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Restoring soil fertility in previously sugarcane cropped farms for maize production in Butere- Kakamega County

S. Oyamo*, C. Serrem and A. N. Otinga

Department of Soil Science, School of Agriculture and Biotechnology, University of Eldoret, P. O. Box 1125, Eldoret, Kenya.

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The depletion of fertility in tropical soils of sub Saharan Africa (SSA) is mainly due to continuous cropping without proper nutrient replenishment. This study was intended to find ways of restoring soil fertility towards sustainable maize production in previously sugarcane cropped fields in Butere-Kakamega County. Field experiments were conducted in Butere and Bukura sites located in Kakamega County in the long rains of 2014. The field experiments consisted of twelve treatments with one control. The treatments included *Tithonia diversifolia* (a green manure), Di ammonium phosphate (DAP) filter mud, and bagasse (both sugarcane processing by products), each to supply 39 kg P ha^{-1} and eight other treatments consisting of a combination of either two of the above materials to supply either 26 or 39 kg P ha^{-1} treated either with or without lime using a split plot arrangement in a randomized complete block design (RCBD). Lime was allocated in the main plot and the treatments as the sub plots. The experiment was replicated three times in each site. Application of lime, with the consequent use of either filter mud or *Tithonia* in combination with DAP was quite significant in raising maize grain yield as compared to the control. The best treatment was the one consisting of lime (3 tons ha^{-1}) with a combination of filter mud + DAP (to supply 39 kg P ha^{-1}) which yielded 5.14 and 5.23 tons ha^{-1} in Bukura and Butere sites, respectively. This could be attributed to high levels of organic matter and suitable pH of 6.0 in filter mud that improved the physical and chemical properties of the soil. Farmers are thus advised to consider applying filter mud together with appropriate mineral fertilizers as filter mud can be supplied freely from sugar factories.

Key words: Soil fertility, bagasse, filter mud, lime, *Tithonia*.

INTRODUCTION

In Kenya, maize, *Zea mays* L, is recognized as the staple food among most communities serving as human food (Guantai et al., 2007). Low maize yields in the Country are strongly associated with soil acidity and phosphorus (P) deficiency (Kisinyo et al., 2014).

In the entire sub Saharan Africa (SSA), Kenya

*Corresponding author. E-mail: steveoyamo@gmail.com.

included, grain yields have been highly variable and low; for instance, between 2011 and 2013, the average yield was estimated at 1.8 mg ha^{-1} (Beyene et al., 2015).The major climatic divisions in SSA are tropics, sub tropics, temperate and boreal. But the tropics occupy more than 50% of the whole area of SSA; hence, maize can be grown in most of this region as it grows well in such a climate (Research Institute, 2010). Edaphic characteristics such as levels of macro and macro nutrients, soil parameters such as pH, organic carbon content, soil texture and cation exchange capacity vary depending on altitudinal gradients. This means for maximum maize yields one has to get an understanding on the altitude levels (Njuguna et al., 2015). Poor soil fertility is a major limitation to crop production (Kisinyo et al., 2014). This has resulted to widespread food insecurity in most parts of Kenya.

In western Kenya, the major problem causing poor maize yields is attributed to continuous mining of macronutrients due to cropping, without proper replenishment of the soils. The current status of most soils in western Kenya is that the amount of organic matter has gone down, hence less humus in the soil. In Butere region, the Acrisol soils with reasonable proportions of clay and organic matter and a fairly moderate cation exchange capacity of 35 to 45 cmol kg^{-1}, have now deteriorated. These soils are less fertile due to the low pH of <5.0, hence fixation of phosphorus is common (Oyamo et al., 2016).

MATERIALS AND METHODS

The study was on farm and the experiment was carried out on a farmer's field in Shihaka sub location in Butere Sub County. This experiment was also replicated on station at Bukura Agricultural College. The two sites are both in Kakamega County of western province and have a bimodal rainfall pattern. Both sites are suitable for maize and sugarcane production. The experiment was run between January 2014 and August 2014.

Experimental treatments

There were two levels of phosphorus (26 and 39 kg P ha^{-1}) supplied through the mineral fertilizer Di ammonium phosphate (DAP) and three organic materials. These organic materials were incorporated in the soil thoroughly three months prior to planting to allow for mineralization. The quantity of nitrogen was topped up by calcium ammonium nitrate (CAN) so that each treatment received a uniform rate of 75 kg N ha^{-1} during top dressing. The experiment thus consisted of thirteen treatments as shown in Table 1.

