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Soil Chemical Properties as Affected by Tillage Method, Phosphorus and Lime Application

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Continuous land degradation and soil acidity are some of the major causes of below optimal crop yields in Kenya. Sustainable crop production therefore calls for efficient soil health management strategies. Field experiments were carried out at Waruhiu Farmers Training Centre, Kiambu for two seasons to evaluate the effects of tillage methods, phosphorus and lime application on selected properties of acid soils. Ploughing, strip tillage and hand hoe tillage methods and, DAP + lime (DAPL), TSP + lime (LP), TSP (P) were evaluated. Burnt lime at 3.2 tones ha^{-1} rate was used as lime source while 52kg P ha^{-1} was used as Phosphorus source. Obtained data indicated that the soils were strongly acidic with high exchangeable Al^{3+} and Al saturation, low cation Exchange capacity (CEC) and available P. Combination of Ploughing, lime and phosphorus in form of TSP significantly ($P \leq 0.05$) led to > 38% increase of soil pH, >75% extractable P, 51% exchangeable Ca, >60% CEC, 54% Exchangeable Mg and reduced Al concentrations by >83% compared to the

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control. Similarly, combination of ploughing, DAP and lime significantly ($P \leq 0.05$) increased CEC by 42% and available P by 81% compared to control. DAPL was observed to significantly ($P \leq 0.05$) promote higher levels of exchangeable Al Compared to control and LP in both seasons. Plough DAPL also increased available P by 49% compared to strip DAPL. Strip LP significantly increased Exchangeable Ca by 46% compared to control. Sole tillage methods did not significantly affect soil properties. It can, be concluded that integrating ploughing with either DAPL or LP improves the selected acid soil properties. There is however need for long term studies to understand long term effects of the fertilizer- lime -tillage methods interaction on soil acidity management.

Keywords: Acid soils; phosphorus; lime; tillage; fertilizer.

1. INTRODUCTION

Acid soils occupy approximately 13% of the Kenyan land area [1] and most of them are found in the highland east and west of the Rift Valley [2]. The soil acidity is attributed to either clay mineralogy, leaching of bases due to high rainfall, presence of Al, Fe and Si-oxides and oxyhydroxides, and/ or continuous use of acid forming fertilizers [3,2]. Most of the acid soils in Kenya were developed from non-calcareous parent materials such as syenites, phololites, trachytes, olivines, older basic tuffs and nepholites which are acidic in nature [3]. The predominant clay minerals in the highlands of Kenya are kaolinite, gibbsite, goethite, Al and Fe oxides [2,4,5], which are the products of extensive weathering of the parent materials.

According to [6] soils of the highlands east of the Rift Valley are strongly acidic (pH < 5), have high exchangeable Al^{3+}, and high % Al saturations attributed to extensive weathering and leaching of the bases. The exchangeable Al^{3+} is usually > 2.0 cmol kg^{-1} and Al saturation > 20 %. This high level of exchangeable Al^{3+} is considered by Landon [7] to be too high for many crops, and such Al saturation level cannot be tolerated by many maize germplasms grown in Kenya [8]. The P sorption capacities of the soils have been reported to vary from 434-208 mg kg^{-1} soil [6,9, 10]. This leads to low recovery of applied P, hence low availability of soil P (< 5 mg P kg^{-1}) in most soils for crop and soil biota uptake.

The form in which applied P accumulates in soils after regular fertilization depends on the amounts applied, amounts exported, soil type and soil management practices [11,12]. Practices like liming and tillage have been documented to play a significant role in soil P management. According to Robson and Taylor [13], tillage practices alter nutrients via 3 processes: (i) mixing nutrients through the soil and altering their availability to crops (ii) changing the soil physical environment and (iii) modifying the soil biological activities. For example, long term zero tillage produced significantly higher concentrations of P in the surface soil (0-0.05 m), whereas P levels were decreased at the 0.05-0.15 m depth as compared to chisel ploughing [14]. The accumulation of P in the surface soil under zero-tillage was attributed to the lack of physical disturbance that mixes fertilizer P thoroughly within the plough layer [15] and the P immobility in soils. According to Redel et al. [16] and Zamuner [17], the accumulated P gradually saturates the high P affinity in the acid soils' surface layer, decreasing the binding energy of P hence increasing its availability [18,19].

