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Interactive effect of goat manure, phosphate fertilizer and lime on soil fertility in Embu County, Kenya

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ABSTRACT

Soybean (*Glycine max* (L.) Merrill) is one of the most important legume crops being introduced into the smallholder farming systems of the Central Highlands of Kenya (CHK) to improve income and household nutrition of farmers. However, nutrient mining resulting from crop uptake and erosion; and soil acidity which affects plant nutrients less available through different means such as phosphorus fixation and impairment of biological mediated processes in the soil. The objective of the study was to evaluate the interactive effects of manure, lime and phosphorus fertilizer on soil chemical properties in an acid soil. The study consisted of 5 treatments: manure (0 and 5 ton.ha^{-1}), lime (0 and 2 ton.ha^{-1}) and P fertilizer (0 and 30 kg P_2O_5 ha^{-1}). The experiment was laid out in a randomized complete block design (RCBD) with 4 replicates in plots of 4.0 m x 4.5 m. Integrated application of manure, lime and phosphate fertilizer proved to affect positively soil chemical properties by increasing the most soil pH, exchangeable Ca, Mg and K; and reduced exchangeable acidity. The same combination recorded the highest soil cations exchange capacity (CEC) then considered best option to improve soil fertility.

Keywords: Manure, Lime, P fertilizer, Soil pH, Exchangeable acidity, CEC.

Abbreviations: SSA (Sub Saharan Africa), ISFM (Integrated Soil Fertility Management), SR (Short Rain), LR (Long Rain), ANOVA (Analysis of Variance), SAS (Statistical Analysis Software), a.s.l (above sea level)

1. INTRODUCTION

Crop production all over the world is mainly affected by fertility status of the medium by which the crop is grown. In smallholder farmers the medium is soil. Therefore, soil fertility play a very important role by providing essential nutrients required for crop growth and yields. However, in most Sub Saharan African (SSA) region soil fertility depletion still contributes for low crop yields, food insecurity, hunger and poverty among smallholder farmers (Sanginga and Woomer, 2009). Factors that include over cultivation, removal of nutrient by crop without adequate management measures, soil erosion, soil acidity and lack of knowledge are the major cause of poor (Okalebo *et al*., 2006, Njeru, 2009).

In the Central Highland of Kenya (CHK) is a predominant soils class with inherent good soil fertility such as nitisol. Due to its high yielding capability and high amount of rainfall observed and aggravated by the high population density has increased the pressure over the land in recent years. This drove the soil to a rapid declining in soil fertility mainly due to man maid causes, erosion and leaching of nutrients. In order to feed the increasing population in the region there is a need to adopt measures which will increase soil productivity by square meter which envisage increased crop yield and food availability.

Nutrient sources can be organic and inorganic. Thus, adoption of inorganic nutrient source such as mineral fertilizers will definitely increase crop yield and sustain crop yield but are required in large amounts which also most farmers cannot afford. In the other hand organic nutrient sources can also supply necessary nutrients and increase crop yields. Although, organic materials are needed in big amounts and depends on the soil conditions and microbial activity to mineralize and release nutrients with time. Apart from providing nutrients, organic materials contribute to improved soil physical fertility which includes aeration, water storage and can sustain soil fertility for long time (Gachene and Kimaru, 2003; Otieno *et al*., 2007).

Due to the diverse farmer's incapability to acquire high amounts of either mineral or organic fertilizers has raised need to adopt new approaches among smallholder farmers. This includes the Integrated Soil Fertility Management (ISFM) which relies on combined application of inorganic and organic nutrient sources with good genetic material and site specific (Sanginga and Woomer, 2009; Vanlauwe *et al*., 2010). Thus, the main objective of the study was to evaluate the integrated application of manure, lime and phosphate fertilizer on soil chemical properties in Embu County.

