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Effect of lime and goat manure on soil acidity and maize (*Zea mays*) growth parameters at Kavutiri, Embu County- Central Kenya

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A greenhouse pot experiment was conducted to determine the effect of agricultural lime and goat manureon soil acidity and maize growth parameters using soils from Kavutiri-Embu County. Nitrogen and phosphorus fertilizers at the rates of 50 and 70 kg ha^{-1}, respectively, and goat manure at three rates (0, 5 and 10 mg ha^{-1}) and agricultural lime ($CaCO_3$) at six rates (0, 2.5, 5, 7.5, 10, and 12.5 mg ha^{-1}) were used for the study. The pot experiment was arranged in a complete randomised design and replicated three times. Maize, variety H513as test crop, was grown for a period of 8 weeks. The results were measured on maize crop parameters (plant heights, root lengths and dry matter biomass) and soil parameters (soil pH and exchangeable acidity). All the biophysical data generated were subjected to analysis of variance (ANOVA) and the difference between the treatments means separated using the Fischer's least significant difference at 5% probability level. Linear correlation analyses were done using the Microsoft Excel 2010. Results generally showed that soil acidity decreased with increasing levels of manure and lime. The treatment with 12.5 Mg ha^{-1} of lime and 10 Mg ha^{-1} of manure had the best reducing effect on soil acidity and better maize yield performances reflected in the highest pH (6.3), highest root length (41.3 cm), plant height (150.3 cm) and dry biomass weight (755.4 kg ha^{-1}) obtained.

Key words: Acid soil, agricultural lime, manure, maize productivity andpot experiment.

INTRODUCTION

Soil acidity is a major yield limiting factor for crop production worldwide. Land area affected by acidity is estimated at 4 billion hectares, representing approximately 30% of the total ice-free land area of the world (Sumner and Noble, 2003). In the tropics, substantial weathering of soils over millennia has resulted in the leaching of crop nutrient bases (mainly K, Mg and Ca) followed by their replacement by H, Al, Mn cations which have contributed to acid related stresses on crop production (Okalebo et al., 2009). Acid infertility factors limit crop growth and yield as well as soil productivity in highly weathered soils of humid and sub-humid regions of the world due to deficiency of essential nutrient elements (Akinrinade et al., 2006).

In Kenya, acid soils cover about 13% of total land area and are distributed widely in the croplands of central and western Kenya regions, covering over one million hectares under maize, legume, tea and coffee crops, grown by over 5 million smallholder farmers (Gudu et al., 2007). Crop production is low and declining on such acid

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soils and particularly where acid forming fertilizers, such as di-ammonium phosphate (DAP) and other ammonia fertilizers have been applied continuously to already acidified soils over years (Nekesa, 2007). As these soils suffer in multi-nutrient deficiencies, application of mineral fertilizers has become mandatory to increase crop yields. However, mineral fertilizers are commonly scarce, costly; having imbalanced nutrition and their use could exacerbate the problem of soil acidity (Oguike et al., 2006; Nottidge et al., 2006). The practice of liming acid soils is not common in Sub-Saharan Africa (SSA), probably because of limited knowledge online usage and its effectiveness, availability and high hauling costs of liming materials (Okalebo et al., 2009).

Continuous cropping using incorrect fertilizer types has intensified soil chemical degradation of arable lands resulting in reduced capacity of soils to produce crops sustainably (Nandwa, 2003; Ayuke et al., 2007; Mugendi et al., 2007). According to Kisinyo et al. (2005), continuous cropping has led to development of soil acidity which is a major constraint to maize production on tropical soils due to toxic levels of aluminium (Al) and the concomitant phosphorus (P) deficiency that hinder plant growth.

The Fertilizer Use Recommendation Project (FURP) carried out between 1986 and 1991 by Kenyan Government in the rain-fed areas of the country, established area-specific and crop-specific fertiliser recommendations for various agro-ecological zones (KARI, 1994, Mochoge, 1992). Mochoge (1992) established that 29% of the trial sites which included quite a number from central Kenya and specifically Kavutiri area could not give conclusive fertiliser recommendations due to high soil acidity that affected the performance of most crops. Maize crop for example could not grow more than 100cm high. Kanyanjua et al. (2002), carried a liming study on some of these acid soils (pH 4.6) from central Kenya and came up with fertilizer and lime recommendations for the soils. The rates, however, they recommended were rather high that most resource poor farmers in the region cannot afford to purchase. Due to high cost of fertilizers and other farm inputs, management of acid infertility soils still remains a major challenge to smallholder subsistence farmers in the area and Sub-Saharan Africa at large. Hence theneed of searching for alternative ways and means of addressing soil acidity challenges (Makokha et al., 2001; Kimani et al., 2007). The main objective of this work, therefore, was to determine the combined effect of lime and manure on soil acidity improvement and maize productivity.