Experimental design

The design was Randomized Complete Block Design (RCBD) with a split plot arrangement where the main plot was with or without lime and the sub plots were the treatments. The experiment was replicated three times with a replication consisting of 13 plots with lime and 13 plots without lime totaling to 26 plots.

Statistical analysis

Crop yield, soil and plant data obtained were subjected to analysis of variance (ANOVA) with the mixed procedures using statistical analysis system (SAS) for windows 9.1 service pack 4 (SAS institute 2011). Means were separated by way of contrast and correlations were done.

Statistical model

$$Y_{ijkl} = \mu + L_i + R_j + LR_{ij} + S_k + LS_{ik} + F_l + FS_{lk} + €_{ijklm} \quad (1)$$

Where Y = observations on experimental unit on ijkl rows, μ = General mean, L = Effect due to i^{th} level of lime, R= Effect due to j^{th} replication, S = Effect due to k^{th} site, F = Effect due to l^{th} amendment (fertilizer), LR_{ij} = Error term 1, and $€_{ijklm}$ = Error term 2.

Economic analysis

After computing the grain yield (tons ha^{-1}) for each treatment, gross returns were calculated based on the prevailing market price of maize in the region.

Total costs were also computed after adding up all the costs from land preparation, farm inputs, labour, etc. Benefit cost ratio (BCR) was then calculated by the formulae:

$$BCR = \frac{Gross\ returns}{Total\ costs} \quad (2)$$

RESULTS

Initial soil characterization for the study sites

Soil properties at the experimental sites are presented in Table 2.

The treatments with filter mud supplying 39 kg P ha^{-1} (FL_1) significantly increased the soil pH in both sites. In Bukura site limed plots, this treatment, that is, FL_1 (filter mud alone; 39 kg P ha^{-1}) raised the pH from 5.67 (control) to 5.80 where as in the same site for the unlimed plots the treatment raised the pH from 5.18 to 5.30. Effect of lime on available P was significant ($p < 0.0001$) and was able to raise the soil extractable P (in Bukura site) from 5.27 mg kg^{-1} (control without lime) to 13.55 mg kg^{-1} (control with lime) as shown in Table 3.

Effect of treatments on maize grain yield

Lime application was significant ($p < 0.0001$) in raising the maize grain yield in both sites, where it raised yields from 1.38 to 2.16 tons ha^{-1} and from 1.52 to 1.95 tons ha^{-1} in Bukura and Butere sites, respectively. The average of all the treatments with lime (L_1) produced a mean grain yield of 3.24 tons ha^{-1} where as those without lime (L_0) produced a mean grain yield of only 2.27 tons ha^{-1} in Butere site. For Bukura site, the treatments with lime (L_1) yielded 2.92 tons ha^{-1} whereas those without lime (L_0) yielded only 2.30 tons ha^{-1}.

Table 1. Treatments in the experiment, their codes and rate of phosphorus per treatment.

S/N	Treatment	Code	Rate of P (Kg P_2O_5 ha^{-1})
1	Control	C	0
2	Tithonia alone	TN_1	39
3	Bagasse alone	BG_1	39
4	Filter mud alone	FL_1	39
5	DAP alone	D_1	39
6	Tithonia + DAP	TN/D_2	26
7	Bagasse + DAP	BG/D_2	26
8	Filter mud + DAP	FL/D_2	26
9	Tithonia + Bagasse	TN/BG_2	26
10	Tithonia + DAP	TN/D_1	39
11	Bagasse + DAP	BG/D_1	39
12	Filter mud + DAP	FL/D_1	39
13	Tithonia + Bagasse	TN/BG_1	39

Table 2. Initial chemical and physical characteristics of the soils from the sites.

Parameter	Butere	Bukura
pH 1:2.5 soil: water	4.66	5.35
Exchangeable acidity ($cmol_c$ kg^{-1})	0.3	0.4
Organic carbon (%)	1.35	1.65
Clay (%)	38	30
Sand (%)	25	30
Silt	37	40
Textural class	Clay loam	Clay loam
Available P (mg kg^{-1})	3.81	5.88

The effect of treatments was highly significant in both sites ($p < 0.0001$) where treatment FL/D_1 (Filter mud + DAP: 39 kg P ha^{-1}) yielded the highest in both sites. This treatment (FL/D_1) raised the yield from 2.16 (control-L_1) to 5.14 tons ha^{-1} in limed treatments (L_1) in Bukura site and raised the yield from 1.38 (control- L_0) to 3.52 tons ha^{-1} in the unlimed treatments (L_0) in the same site. In Butere site, the same treatment (FL/D_1) increased the yields from 1.95 to 5.23 tons ha^{-1} in the limed treatments (L_1) and raised the yield from 1.52 to 3.68 tons ha^{-1} in the unlimed treatments (L_0) as shown in Figures 1 and 2.