2. MATERIAL AND METHODS

2.1. Description of the study area

The experiment was carried out at Embu Agricultural Training College (Embu-ATC); located inEmbu West district (0°35′ 25.58′′S and 37° 25′ 31.84′′E); in Central Highlands of Kenya at an elevation of 1494 m above sea level. Embu West district is in Upper Midland 2 and 3 (UM 2 -UM 3) agro ecological zones having an altitude of about 1440 m a.s.l with annual temperature of about 20^0 C and annual rainfall of 909 - 1230 mm (Jaetzold et al., 2006). The rainfall is bimodal with two seasons; long rains (LR) in March through to June and Short Rains (SR) from October through to January. Over 65% of the rains occur in the LR season (Jaetzold et al., 2006).The soils are mainly humic Nitisols (Jaetzold et al., 2006), which are deep, well weathered with moderate to high inherent fertility but over time soil fertility has declined due to continuous mining of nutrients without adequate replenishment. Recent studies have reported that they have generally low levels of organic carbon (< 2.0%), nitrogen (<0.2 %), phosphorus (< 10 ppm) and moderately to strongly acidic (pH ranges from 4.8 – 5.4), conditions that result in low crop production (Mugwe, 2007). The district is a predominantly maize growing zone with small land holdings ranging from 0.1 to 2 ha with an average of 1.2 ha per household.

The area is characterized by rapid population growth, low agricultural productivity, increasing demands on agricultural resources and low soil fertility. The farming systems are complex consisting of an integration of crops trees and livestock, and smallholder farms that are intensively managed (Mairura et al., 2007). Land sizes are small ranging from 0.1 to 1.5 ha (mean=1 ha), and slope cultivation is widespread. The main cash crops are coffee (*Coffeaarabica* L) and tea (*Camelinasinensis*(L) O. Kuntze) while the main staple food crop is maize (*Zea mays* L.), which is cultivated from season to season mostly intercropped with beans (*Phaseolus vulgaris L*). Other food crops include potatoes (*Ipomeabatatas* (L.) Lam), bananas (*Musa spp*. L.) and vegetables that are mainly grown for subsistence consumption. Livestock production is a major enterprise especially improved breeds of dairy cattle, sheep, goats and poultry.