MATERIALS AND METHODS

The research was carried out for a period of eight weeks in a greenhouse pot experiment using soils from Kavutiri. Kavutiri is located in agro-climatic zone I at an altitude of 1700m above sea level (Jaetzold et al., 2007) on the eastern slopes of Mount Kenya, representing the acid soils of central Kenya. It is found at latitude 0°25´S and longitude 37°30´E with annual mean temperature of 18°C and total annual rainfall ranging from 1200 to 1400 mm. These soils are classified as Ando-humic Nitisols (Jaetzold et al., 2007) and are sandy-clay in texture. Soil samples from the top 0 to 20 cm were collected from a farmer's field at Kavutiri for laboratory analysis and pot experiment. The sampled soils from different points were thoroughly mixed to get one representative composite sample. The composite sample was used for pot experiment and for physical chemical soil characterisation. However, for physical and chemical analyses, the soil samples were air dried, ground and sieved to pass through a 2 mm sieve.

The soil samples were analysed for soil texture, pH, organic carbon, total N, extractable P, exchangeable Ca, Mg, Na and K, and cation-exchange capacity. Soil texture was determined by the Bouyoucos hydrometer method as outlined by Okalebo et al. (2002), soil pH was measured electrometrically in a 1:2.5 soil-water suspension (McLean, 1982), organic carbon was determined by the modified Walkley-Black method (Nelson and Sommers,1982), total nitrogen by the Micro Kjeldahl method (Bremner and Malvaney, 1982) whereas soil exchangeable bases were extracted using Mehlich-3 (M-3) procedures (Mehlich, 1984; Bolland et al., 2003). The extractable P was determined by Bray 1 Method (Bray and Kurtz, 1945). Cation exchange capacity was determined by the ammonium-acetate saturation method (Thomas, 1982). The initial soil physico-chemical properties are summarised in Table 1.

Chemical analytical characteristics of goat manure and agricultural lime

The manure samples used were sourced from farmers around Kavutiri area. The samples were air dried until a constant weight was obtained. The dried manure samples were then ground and passed through 2 mm sieve. The samples were analysed for P, K, Na, Ca and Mg using the dry ashing method as explained by Kalra and Maynard (1991). The chemical analytical results for these samples are summarized in Table 2.

Analysis of lime nutrient content

The standard method of analyzing $CaCO_3$ equivalent as described by Ryan et al. (2001) was used for lime analysis. Table 3 shows the lime analytical results. The lime was found to be rich in calcium carbonate (35.2%) but slightly poor in Magnesium oxide (17.1%).

Design and set up of greenhouse pot experiments

The pot experiments were conducted at the Departmentof Plant and Microbial sciences greenhouse, Kenyatta University. Soil quantities of 4 kg were weighed from the composite soil samples collected from the field and put into each pot. The experiment had 18 treatments from the combination of three levels of manure (0, 5 and 10 Mg ha^{-1}) and six levels of lime (0, 2.5, 5, 7.5, 10, and 12.5 Mg ha^{-1}) which were thoroughly mixed with the soil (Table 4). The treatments were replicated three times and were arranged in three rows in a Complete Randomised Design (CRD). The spacing between the rows was 0.75 m while between pots in a row was 0.5m. This was to mimic the field spacing such that one hectare could hold 26600 pots with two maize plants. The locations of pots in the greenhouse were rotated regularly to minimize the effect of variations in ambient light and temperatures. Phosphorus (P_2O_5) using triple super phosphate (TSP) fertilizer at the rate of 50 kg $ha^{-1}$and nitrogen (N) using calcium ammonium nitrate (CAN) fertilizer at the rate of 70 kg ha^{-1} were applied. CAN was top-dressed at the 4th week after planting. The test crop was maize (*Zea mays*, variety H513). Three seeds were sownper pot and thinned to two after emergence.

Table 1. Initial soil physico-chemical properties of Kavutiri soils used in the study (0 to 20 cm).