The closest treatment in performance from this one was TN/D_1 (*Tithonia* + DAP: 39 kg P ha^{-1}) that increased the yield from the control value of 1.95 to 4.56 tons ha^{-1} for treatments where lime was applied (L_1) in Butere site. In Bukura site, the same treatment (TN/D_1) also increased yields from 2.16 to 4.57 tons ha^{-1} in the limed treatments (L_1).

Correlation between grain yield and available phosphorus

Maize grain yield in Bukura had a high correlation with available P with an r of 0.65 where as in Butere site the coefficient of determination (r) was 0.66 as seen in Figure 3.

Correlation between nitrogen percentage and yield in the two sites

The level of nitrogen (%N) was strongly correlated with the yield in both sites with r = 0.60 and 0.81 for the Bukura and Butere sites, respectively as shown in Figure 4.

On average of the two sites, lime was significant ($p = 0.001$) by raising the BCR from 0.64 (unlimed treatments) to 0.78 (limed treatments).

For Bukura site treatments with lime (L_1), the two treatments: FL/D_1 (Filter mud + DAP: 39 kg P ha^{-1}) and TN/D_1 (*Tithonia* + DAP: 39 kg P ha^{-1}) were the only ones with BCR over 1.0, having BCR of 1.32 and 1.30, respectively. For Butere site, in the limed treatments (L_1), the three treatments: FL/D_1 (filter mud + DAP: 39 kg P ha^{-1}), TN/D_1 (*Tithonia* + DAP: 39 kg P ha^{-1}) and TN_1 (*Tithonia* alone: 39 kg P ha-1) were the only ones with BCR of over 1.0 by attaining BCR of 1.35, 1.30 and 1.09, respectively (Tables 4 and 5).

Table 3. The influence of organic resources on pH and available P in Bukura and Butere sites during the 2014 long rain season.

Lime	Bukura site			Butere site		
	Organic resources (Treatments)	pH (H_2O)	Available P (mg kg^{-1})	Organic resources (Treatments)	pH (H_2O)	Available P (mg kg^{-1})
	1 (C)	5.47	13.55	1 (C)	5.20	16.55
	2 (TN_1)	5.69	23.84	2 (TN_1)	5.57	22.79
	3 (BG_1)	5.78	17.94	3 (BG_1)	5.69	18.27
	4 (FL_1)	5.80	20.17	4 (FL_1)	5.77	26.31
	5 (D_1)	5.64	27.00	5 (D_1)	5.38	31.70
	6 (TN/D_2)	5.66	18.97	6 (TN/D_2)	5.54	15.80
Lime-1 (3 tons ha^{-1})	7 (BG/D_2)	5.63	22.60	7 (BG/D_2)	5.45	22.04
	8 (FL/D_2)	5.51	17.52	8 (FL/D_2)	5.67	16.87
	9 (TN/BG_2)	5.71	18.38	9 (TN/BG_2)	5.67	17.07
	10 (TN/D_1)	5.64	27.61	10 (TN/D_1)	5.56	25.33
	11 (BG/D_1)	5.70	19.54	11 (BG/D_1)	5.60	22.89
	12 (FL/D_1)	5.78	29.24	12 (FL/D_1)	5.74	30.07
	13 (TN/BG_1)	5.64	20.74	13 (TN/BG_1)	5.55	18.57
Mean	-	5.70	21.32	-	5.64	21.88
SED (treatment)	0.04**			0.71***		
SED (lime)	n.s			0.71***		
SED (lime * trt)	0.04***			n.s		
SED (site)	n.s			1.90***		
SED (site*trt)	n.s			1.94**		
SED (site*lime*trt)	n.s			n.s		
CV	2.90			18.05		