Wortmann [20] observed that lime mobility in soils is about 1.27cm per year on fine textured soils, hence taking several years to reach considerable depths. This makes it difficult to ameliorate subsurface acidity through surface liming alone and makes a combination of deep tillage and incorporation of lime an important method for ameliorating subsurface soil acidity. Deep tillage has also been observed by Bollard and Brennan [21] to aid in mixing previously applied P fertilizer, hence improving the effectiveness of P fertilizer for subsequent crops.

Soil acidity management practices such as use of organic materials as an alternative to liming, liming and breeding for acid tolerant maize germplasms [22-26] have been widely evaluated in some parts of Kenya. Despite the significant effects of tillage on soil physical, chemical and biological properties, the role of tillage methods in soil acidity management have however received limited attention in Kenya. The study, therefore, aimed at evaluating (i) the effects of tillage methods on selected soil chemical properties and (ii) the interaction effects of tillage methods, lime and phosphorus application in the management of soil acidity in Kenya.

2. MATERIALS AND METHODS

2.1 Experimental Design, Layout and Crop Husbandry

A field experiment was conducted at Waruhiu Agricultural Training Centre (ATC), Githunguri, Kiambu County, to evaluate the effects of tillage, lime and P applications on selected properties of acid soils. Treatments were laid out in a Randomized Complete Block Design with split plot arrangement and replicated three times. Main plots consisted of tillage practices while subplots were fertilizer P and lime treatments. Tillage practices evaluated were: ploughing (15 cm), hand-hand hoe tillage (5-10 cm) and double-digging strip tillage (30 cm deep) using modified hand hoe15 cm wide. Fertilizer and lime treatments were DAP (Diammonium Phosphate) + lime (DAPL), TSP (Triple super phosphate) + lime (LP), TSP alone (P) and lime alone (L). Controls consisted of plots without fertilizer and lime treatments. Plots of 3 m x 4.5 m were planted with certified maize seed, Nduma variety, at the spacing of 75 cm between rows and 30 cm within rows. The distance between blocks was 2 m while 1 m wide spaces separated the subplots. Each subplot consisted of six rows of maize plants with 11 plants in each row. The two outer rows acted as guard rows, while sampling was done in the four inner rows.

Lime at the rate of 3.2 tones ha^{-1} was applied three weeks before planting during land preparation and thoroughly mixed with soils in the lime treatment plots. Other fertilizer treatments were applied during planting, and a blanket amount of calcium ammonium nitrate (CAN) 100 kg N ha^{-1} was applied to all treatments except control and those treated with DAP. Weeding was done using hand hoe but strip tillage plots were weeded by clearing using a panga. Top dressing was carried out when the crop was knee high using CAN at a rate of 100 kg N ha^{-1}. Triple superphosphate (TSP) fertilizer was used as P source. All P applications were done at a rate of 52 kg P ha^{-1}. Data collected included, soil pH, extractable P, CEC, Ca, Mg and exchangeable Al.

2.2 Soil Characterization

Soil physicochemical properties and lime requirement of the soils in the research plots were evaluated before planting and after harvesting. Subsoil samples were taken with a soil auger from the topsoil (0-30 cm) based on procedures described by Carter and Gregorich [27]. The composite samples were then packed in polythene bags, properly labelled and taken to the laboratory for both physio-chemical analyses. Laboratory analyses were carried out as as described by Okalebo [28] and soil characterization data in Table 1 was used for lime requirement determinations.

2.3 Data Analysis

For each variable determined, data were subjected to Analysis of Variance (ANOVA) using the PROC ANOVA procedure of GenStat (Lawes Agricultural Trust Rothamsted Experimental station 2011, version 14.2) [29]. Means were ranked using the Duncan's New Multiple Range Test.