Parameter	Sample 1	Sample 2	Mean
$pH_{(water)}$ (1 :2)	4.12	4.30	4.21
Exchangeable acidity (me %)	2.8	2.6	2.7
Extractable P (Mg kg^{-1})	1.09	1.21	1.15
Exchangeable K (me %)	0.6	0.5	0.55
Exchangeable Na (me %)	0.4	0.4	0.4
Exchangeable Ca (me %)	3.6	3.0	3.3
Exchangeable Mg (me %)	1.2	0.9	1.05
Base saturation (%)	24	23	23.5
CEC (me %)	23.6	23.2	23.4
Total N (%)	0.13	0.14	0.135
Organic C (%)	1.4	1.6	1.5
Sand %	48	49	48.5
Silt %	8	7	7.5
Clay %	44	44	44
Texture class	Sandy Clay	Sandy Clay	Sandy Clay

Table 2. Chemical analysis of goat manure.

Fertility index	$pH_{(water)}$	P (%)	K (%)	Na (%)	Ca (%)	Mg (%)	DM (%)	OC (%)	Total N (%)	C:N (ratio)
	6.82	0.12	0.95	1.28	0.9	0.34	95.4	25.4	1.94	13.1

Table 3. Chemical analysis for agricultural lime used in the study.

Parameter	Total nutrient content (%)
Calcium carbonate ($CaCO_3$)	35.2
Magnesium oxide (MgO)	17.1

Maize plant data collection for analysis

Maize data collection was carried out at 4th and 8th week after planting (WAP). One of the two plants from each pot was randomly selected at the 4th week while the remaining plant at the 8th week after planting for analysis. The plant height was measured from the soil level to the tip of the youngest leaf. At the 8th week, the pots were split open and soil carefully separated from the fibrous roots to retrieve the roots. The average length of the roots from the main stock was then measured in centimetres using a ruler. Lastly, all the shoots and roots materials were chopped into small pieces, placed in sampling brown paper bags No. 10 and oven dried at 50°C for 48 h. Their dry weight were recorded in grams per pot and converted to kg/ha by multiplying by 53200 (total number of maize plants per ha).

RESULTS AND DISCUSSION

Effects of the amendments on soil acidity

Results of soil potential hydrogen (pH) and exchangeable acidity (Hp) are presented in Table 5. Treatment with 10Mgha^{-1} manure and 12.5Mgha^{-1}lime (M_3 $L_{6)}$ recorded the highest pH value of 6.3 which translates to a 49.6% increase from the initial level value of 4.21 (Table 1). There was a gradual pH decrease as lime and manure levels decreased to the lowest value (4.4) in treatment with no manure but with 2.5Mg ha^{-1} lime (M_1L_2). This value was still slightly higher than the control treatment (4.1) value which had declined by 3.1% from the initial value of pH 4.21. The pH from the various treatments decreased in the order of: M_3L_6 > M_1L_6 > M_2 L_6> M_3 L_5> M_2L_4> M_2L_5> M_3 L_4> M_1L_5> M_2L_3> M_3L_3> M_2L_2> M_3L_2> M_1L_4>$M_3L_{1,}$while exchangeable acidity (Hp) decreased with increase in lime and manure levels in the order of: M_1L_1> M_1L_2> M_1L_3> M_1L_4> M_1L_5> M_2L_1> M_1L_6> M_2L_2> M_2L_3> M_2L_4> M_2L_5> M_3 L_1> M_3L_2> M_2L_6> M_3L_3> M_3L_4 = M_3L_5 = M_3L_6 (Table 5). Treatments; M_3L_4, M_3L_5, and M_3L_6, had the lowest Hp value of 0.1 for each. A gradual increase in Hp was noticed as lime and manure decreased to the highest value of 2.8 in the control

Table 4. Treatment combinations and their actual rates as applied per pot in greenhouse experiment.