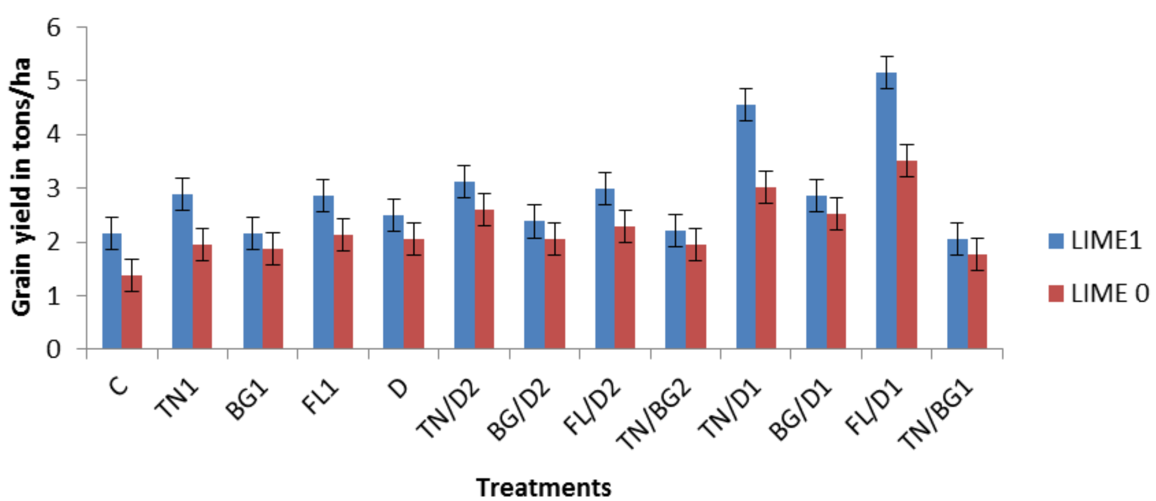

Figure 1. Effect of lime/organic resources on mean maize grain yield in Bukura site during long rains season of 2014. Where LIME 1 = Lime applied at the rate of 3.0 tons ha^{-1} and LIME 0 = No lime applied.

DISCUSSION

Effect of treatments on selected soil properties

Application of lime was significant ($p < 0.0001$) in both sites in raising the pH from 5.18 to 5.47 and 4.66 to 5.20 in Bukura and Butere sites, respectively. This is supported by Kisinyo et al. (2014), who found out that lime application increases soil pH and available P because Ca^{2+} ions contained in lime displaces the H^+

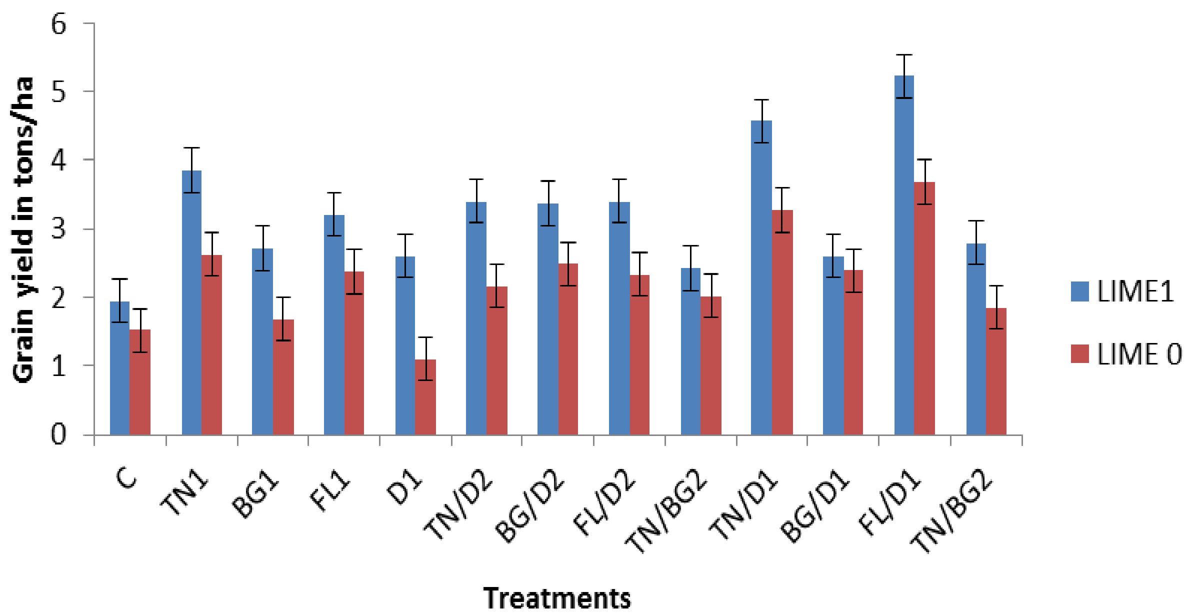

Figure 2. Effect of lime/organic resources on mean maize grain yield in Butere site during the long rains season of 2014.