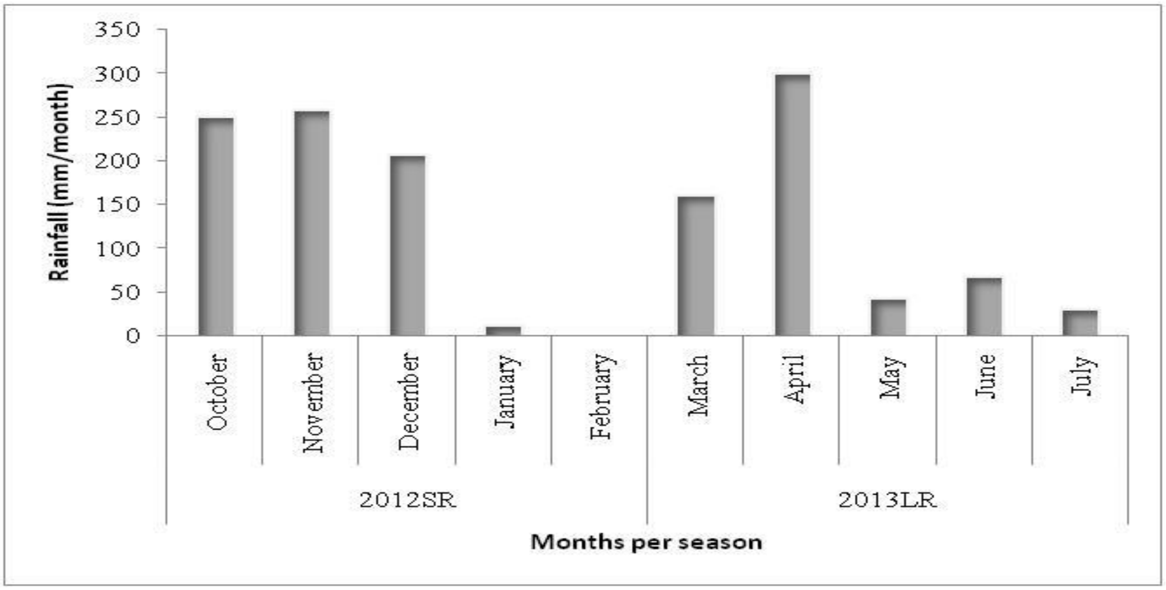

Figure 3 Rainfall amount during 2012SR and 2013LR at Embu, Kenya

2.2. Experimental design and field management

The experiment was conducted for two seasons which included the 2012 short rain season (2012SR) and 2013 long rain season (2013 LR). It was set as a Randomized Complete Block Design (RCBD), in plots measuring 4.0 m x 4.5 m and replicated four times. The experiment had 5 treatments with the following factors; manure (M) (0 and 5 ton ha^{-1} as goat manure); lime (0, 2 ton ha^{-1} as CaO) and P fertilizer (0 and 30 kg P_2O_5 ha^{-1}) as Triple Super Phosphate (TSP). The treatments are presented in Table 1.

Table 1 Treatments and their description

Treatment	Abbreviation	Treatment description
1. ½ Manure+Lime	ML	5 t ha^{-1} M + 2 t ha^{-1} CaO
2. ½ Manure+ ½ P	MP	5 t ha^{-1} M + 30 kg ha^{-1} P_2O_5
3. ½ Manure+Lime+ ½ P	MLP	5 t ha^{-1} M + 2 t ha^{-1} CaO + 30 kg ha^{-1} P_2O_5
4. Lime+ ½ P	LP	2 t ha^{-1} CaO + 30 kg ha^{-1} P_2O_5
5. Control	CL	No inputs

2.3. Soil sampling and analysis

Prior to experiment set up soil samples were collected from 0-15 cm depth for initial determination of soil fertility parameters. Thereafter, and to evaluate changes in soil as a result of applied treatments soils were sampled at harvest. The soil samples were analyzed for pH, exchangeable acidity, available P and exchangeable cations (Ca, Mg, K and Na). Soil pH was measured in a 1:2.5 ratio soil to water (pH_{H2O}) and to KCl (pH_{KCl}) using a pH meter model AD1000 (Okalebo et al., 2002). Soil exchangeable acidity was determined by titration (0.1M NaOH) method using 1M KCl for extraction (Okalebo et al., 2002). Soil mineral N was determined by flow injection method after extraction with 2M KCl. Exchangeable cations and available P were determined by Mehlich 1 method as described by Okalebo et al. (2002). The soils of the experimental site were moderately acidic (pH = 5.07) according to soil classification based on soil pH (Kanyanjua et al., 2002); and moderately low in available P (Table 2).

Table 2 Soil chemical properties of the soil (0-15 cm depth) prior to planting

Parameters	**Soil**
pH water (1:2.5)	5.06
pH KCl (1:2.5)	4.21
Exchangeable acidity (cmol kg^{-1} soil)	3.72
Exchangeable cations (cmol kg^{-1} soil)	
Ca^{2+}	0.63
Mg^{2+}	0.51
K^{+}	0.12
Na^{+}	0.14
Extractable P (mg kg^{-1} soil)	7.54
Total N (%)	0.06

Table 3 Analysis of manure used in the study

Parameters	pH $_{water}$ (1:2.5)	Ca (%)	Mg (%)	K (%)	Na (%)	P (%)	N (%)	C (%)
Value	9.3	0.92	0.44	1.69	0.43	0.46	1.6	21.3

2.4. Data analysis

Data generated was subjected to analysis of variance (ANOVA) using Statistical Analysis Software (SAS) version 8. Least Significance Difference (LSD) at 95% of significance level was used to separate means. The means were subjected to *t*-test at 95% of confidence to test means difference.