Treatment No.	Treatment code	Description	Actual amount applied/pot	
			Manure(g)	Lime(g)
1	$M_1 L_1$	Control (No Manure and Lime)	0	0
2	$M_1 L_2$	Manure (0 Mg ha^{-1})+ Lime (2.5 Mg ha^{-1})	0	5.0
3	$M_1 L_3$	Manure (0 Mg ha^{-1})+ Lime (5.0 Mg ha^{-1})	0	10.0
4	$M_1 L_4$	Manure (0 Mg ha^{-1})+ Lime (7.5 Mg ha^{-1})	0	15.0
5	$M_1 L_5$	Manure (0 Mg ha^{-1})+ Lime (10.0 Mg ha^{-1})	0	20.0
6	$M_1 L_6$	Manure (0 Mg ha^{-1})+ Lime (12.5 Mg ha^{-1})	0	25.0
7	$M_2 L_1$	Manure (5 Mg ha^{-1})+ Lime (0 Mg ha^{-1})	188	0
8	$M_2 L_2$	Manure (5 mg ha^{-1})+ Lime (2.5 Mg ha^{-1})	188	5.0
9	$M_2 L_3$	Manure (5 Mg ha^{-1})+ Lime (5.0 Mg ha^{-1})	188	10.0
10	$M_2 L_4$	Manure (5 Mg ha^{-1})+ Lime (7.5 Mg ha^{-1})	188	15.0
11	$M_2 L_5$	Manure (5 Mg ha^{-1})+ Lime (10.0 Mg ha^{-1})	188	20.0
12	$M_2 L_6$	Manure (5 Mg ha^{-1})+ Lime (12.5 Mg ha^{-1})	188	25.0
13	$M_3 L_1$	Manure (10 Mg ha^{-1})+ Lime (0 Mg ha^{-1})	376	0
14	$M_3 L_2$	Manure (10 Mg ha^{-1})+ Lime (2.5 Mg ha^{-1})	376	5.0
15	$M_3 L_3$	Manure (10 Mg ha^{-1})+ Lime (5.0 Mg ha^{-1})	376	10.0
16	$M_3 L_4$	Manure (10 Mg ha^{-1})+ Lime (7.5 Mg ha^{-1})	376	15.0
17	$M_3 L_5$	Manure (10 Mg ha^{-1})+ Lime (10.0 Mg ha^{-1})	376	20.0
18	$M_3 L_6$	Manure (10 Mg ha^{-1})+ Lime (12.5 Mg ha^{-})	376	25.0

Table 5. Mean Soil potential hydrogen (pH) and exchangeable acidity (Hp) at the end of 8 weeks after planting (WAP).

Treatment No.	Treatment Code	pH (H_2O) 8 WAP	% Change from the initial value(4.21)	Hp (me %) 8 WAP	% Change from the initial value (2.7)
1	$M_1 L_1$ [c]	4.1^{f}	- 3.1	2.8^{a}	7.7
2	$M_1 L_2$	4.4^{f}	3.6	1.4^{b}	-46.2
3	$M_1 L_3$	4.7^{f}	11.9	1.3^{c}	-50.0
4	$M_1 L_4$	5.1^{e}	21.6	1.1^{d}	-57.7
5	$M_1 L_5$	5.4^{d}	19.7	1.0^{e}	-61.5
6	$M_1 L_6$	6.0^{b}	15.9	0.8^{f}	-69.2
7	$M_2 L_1$	4.9^{e}	26.6	1.0^{e}	-61.5
8	$M_2 L_2$	5.3$^{d e}$	29.5	0.8^{f}	-69.2
9	$M_2 L_3$	5.4^{d}	36.3	0.7^{g}	-73.1
10	$M_2 L_4$	5.7^{c}	35.9	0.5^{h}	-80.8
11	$M_2 L_5$	5.7^{c}	42.0	0.4^{i}	-84.6
12	$M_2 L_6$	6.0^{b}	19.2	0.2^{k}	-92.3
13	$M_3 L_1$	5.0^{e}	23.8	0.4^{i}	-84.6
14	$M_3 L_2$	5.2$^{d e}$	28.7	0.3^{j}	-88.5
15	$M_3 L_3$	5.4^{d}	34.7	0.2^{k}	-92.3
16	$M_3 L_4$	5.7^{c}	34.7	0.1^{l}	-96.2
17	$M_3 L_5$	5.8$^{b c}$	38.0	0.1^{l}	-96.2
18	$M_3 L_6$	6.3^{a}	49.6	0.1^{l}	-96.2
S.E.D	-	0.118	-	0.042	-
$L.S.D_{5\%}$	-	0.238	-	0.084	-
P-Value	-	< 0.001	-	< 0.001	-

Means with different letter(s) along the same column are statistically different at P= 0.05.

treatment (M_1L_1) as shown in Table 5.

In all the treatments except control, pH progressively

Table 6. Mean plant height and dry matter (DM) weight at 4 and 8 weeks after planting (WAP).