Mn^{2+}, Fe^{3+} and Al^{3+} ions from the soil sorption sites resulting into increased soil pH.

Effect of treatments on soil pH

Filter mud was very effective in raising the pH mainly because it had a high pH of 8.82 and also high levels of organic matter, that is, 69.4% which probably due to its ability to reduce exchangeable Al resulted in raising the pH as documented by Opala et al. (2009) in his previous research in the same area while working with farm yard manure.

Effect of treatments on soil available P

Results in this study indicate that lime (calcitic) was able to raise the extractable P from 5.27 mg p kg^{-1} (control without lime) to 13.55 mg P kg^{-1} (control with lime). Lime enhanced the availability of more P by the Ca^{2+} contained in lime displacing H^{+}, thus resulting in a reduction in acidity implying less solubility of Al^{3+} that had fixed P. This is supported by Muindi et al. (2015) who found out that application of lime results in increase of soil pH and extractable P and decrease of P adsorption levels leading to replacement of hydrogen ions on the soil surface by Ca^{2+}.

It was found out in this study that, limed treatments of *Tithonia* and filter mud having 39 kg P ha^{-1} significantly raised the available P in both sites. This is due to a likelihood that both *Tithonia* and filter mud being organic materials were able to liberate low molecular organic acids such as malic and citric acids which bind on Al^{3+} in solution thus reducing P sorption as clarified by Opala (2011).

Mean maize grain yield as affected by lime in the two sites

In general, lime increased the maize grain yields in both Bukura and Butere. There is a high possibility that the Ca^{2+} in lime displaced the Al^{3+} H^{+} and Fe^{3+} in soil colloids thus reducing the P sorption and hence increasing its availability with the resultant positive response in maize yield. This is confirmed by Kanyanjua et al. (2002) who stated that use of lime is highly recommended to enhance food production in the Kenyan acid soils.

Influence of treatments on mean maize yield

This study indicates a very high superiority of combining filter mud and DAP in maize production as compared to all the other treatments. Where DAP was used alone (D_1) the yield increase was from 2.16 to only 2.51 tons ha^{-1} and where filter mud was used alone (FL_1) the yield increase was also from 2.16 to only 2.90 tons ha^{-1} for the limed plots. Now when this inorganic fertilizer (DAP) is combined with the organic material (Filter mud) the yield shoots to 5.14 tons ha^{-1}. This implies there is something found in combining DAP and filter mud that is not available when the two are used separately. This could