3. RESULTS

3.1 Initial Soil Chemical and Physical Characteristics

Some of the chemical and physical properties of the soil used in the study are presented in Table 1. The soil was strongly acidic, with low pH values (4.5-5.0). The exchangeable aluminium and % aluminium saturation was high (> 2 cmol kg^{-1} soil and > 20% Al, respectively). The standard phosphate requirements (SPR) of the soils were also high (> 150 mg kg^{-1} soil) while available P and CEC were low (< 30 mg kg^{-1} Mehlich P and < 15 cmol kg^{-1} soil, respectively).

3.2 Effects of Tillage, Phosphorus and Lime Application on Soil Ph

Combination of tillage, phosphorus and lime application significantly ($P \leq 0.05$) increased the acid soils pH values (Fig. 1). Combination of plough tillage, lime and P inform of TSP was observed to have the highest ($P \leq 0.05$) soil pH increase in the two seasons compared to other treatments. The mean soil pH increase was > 38% compared to the control.

3.3 Effects of Tillage, Phosphorus and Lime Application on Exchangeable Phosphorus

Extractable P was significantly ($P \leq 0.05$) increased by Tillage-P-lime interactions (Table 2). Plough-DAPL interaction was observed to have the highest extractable P levels during the long rains while the P levels from plough-DAPL and plough-LP interactions were not significantly different during the short rains. Phosphorus levels in Plough DAPL treated soils were 81% higher than control and 49% higher than strip tillage in the long rains. Phosphorus levels in Plough DAPL and Plough LP was 75% higher than control in during the short rains. Tillage methods did not have significant effect on phosphorus levels.

Table 1. Some baseline physical and chemical properties of the soil at the study site

	Long rains	Short rains
pH (1:2.5 soil:water suspensions)	4.7	4.8
Exch. Al (cmol kg^{-1})	2.5	2.6
Total N (%)	0.3	0.3
OC (%)	2.5	2.4
Extractable P (mg kg^{-1})	20.0	11.0
Exchangeable K (cmol kg^{-1})	0.8	0.8
Exchangeable Ca (cmol kg^{-1})	3.5	2.1
Exchangeable mg (cmol kg^{-1})	3.2	3.2
Exchangeable Na (cmol kg^{-1})	0.2	0.2
CEC	11.9	12.4
AL Saturation (%)	35.1	37.7
SPR mg kg^{-1} soil	257.0	260.0
PSD*		
% Clay	9	12
% Silt	31	31
% Sand	60	57
Textural Class	Sandy loam	Sandy loam

Particle size distribution; SPR Standard phosphate requirement defined as the amount of P required to raise equilibrium solution P level to 0.2 mg P L^{-1}; Long rains- March to June rains; Short rains- October to December rains*

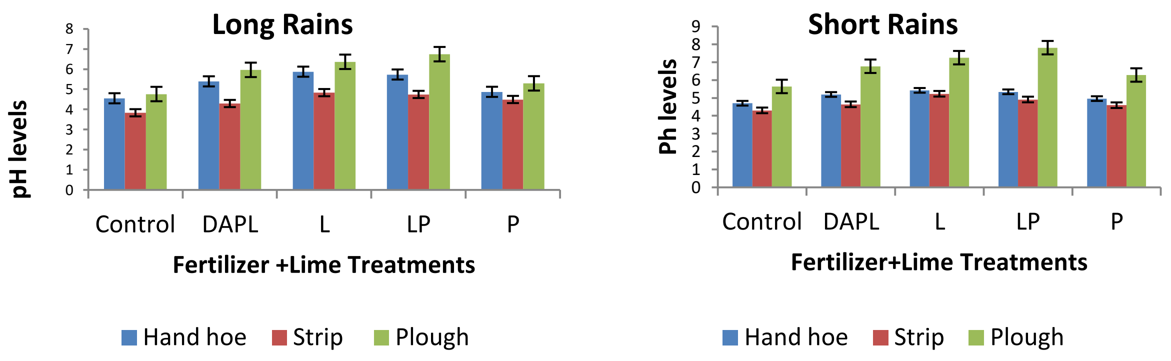

Fig. 1. Effect of tillage-p-lime interaction on ph of acid soils

Table 2. Effect of Tillage-P-lime interaction on extractable P (mg kg^{-1}) in acid soils