Treatment No.	Treatment code	Plant height (cm)		DM weight			
		4 WAP	8 WAP	4 WAP		8 WAP	
		(cm)	(cm)	(g/plant)	(kg/ha)	(g/plant)	(kg /ha)
1	$M_1 L_1$ ©	34.0^{j}	89.7^{h}	1.2^{i}	63.8	6.7^{k}	356.4
2	$M_1 L_2$	39.0^{i}	115.0^{g}	1.8^{h}	95.8	7.4^{j}	393.7
3	$M_1 L_3$	42.0^{h}	116.3^{f}	2.3^{g}	122.4	7.9^{i}	420.3
4	$M_1 L_4$	44.0^{gh}	119.0^{f}	2.7^{f}	143.6	8.4^{h}	446.9
5	$M_1 L_5$	45.0^{gh}	124.3^{e}	2.9^{f}	154.3	9.0^{g}	478.8
6	$M_1 L_6$	47.3^{fg}	124.0^{e}	2.9^{f}	154.3	9.0^{g}	478.8
7	$M_2 L_1$	47.0^{fg}	126.3^{e}	2.8^{f}	149.0	8.9^{h}	473.5
8	$M_2 L_2$	49.0^{ef}	132.7^{d}	3.4^{e}	180.9	9.4^{g}	500.1
9	$M_2 L_3$	51.3^{de}	135.7^{cd}	3.3^{e}	175.6	9.9^{f}	526.7
10	$M_2 L_4$	53.3^{d}	139.0^{bc}	3.7^{d}	196.8	10.3^{f}	548.0
11	$M_2 L_5$	56.3^{cd}	140.7^{b}	3.9^{d}	207.5	11.3^{e}	601.2
12	$M_2 L_6$	54.7^{cd}	136.7^{c}	4.0^{d}	212.8	11.9^{d}	633.1
13	$M_3 L_1$	55.3^{c}	139.3^{bc}	3.9^{d}	207.5	11.9^{d}	633.1
14	$M_3 L_2$	58.3^{bc}	141.3^{b}	4.3^{c}	228.8	12.4^{c}	659.7
15	$M_3 L_3$	61.3^{a}	143.7^{b}	4.7^{b}	250.0	13.0^{b}	691.6
16	$M_3 L_4$	62.3^{ab}	146.3^{ab}	4.7^{b}	250.0	13.8^{a}	734.2
17	$M_3 L_5$	63.7^{a}	150.3^{a}	5.0^{a}	266.0	14.2^{a}	755.4
18	$M_3 L_6$	61.0^{ab}	148.7^{a}	5.1^{a}	271.3	14.1^{a}	750.1
S.E.D	-	1.746	1.771	0.104	-	0.243	-
$L.S.D_{5\%}$	-	3.542	3.591	0.219	-	0.493	-
P-Value	-	<0.05	<0.05	<0.05	-	<0.05	-

*Means with different letter(s) along the same column are statistically different at P=0.05.

increased while the Hp decreased with increase in manure and lime application.This could be attributed to the reduction of Al^{3+}ions concentration in soil solution and in exchangeable sites as a result of Ca in lime and manure effect on the reduction of Al ions in the soil solution. This increase of pH with manure application agrees with the findings of Egball (2002), Mucheru (2003) and Summer(1997) who reported that addition of organic manures to acid soils lead toan increase in soil pH, decrease of Al ions in soil solution and thereby improve soil conditions for plant growth.

The rise in pH and reduction of soil exchangeable acidity can also be associated with the presence of basic cations (Ca^{2+} and Mg^{2+}) (Fageria et al., 2007) and anions (CO_3^{-2}) in these liming materials that are able to react with H^+ ionsfrom exchange sites to form H_2O + CO_2. Cations occupy the space left behind by H^+ on the exchange sites leading to rise in pH. The change in soil pH with time concurs with the findings by Fageria (2001a) who reported that significant chemical changes could take place within 4–6 weeks after applying liming materials if a soil has sufficient moisture.

The rise of soil pH through addition of manure could have been caused by the consumption of H+ due to humic-type substances which have a large number of carboxyl, phenolic and enolic functional groups as proposed by Wong et al. (1998).These substances are formed during decomposition processes and are relatively stable against further decomposition.Their capacity to consume H^+ therefore, controls their buffer characteristics and their ability to neutralize soil acidity. This finding agrees also with the findings of Mokolobate and Haynes (2002) who reported rise of pH after use of lime and manure as amendments in acid soils.