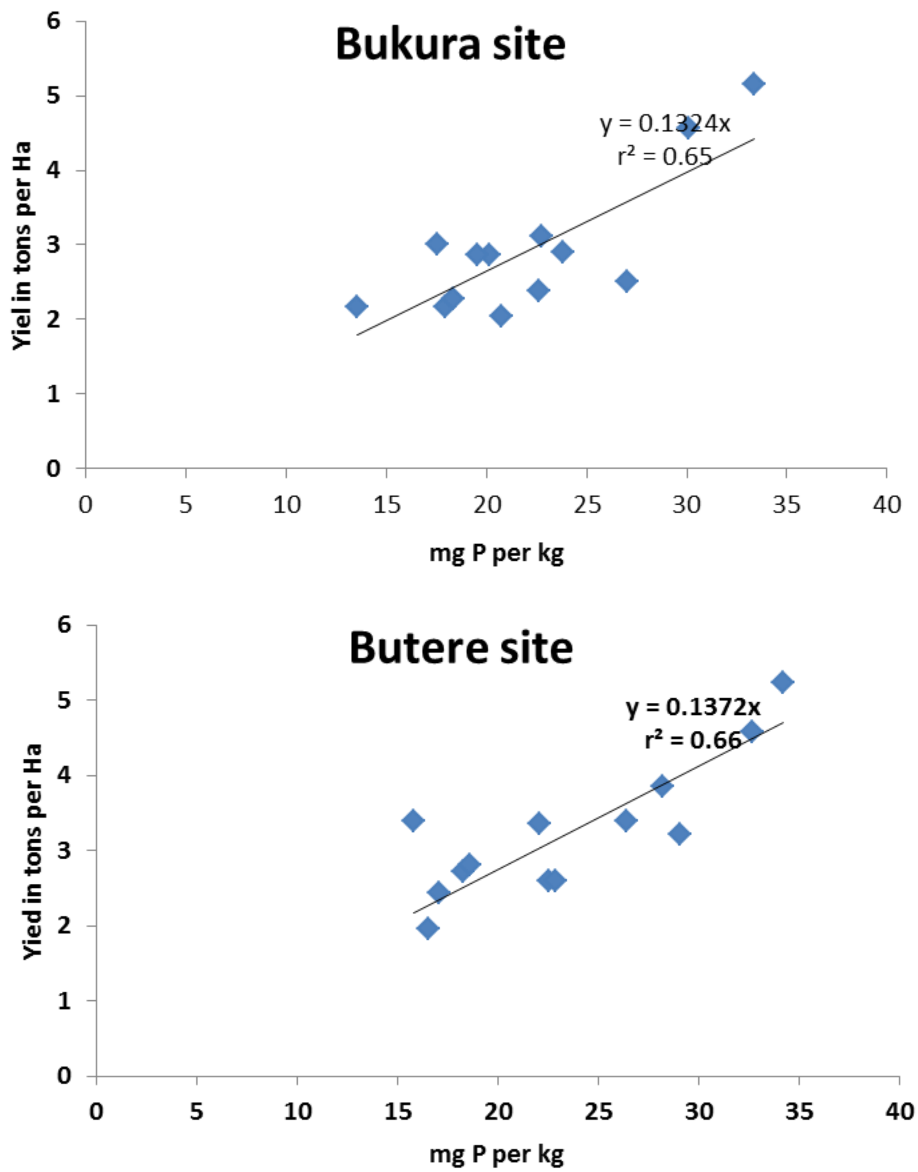

Figure 3. Correlation between available P and yield in Bukura and Butere sites.

be the synchronizing effect in the release of nutrients when the two are judiciously applied together and is in agreement with the view held by Muambole (2013) who affirmed that combination of mineral fertilizers with organic nutrient sources are superior in increasing fertilizer use efficiency as a result of the organic resources enhancing the soil organic matter status and the functions it supports while mineral resources supply key limiting nutrients. This improved synchronization of nutrient release and uptake by the crop. The other reason for the superiority in filter mud and *Tithonia* treatments is attributed to their ability to provide micronutrients not present in DAP and improve both physical and chemical properties of the soil which ultimately reflect positively on nutrient acquisition and plant growth (Haynes and Mokolobate, 2001).

Comparison in maize grain yield for the two sites

The highest treatment in the grain yields in the limed plots for both sites was the combination of filter mud and DAP to supply 39 kg P ha. This treatment yielded 5.15 and 5.23 tons ha^{-1} in Bukura and Butere sites, respectively. The Butere site (Humic Acrisol) had superior yields than Bukura site (Orthic Ferralsol) probably due to the higher cation exchange capacity of Arisol soils as compared to Ferralsol soils in Bukura. This is in agreement with Harlemink et al. (2008) who found out that the fertility of Ferralsols that had been in continuous

