompanied by a general increase in foliar-N values in excess of 2.5 %. In this study foliar N (%) never exceeded 2.5. Our findings, also, do not agree with those of Singha (2006) who observed increased quality of juice by increasing the sucrose and decreasing the glucose content of cane juice caused by lime application and enhanced maturity. In this study liming and P application had no pronounced effect on the fibre content. This is in agreement with findings of Leong (1980) who reported that liming of sugarcane on acid latosols had no effect on the fibre content.

Agronomic efficiency (AE)

In this study AE of P application on sugarcane and sugar yield decreased with increase in P. The AE was greater in plots supplied with agricultural lime along with N and P possibly due to release of soil nutrients for plant growth. The results of this experiment agree with those of Kidanemariam et al. (2013) who found out that yield and yield attributes of wheat showed significant response to the main effects of lime and fertilizer applications. Fertilizer x lime interaction effect was significantly different in grain yield, total biomass and N and P uptake. The highest AE and apparent recovery efficiency were recorded in the soils treated with lime along with recommended P and NP fertilizers. Our results agree with the findings of Colleen (2004) who reported that agricultural lime increased fertilizer use efficiency and saved money. He concluded that money spent on fertilizer is not well invested unless soil pH is properly adjusted first through liming.

Economic Evaluation

Although lower value cost ratios (VCRs) were realized with liming, there were higher NR per ha with liming and P application at 46-92 kg/ha P₂O₅ due to higher sugarcane yields realized in the limed treatment. Application of P beyond the recommended 92 kg/ha P₂O₅ cost 29-70 % more without liming and 17-105 % with liming. It would, therefore, be cost effective to lime and reduce the current recommendation of P as supported by results of this study

CONCLUSION AND RECOMMENDATION

The result of this study suggests that when agricultural lime is used, the rate of P fertilizer used could be reduced without compromising the cane yield and juice quality. The current fertilizer recommendation of 92 kg/ha P₂O₅ should be retained along with liming, while P application at 46 kg/ha P₂O₅ along with liming could be adopted on high P response soils for sugar cane production.

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