Effect on plant height

Table 6 presents the results of plant height and dry matter. Analyses of variance indicated that there was significant difference (P <0.05) between treatments. It was observed that treatment with 10Mg ha^{-1}manure and 10Mg ha^{-1}lime (M_3L_5)recorded the highest plant heights both at 4thand 8th WAP of 63.7 and 150 cm, respectively whereas the control treatment recorded 34.0 and 89.7cm as measured in 4th and 8th WAP, respectively, which were significantly (P <0.05) the lowest heights of the experiment. The order in which plant heights decreased according to treatments was: M_3L_5>M_3L_6>M_3L_4>M_3L_3>M_3L_2>M_2L_5>M_3L_1>M_2L_4>M_2L_6>M_2

$L_3>M_2L_2>M_2L_1>M_1L_5>M_1L_6>M_1L_4>M_1 L_3>M_1L_2>M_1L_1$.

Effect on dry matter

The dry matter of the maize as shown in Table 6 indicates that the control treatment (M_1L_1) had the lowest dry matter weight of 1.2 and 6.7g per plant at 4th and 8th WAP, respectively which corresponds to 63.8 and 356.4 kg ha^{-1},respectively. There was generally significant (P<0.05) increase of dry matter with increase levels of manure and lime in the order of: $M_1L_1<M_1L_2<M_1L_3<M_1L_4<M_2L_1<M_1L_5<M_1L_6<M_2L_2<M_2L_3<M_2L_4<M_2L_5<M_2L_6<M_3L_1<M_3L_2<M_3L_3<M_3L_4<M_3L_5 <M_3L_6$.The highest dry matter weight in week 8 was 755.4 kg ha^{-1}obtained by treatment with 10.0Mg ha^{-1} manure and 10.0 Mg ha^{-1} lime while in week 4,the highest weight was 271.3Mg ha^{-1}and was obtained by treatment M3L6 (10.0Mg ha^{-1} manure and 12.5 Mg ha^{-1} lime).

Effect on root length

Mean root lengths as influenced by lime and manure application are presented in Table 7. It was observed that root length significantly (P<0.05) increased with increase in inputs from one level to the other. Treatment M_3L_6 had the longest roots averaging 41.3 cm, a significant difference of 555.5% longer that of control (6.3 cm). The order of root lengthsin terms of treatments from the longest to the shortest was as follows: $M_3L_6 > M_3L_5 > M_3L_3 > M_3L_4 > M_3L_2 > M_3L_1 > M_2L_6 > M_2L_5 > M_2L_4> M_2L_3 > M_2L_2 > M_1L_6 > M_1L_5 > M_1L_4 > M_1L_3 > M_1L_2> M_1L_1$.

Relationship between maize growth parameters and soil acidity indices

The relationship between soil pH and maize growth parameters (dry matter and plant height) are shown in Figure 1a. A highly significant and positive correlation was observed between soil pH and the maize growth parameters. Dry matter showed a high correlation of r^2 =0.622 with pH changes in soil while that of plant height with pH was r^2 =0.7244.

In Figure1b, plant height had a negative linear correlation with soil Hp (r^2 = -0.9517) while that between dry matter and Hp was also high and negative with a coefficient of determination (r^2) of -0.7588.

In Figure 2, the relationship between soil acidity indices and root length is shown. Root length was found to have a positive linear correlation with soil pH (r^2 = 6598) (Figure 2a) and a negative non- linear relationship with Hp (r^2 = -0.969) (Figure 2b).The correlation study showed that soil acidity indices affect maize root differently. This trend agrees with Comin et al. (2006) who observed in their work effects of soil acidity on the adventitious root system in the field that soil acidity negatively affected the root branching and root length of maize crop.

The increase in plant height and dry matter weight with decrease in soil acidity can be attributed to improved efficient use of plant nutrients and their availability as a result of enhanced root system by liming (Fageria et al., 2004). Lime and P interactions are highly associated with soil acidity that limit root growth and proliferation, and nutrient uptake. This could have been the reason for poor performance in the control (M_1L_1) treatment in this study. Aluminium ions absorbed by roots can also precipitate root-absorbed P and hinder its subsequent translocation to plant tops (Mora et al., 2005)

The significant increases in maize growth with application of lime and farmyard manure observed in this study could be attributed to the readily available N and P nutrients supplied in the fertilizers applied and the favourable environment created by the manure and Ca from the lime. Tejada et al. (2006) reported that manure is a good amendment on soil that requires P and N to produce high yields.