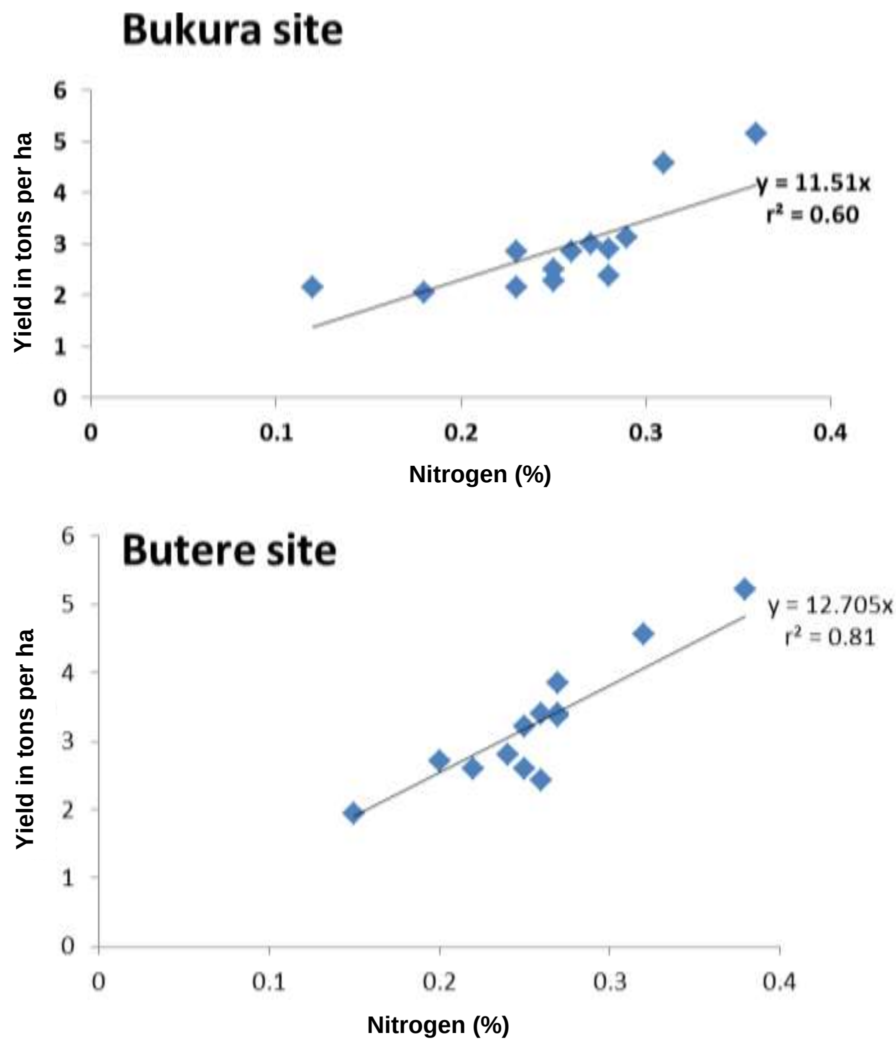

Figure 4. Correlation between % nitrogen and yield in Bukura and Butere sites.

cultivation was extremely low as compared to Acrisols which were less depleted due to their intrinsic fertility.

Correlation between grain yield and available phosphorus

Maize grain yield was significantly correlated with available soil P in both Bukura and Butere sites. This is likely due to maize taking up phosphorus for its rapid fast growth in roots and stems translating into high yields. This is in agreement with Onasanya et al. (2009) who affirmed that phosphorus plays an important role in many physiological processes in a developing and a maturing plant.

Economic analysis

In Bukura site where lime was applied together with either TN/D_1 (*Tithonia*+ DAP; 39 kg P ha^{-1}) or FL/D1 (Filter mud + DAP 39 kg P ha^{-1}) the economically viable returns of BCR of 1.30 and 1.32, respectively imply that KES. 1.0 invested in the production of maize using these treatments would generate a profit of 30 and 32%, respectively.

Conclusions

(1) Application of lime significantly raised the pH and was very effective in reducing P sorption in both sites.
(2) The limed treatments with filter mud and *Tithonia* each in combination with DAP were the best in raising available phosphorus. In Butere site, these treatments: FL/D_1 (Filter mud + DAP; 39 kg P ha^{-1}) and TN/D_1 (*Tithonia* + DAP; 39 kg P ha^{-1}) raised the available P from 16.55 mg kg^{-1} P (control) to 30.07 and 25.33 mg kg^{-1} P, respectively.
(3) These two treatments: FL/D_1 and TN/D_1 yielded the

Table 4. Effect of treatments/lime on net returns and benefit cost ratio in Bukura site during the 2014 long rains.

Lime/Treatment/Code		Grain yield (tons Ha^{-1})	Gross returns (KES)	Total costs (KES)	Net returns (KES)	Benefit cost ratio
L_1 lime (3 tons ha^{-1})	1.C	2.16	86,400	132,995	-46,595	0.60
	2.TN_1	2.90	116,000	140,911	-24,911	0.82
	3.BG_1	2.16	86,400	201,325	-114,925	0.43
	4.FL_1	2.86	114,400	171,326	-56,926	0.67
	5.D_1	2.50	80,400	139,661	-59,261	0.58
	6.TN/D_2	3.12	98,000	137,995	-39,995	0.71
	7.BG/D_2	2.38	95,200	157,994	-62,794	0.60
	8.FL/D_2	3.00	120,000	147,828	-27,828	0.81
	9.TN/BG_2	2.27	90,800	157,994	-67,194	0.57
	10.TN/D_1	4.57	182,800	140,495	+42,305	1.30
	11.BG/D_1	2.86	114,400	170,494	-56,094	0.67
	12.FL/D_1	5.15	206,000	155,494	+50,506	1.32
	13.TN/BG_1	2.05	82,000	171,327	-89,327	0.48
L_0 (0 lime)	1.C	1.38	55,200	122,495	-67,295	0.45
	2.TN_1	2.78	111,200	130,411	-29,211	0.85
	3.BG_1	1.87	74,800	190,825	-116,025	0.39
	4.FL_1	2.13	85,200	160,826	-75,626	0.53
	5.D_1	2.05	82,000	129,161	-47,161	0.63
	6.TN/D_2	2.60	104,000	127,495	-23,495	0.82
	7.BG/D_2	2.05	82,000	147,494	-65,494	0.56
	8.FL/D_2	2.28	91,200	137,328	-46,128	0.67
	9.TN/BG_2	1.94	77,600	147,494	-69,894	0.53
	10.TN/D_1	3.01	120,400	129,995	-9,595	0.93
	11.BG/D_1	2.53	101,200	159,994	-58,794	0.63
	12.FL/D_1	3.52	140,800	144,994	-4,194	0.97
	13.TN/BG_1	1.76	70,400	160,827	-90,427	0.44