3. RESULTS AND DISCUSSION

The results of the study are presented in Table 4. The treatments had significant effect on soil pH ($p < 0.0001$) and exchangeable acidity ($p = 0.0053$). The MLP treatment recorded the highest soil pH value (5.82) and the lowest soil exchangeable acidity (1.25) values. Meanwhile the MP treatment recorded the lowest increase in soil pH and reduction in exchangeable acidity by recording pH = 5.50 and EA = 2.25, respectively. Soil exchangeable cations, except Na, were significantly affected by the application of treatments. The MLP treatment application resulted in highest soil exchangeable Ca^{2+} (0.84 cmol(+).kg^{-1}), Mg^{2+} (0.34 cmol(+).kg^{-1}) and K^{+} (0.22 cmol(+).kg^{-1}) respectively. The lowest values were recorded under MP treatment application whereby 0.49 and 0.28 cmol(+).kg^{-1} for Ca and Mg respectively. K was lower under LP treatment (0.11 cmol(+).kg^{-1}). There were observed significant differences ($p = 0.0206$) in CEC as result of treatment application. This parameter was higher under MLP (1.65 cmol(+).kg^{-1}) and lower for MP treatment. Soil available P was found to be significantly ($p = 0.0046$) affected by the application of treatments. This was found to be higher under application of LP (9.84 mg.kg^{-1} soil). However, there were no significant differences between the treatments, except the control.

Soils with low pH (pH < 5) are usually of high concentration of H^{+} and Al^{3+} ions in the solution which affects negatively on nutrient (N, P, Ca, Mg and K) availability for the crops. Under the same soil condition microorganism's activity to provide nutrients through mineralization is affected negatively. Therefore, application of combined manure, lime and phosphate fertilizer has contributed to improved soil condition and supplied nutrients to the soil in an integrated manner. Lime CaO content reacts with water leading to production of OH^{-} ions which forms $Al(OH)_3$ and H_2O thus raising the soil pH and decreasing exchangeable acidity (Onwonga et al., 2008; Crawford et al., 2008). In addition, it may have displaced Al^{3+} and H^{+} ions from soil sorption sites by Ca^{2+} cations through its dissolution. This situation may have also acted by enhancing organic matter decomposition and mineralization through improved conditions for microorganism's development. On the other hand lime by raising soil pH it reduced P sorption in the soil resulting in increased soil available P. Similar reports have been reported by other researchers (The et al., 2001; Nekesa et al., 2005; Kisinyo et al., 2012).

Manure effects on increased soil pH and nutrition as reported in this study is in agreement with the findings of several other researchers (Awodun et al., 2007; Adeniyan et al., 2011; Kheyrodin & Antoun, 2012). Manure used in this study was of pH 9.3 therefore alkaline and the OH^- ions may have helped to suppress the Al^{3+} and H^+ ions in the soil (Okwuagwu et al., 2003; Onwonga et al., 2008). According to Nyambati et al. (2003) alkaline pH manure could improve the pH of moderately acid infertile soil if applied repeatedly over season. In the other hand applied manure through its decomposition releases exchangeable cations to the soil solution which replace the Al^{3+} and H^+ ions in the soil sorption sites (Crawford et al., 2008) and in turn lowers their concentration, therefore increase soil pH (Kanyanjua et al., 2002; Repsiene & Skuodiene, 2010) and reduces exchangeable acidity (Whalen et al., 2000; Khoi et al., 2010). However, the effectiveness of manure on soil pH depends on its quality (Gitari & Friesen, 2001), which may explain the slow increase of soil pH by manure when compared with lime. Manure also contributed with exchangeable cations through mineralization and release of the nutrients. Manure used in the study was fair in terms of its Ca, Mg, K and P content (Table 3). Meanwhile, phosphate fertilizer effects may have been more on providing of available P to the soil. This associated with reduction of P fixation by lime and manure liming effects may be seen has the main reason for non-significant differences among the treatments, for available P parameter.

These interactive effects are clear in this study as there was found that soil exchangeable Mg ($p = 0.0403$, $R^2 = 0.80$), CEC ($p = 0.0387$, $R^2 = 0.81$) and available P ($p = 0.0279$, $R^2 = 0.842$) were positively and significantly correlated (Figure 2, 3, 4) to soil pH. This meant the importance of soil pH improvement to enhance soil Mg availability, exchangeable cations (CEC) and available phosphorus (P).