The control treatment had the lowest maize biomass yield probably because of low available nitrogen due to low mineralization in this acid soil, and fixation of P thus making it unavailable for plant uptake. Poor performance could also be attributed to Al saturation. Yamoah et al. (1996) attributed 44% reduction in maize yield to acidity in soils.

Liming acid soils result in the release of P for plant uptake; an effect often referred to as ‘‘P spring effect”of lime (Bolan et al., 2003). Bolan et al. (2003) reported that in soils high in exchangeable acidity, liming could increase plant P uptake by decreasing Al, rather than by increasing P availability per se. This also improves root growth which alleviates Al toxicity by allowing a greater volume of soil to be explored. At the same time, liming creates a better environment for the release of P and decrease of soil acidity. Onwuka et al. (2009) reported that with the application of 2, 4, 6 and 8 mega grams per hectare of $CaCO_3$, the soil pH was increased from 5.02 to 8.04 while from western Kenya, it was reported that agricultural lime (Gudu et al., 2007) and Minjingu phosphate rock (Okalebo et al., 2009) significantly raised soil pH and maize yields. Dierolf et al. (1997) had earlier found out that application of lime to maize allowed the roots of maize to move up to 15 to 30 cm of depth in an acid soil. When the plant roots are increased, it will translate to the aerial biomass increase and that could be the reason why the treatment with 10Mg ha^{-1} manure and 12.5Mg ha^{-1} limein this study gave both the highest roots length and biomass yield.

The positive correlation of soil pH with the maize growth parameters implies that as the pH increased, the growth parameters also increased. Le Van et al. (1994) stated that as the exchangeable acidity is reduced, the plant roots performance is enhanced and nutrient uptake is improved, and thus becomes more effective in

Table 7. Mean plant root length at 8 weeks after planting (WAP).

Treatment No.	Treatment code	Root length (cm)	Treatment No.	Treatment code	Root length (cm)
1	$M_1 L_1$ ©	6.3[j]	10	$M_2 L_4$	30.0[d]
2	$M_1 L_2$	9.3[i]	11	$M_2 L_5$	31.7[d]
3	$M_1 L_3$	13.3[h]	12	$M_2 L_6$	34.3[c]
4	$M_1 L_4$	14.7[h]	13	$M_3 L_1$	35.3[c]
5	$M_1 L_5$	17.7[g]	14	$M_3 L_2$	37.0[b c]
6	$M_1 L_6$	19.0[fg]	15	$M_3 L_3$	38.0[b]
7	$M_2 L_1$	20.0[f]	16	$M_3 L_4$	38.0[b]
8	$M_2 L_2$	23.3[e]	17	$M_3 L_5$	39.7[a]
9	$M_2 L_3$	27.0[e]	18	$M_3 L_6$	41.3[a]
S.E.D	-	1.030	S.E.D	-	1.030
$L.S.D_{5\%}$	-	2.090	$L.S.D_{5\%}$	-	2.090
P-value	-	< 0.05	P-value	-	< 0.05

*Means with different letter(s) along the same column are statistically different at P=0.05.