	Long rains			Short rains		
Fertilizer / Tillage	**Hand hoe**	**Strip**	**Plough**	**Hand hoe**	**Strip**	**Plough**
Control	12.80a	12.70a	10.40a	15.00a	9.30a	18.80a
DAPL	46.60b	28.40b	55.60b	44.70b	29.20b	72.80b
L	18.30a	9.30a	17.50a	19.10a	11.40a	22.80a
LP	43.40b	38.10c	37.40c	41.70b	36.00b	74.20b
P	27.00ac	28.40b	28.60ac	27.00c	16.60a	30.80c
% CV	3.90	3.90	3.90	2.90	2.90	2.90

DAPL -DAP+lime, L-lime alone, LP-lime+TSP, P-TSP alone. Values followed by the same letter(s) on the same column are not significantly different at P ≤ 0.05

3.4 Effects of Tillage, Phosphorus and Lime Application on Cation Exchange Capacity

Cation exchange capacity (CEC) was significantly increased by Tillage-P-lime interactions (Table 3). Although the plough-LP and plough-DAPL interactions gave the highest CEC values compared to the other treatments during both the long and short rains, CEC values from both plough-DAPL and plough-LP were not significantly ($P \leq 0.05$) different. Plough DAPL increased CEC BY 49% and 35% during long and short rains respectively compared to control while plough LP increased CEC by 52.5% and 68% during long and short rains respectively compared to control. The CEC of control-hand hoe and control-strip tillage were observed to be lower than the initial soil CEC of 11.9 cmols kg^{-1} as presented in Table 3.

3.5 Effects of Tillage, Phosphorus and Lime Application on Exchangeable Calcium

Exchangeable Ca values varied among treatments and seasons (Table 4). During the long rains, strip tillage-LP interaction significantly ($P \leq 0.05$) gave the highest exchangeable Ca levels while plough-LP interaction gave the highest Ca levels during the short rains. Exchangeable Ca in strip LP was 46% higher than control while calcium levels in Plough was 52% higher than control. Sole tillage methods did not however significantly affect Calcium levels during the two seasons.

3.6 Effects of Tillage, Phosphorus and Lime Application on Exchangeable Magnesium

Magnesium levels varied greatly among treatments and seasons (Fig. 2). Plough-LP interaction significantly ($P \leq 0.05$) promoted the highest magnesium levels during both long and short rains. Plough LP increased available Mg by 45% and 62% during long and short rains respectively compared to control. Sole tillage methods did not significantly affect magnesium levels.

3.7 Effects of Tillage, Phosphorus and Lime Application on Exchangeable Aluminium

Exchangeable Al in the soils continuously decreased with Tillage-P-lime interactions (Table 5). Ploughing and application of lime and P in form of TSP significant ($P \leq 0.05$) reduced exchangeable aluminium resulting to the lowest Al levels during both the long and short rains. Plough LP led reduced Exchangeable AL by 85.3% and 83.3% during short and long rains respectively compared to control. DAPL was observed to significantly promote higher levels of exchangeable Al Compared to control and LP in both seasons.

Table 3. Effect of tillage-p-lime interaction on cation exchange capacity (cec) (cmol kg^{-1}) in acid soils

	Long rains			Short rains		
Fertilizer / Tillage	Hand hoe	Strip	Plough	Hand hoe	Strip	Plough
Control	8.04a	9.75a	16.96a	12.11a	12.59a	12.58a
DAPL	16.57b	12.79c	33.31b	13.58a	15.53b	35.42b
L	12.53c	12.50c	25.97c	10.54a	10.36a	17.42a
LP	15.37b	17.80b	35.85b	15.38ab	15.41b	39.02b
P	13.97c	17.13b	29.77d	11.98a	13.18ab	20.99a
% CV	4.60	4.60	4.60	8.90	8.90	8.90

DAPL -DAP+lime, L-lime alone, LP-lime+TSP, P-TSP alone. Values followed by the same letter(s) on the same column are not significantly different at P ≤ 0.05