Table 5 Soil chemical properties at 0-15cm depth, Embu County, Kenya

Treatments	**pH**	**Exc. Acidity** cmol(+).kg^{-1}	**Ca^{2+}** cmol(+).kg^{-1}	**Mg^{2+}** cmol(+).kg^{-1}	**K^+** cmol(+).kg^{-1}	**Na^+** cmol(+).kg^{-1}	**CEC** cmol(+).kg^{-1}	**Avail. N** mg.kg^{-1}	**Avail. P** mg.kg^{-1}
ML	5.65^{b}	1.75^{b}	0.54^{bc}	0.29^{abc}	0.12^{bc}	0.25^{a}	1.21^{bc}	13.25^{a}	9.63^{a}
MP	5.50^{c}	2.25^{b}	0.49^{c}	0.28^{bc}	0.17^{ab}	0.21^{a}	1.15^{bc}	14.08^{a}	9.54^{a}
MLP	5.82^{a}	1.25^{b}	0.84^{a}	0.34^{a}	0.22^{a}	0.24^{a}	1.65^{a}	14.30^{a}	9.58^{a}
LP	5.70^{b}	1.50^{b}	0.72^{ab}	0.32^{ab}	0.11^{b}	0.23^{a}	1.38^{ab}	14.84^{a}	9.84^{a}
Control	5.10^{d}	5.25^{a}	0.45^{c}	0.26^{c}	0.06^{c}	0.18^{a}	0.95^{c}	12.40^{a}	7.29^{b}
p-value	**<0.0001**	**0.0053**	**0.0141**	**0.0297**	**0.005**	**0.588**	**0.0206**	**0.1674**	**0.0046**
$LSD_{0.05}$	**0.10**	**1.99**	**0.23**	**0.05**	**0.08**	**0.10**	**0.39**	**2.12**	**1.26**

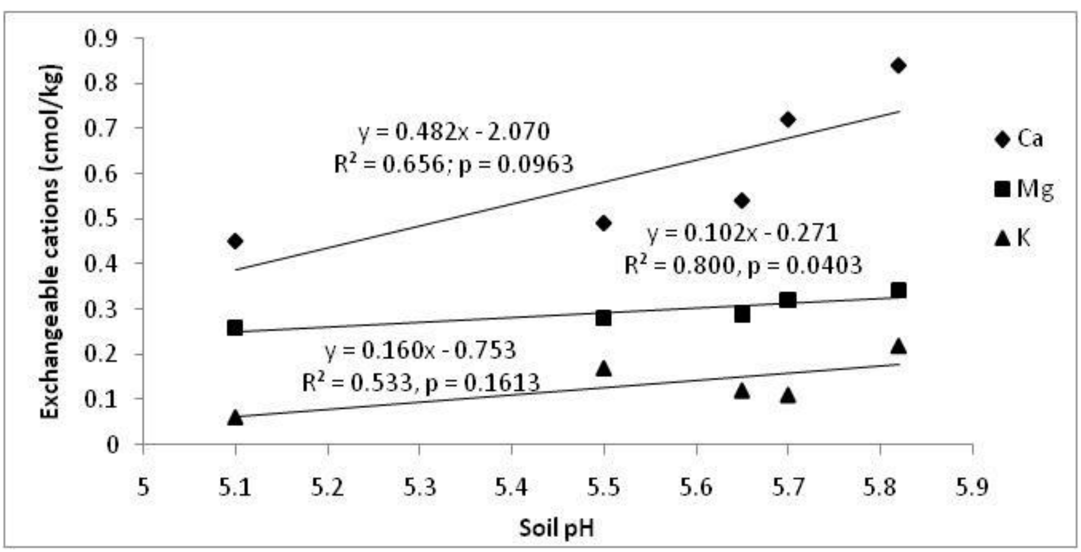

Figure 2 Relationship between soil pH and available cations (Ca, Mg, K)