Table 5. Effect of treatments/lime on net returns and benefit cost ratio in Butere site during the long rains of 2014

Lime/Treatment/Code		Grain yield (tons ha^{-1})	Gross returns (KES)	Total cost (KES)	Net returns (KES)	Benefit cost ratio
LIME -1 (L_1) (3 tons lime ha^{-1})	1.C	1.95	78,000	132,995	-54,995	0.59
	2.TN_1	3.85	154,000	140,911	+13,089	1.09
	3.BG_1	2.72	108,800	201,325	-92,525	0.54
	4.FL_1	3.21	128,400	171,326	-42,926	0.75
	5.D_1	2.60	104,000	139,661	-35,661	0.74
	6.TN/D_2	3.40	136,000	137,995	-1,995	0.99
	7.BG/D_2	2.37	94,800	157,994	-63,194	0.60
	8.FL/D_2	3.40	136,000	147,828	-11,828	0.92
	9.TN/BG_2	2.43	97,200	157,994	-60,794	0.62
	10.TN/D_1	4.57	182,800	140,495	+42,305	1.30
	11.BG/D_1	2.60	104,000	170,494	-66,494	0.61
	12.FL/D_1	5.23	209,200	155,494	+53,706	1.35
	13.TN/BG_1	2.80	112,000	171,327	-59,327	0.65
LIME -0 (L_0) (0 lime)	1.C	1.52	60,800	122,495	-61,695	0.50
	2.TN_1	2.63	105,200	130,411	-25,211	0.81

Table 5. Contd.

	3.BG_1	1.68	67,200	190,825	-123,625	0.35
	4.FL_1	2.38	95,200	160,826	-65,626	0.59
	5.D_1	1.10	44,000	129,161	-85,161	0.34
	6.TN/D_2	2.17	86,800	127,495	-40,695	0.68
	7.BG/D_2	2.49	99,600	147,494	-47,894	0.68
	8.FL/D_2	2.34	93,600	137,328	-43,728	0.68
	9.TN/BG_2	2.02	80,800	147,494	-66,694	0.55
	10.TN/D_1	3.27	130,800	129,995	+805	1.01
	11.BG/D_1	2.39	95,600	159,994	-64,394	0.60
	12.FL/D_1	3.68	147,200	144,994	+2,206	1.02
	13.TN/BG_1	1.85	74,000	160,827	-86,827	0.46
SED (site)			n.s.			
SED (trt)			0.036			
SED (lime)			n.s			
SED (lime*trt)			n.s			
C.V.			10.57			

highest among the twelve treatments tested in this experiment. They raised the yields from 2.16 tons ha^{-1} (control) to 5.14 tons ha^{-1} and 4.57 tons ha^{-1}, respectively for the Bukura site limed plots. In Butere site limed plots the two treatments FL/D_1 and TN/D_1 out shined the rest by increasing the yields from 1.95 tons ha^{-1} (control) to 5.23 and 4.56 tons ha^{-1}, respectively.

(4) Liming at a rate of 3 tons ha^{-1} with the consequent use of filter mud or *Tithonia* in combination with DAP to each supply 39kg P ha^{-1} (on 1: 1 ratio of organic: in organic fertilizer) can be viable as profits can be realized.

Recommendations

(1) Lime requirement for various areas in Butere should be established so that farmers are able to know the specific quantities of lime to apply in their respective fields.

(2) Farmers should be encouraged to judiciously apply in organic and organic fertilizers in their plots for soil fertility restoration. For this case, those farmers near sugarcane factories can use filter mud as an organic material and those far away can use *Tithonia* as it is readily available on farm hedges and then combine them with inorganic P fertilizers like NPK.

(3) For their maize enterprises to be viable, farmers can use filter mud or *Tithonia* in combination with an in organic P fertilizer (at a ratio of 1:1) to supply 39 kg P ha^{-1} with lime applied at the rate of 3 tons ha^{-1}.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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