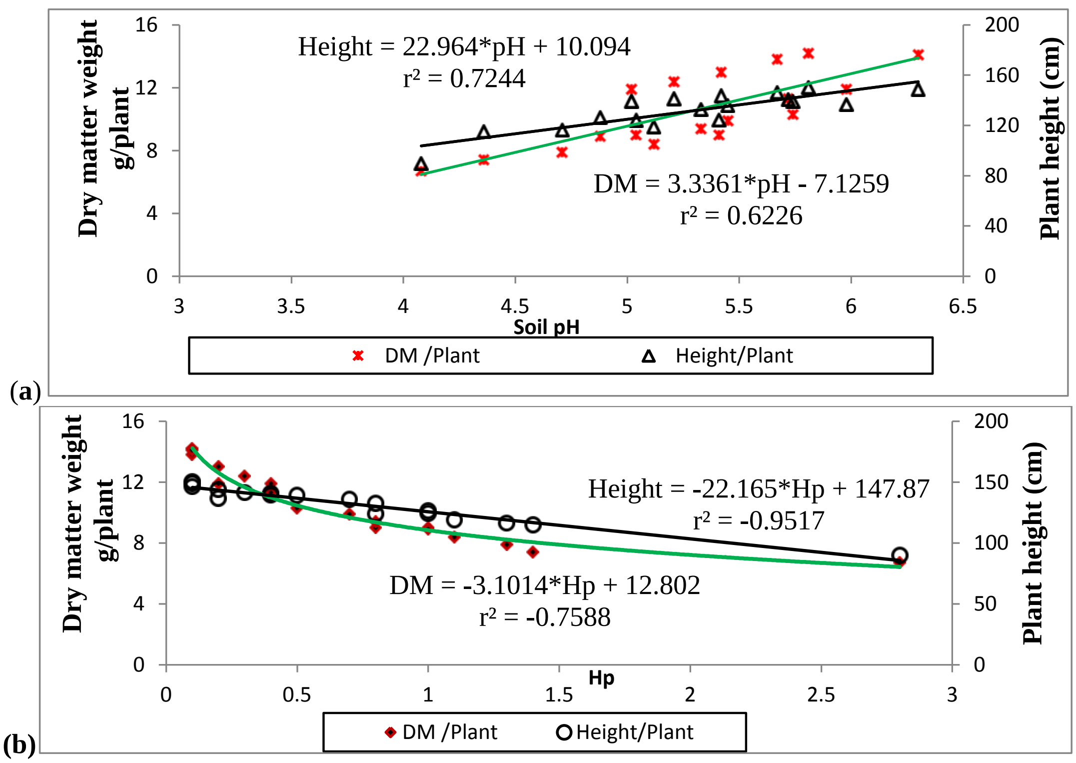
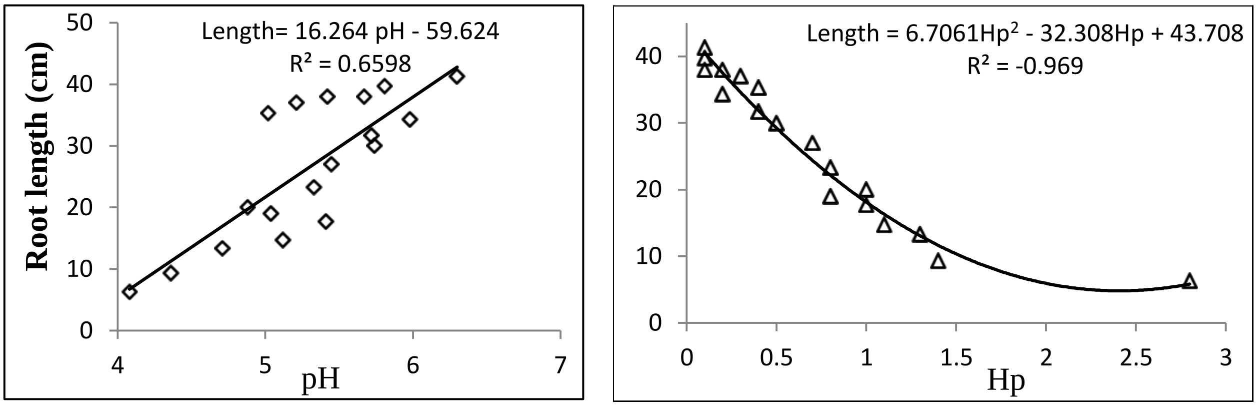


Figure 1. Relationship between maize growth parameters (dry matter weight and plant height) and soil Hp at 8 weeks after planting WAP. (a) pH and (b) Hp.

increasing plant yield parameters.

Conclusion

This greenhouse pot experiment study reveals that application of manure and lime to acid soils has a profound influence on soil pH, exchangeable acidity and consequently on maize biomass yield. In light of these findings, it is evident that combining 10 Mg ha^{-1} of manure and 12.5 Mg ha^{-1} of agricultural lime could be more effective in reducing soil acidity, hence enhancing



(a) **(b)**

Figure 2. Relationship between maize root length and soil acidity indices: (a) pH and (b) Hp at 8 weeks after planting WAP.

maize growth. Thus, the acid soils of Kavutiri- Central Kenya need manure in combination with lime to improve their soil chemical properties and consequently their productivity. This would be a promising alternative in developing more affordable acid soil management strategy.

Conflict of Interest

There is no any conflict of interest with the authors.

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