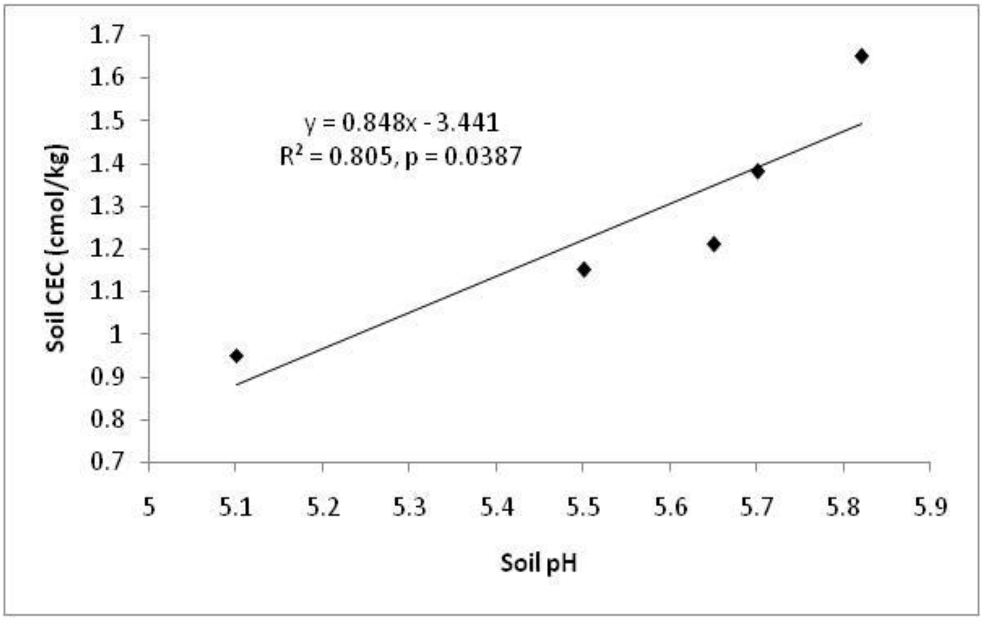

Figure 3 Relationship between soil pH and soil exchangeable cations

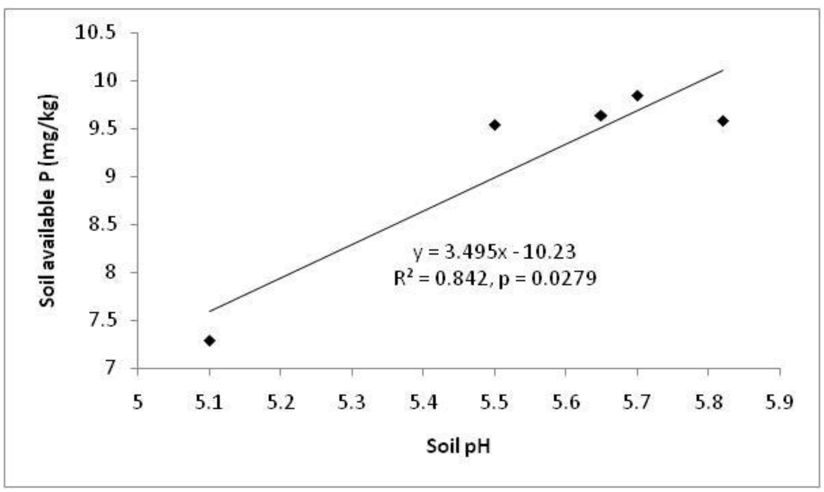

Figure 4 Relationship between soil pH and soil available P

4. CONCLUSION

The integrated application of manure with phosphate fertilizer plus lime revealed to be the best option to improve soil conditions and fertility, which will contribute to increased crop yields and food availability in the region. Application of lime alongside with different soil amendments seemed to be very important for the success of the technology. Lime is very important soil amendment to improve soil chemical status so that nutrients are available role both for crop and microorganisms involved in organic matter decomposition. Thus, farmers should consider application of lime.

SUMMARY OF THE RESEARCH

- The research was looking at the different combinations of manure, lime and P fertilizer on selected soil fertility parameters. The experiment comprised of 5 treatments including the control and was set in a RCBD in Embu County, Central Highlands of Kenya.

- Soil parameters including pH, exchangeable acidity, Available Ca2+, Mg2+, K+, Na+, Cations Exchange Capacity, Available N and P were determined;
- Integrated application of manure, lime and P fertilizer was the best option to improve soil chemical properties.

FUTURE ISSUES

Researchers and farmers should take into consideration the increasing importance of lime in an environmental where soils are increasingly becoming acidic.

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Conflict of Interest:

The authors declare that there are no conflicts of interests.

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Data and materials availability:

All data associated with this study are present in the paper.

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