Table 4. Effect of tillage-P-lime interaction on exchangeable Ca (cmol kg^{-1}) in acid soils

	Long rains			Short rains		
Fertilizer / Tillage	Hand hoe	Strip	Plough	Hand hoe	Strip	Plough
Control	2.86a	2.91a	2.34a	2.00a	2.07a	2.67a
DAPL	4.45b	4.69b	4.19b	3.65b	3.22a	4.64b
L	4.15b	4.47b	3.53b	3.35ab	2.93a	3.55a
LP	5.04c	5.36c	4.86c	4.32c	4.11c	5.47c
P	5.12c	4.86b	3.84b	4.24c	3.49c	4.20b
% CV	1.30	1.30	1.30	2.70	2.70	2.70

DAPL -DAP+lime, L-lime alone, LP-lime+TSP, P-TSP alone. Values followed by the same letter(s) on the same column are not significantly different at P ≤ 0.05

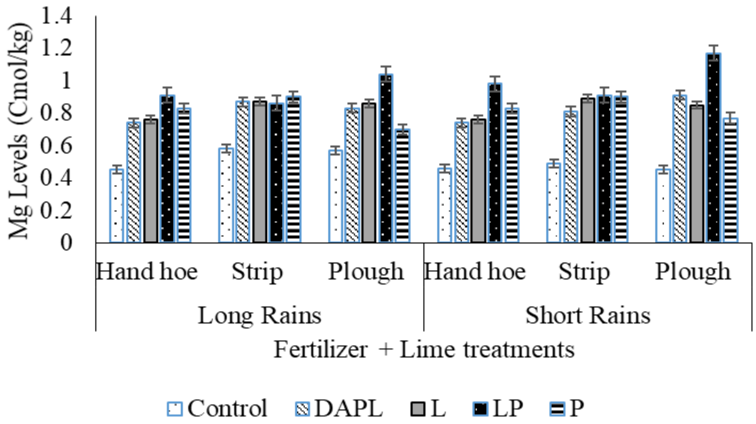

Fig. 2. Effect of tillage-p-lime interaction on exchangeable magnesium (cmol kg^{-1}) in acid soils

Table 5. Effect of tillage-p-lime interaction on exchangeable al (cmol kg^{-1}) in acid soils

	Long rains			Short rains		
Fertilizer / Tillage	**Hand hoe**	**Strip**	**Plough**	**Hand hoe**	**Strip**	**Plough**
Control	2.98a	3.32a	2.08a	3.32a	2.14a	2.04a
DAPL	1.68b	2.44b	1.33b	1.56b	1.71b	1.45b
L	1.46b	1.69bc	1.29b	1.34bc	0.98c	0.86c
LP	0.46c	1.01d	0.39c	0.97c	0.57d	0.30d
P	1.37d	2.02b	1.18a	2.64d	1.96a	1.98a
% CV	3.90	3.90	3.90	3.80	3.80	3.80

DAPL -DAP+lime, L-lime alone, LP-lime+TSP, P-TSP alone. Values followed by the same letter(s) on the same column are not significantly different at P ≤ 0.05

4. DISCUSSION

The high levels of exchangeable Al (> 2.0 cmol Al kg^{-1}) and Al saturation (> 20%) observed in the present studies are classified by Landon et al. [30] as unsuitable for most maize germplasms grown by farmers in Kenya. Based on the rating set by Mehlich et al. [7,31], the available phosphorus in the plough layer of the soils was low and inadequate for supporting optimum crop yields. Additionally, the soil CEC values (< 15 cmol kg^{-1}) and exchangeable Ca^{2+} (< 4.0 cmol kg^{-1}) were limiting [7], implying that the ability of the soil to avail most plant nutrients from the exchange complex for plant uptake was low.

The significant increase of soil pH, CEC and Ca upon ploughing, liming and application of P fertilizers could be attributed to the thorough mixing of soils with lime and P fertilizers through the ploughing process. This might have resulted in the manipulation of the physical, chemical and biological processes in the soils [32] leading to displacement of Al^{3+}, H^+, and Fe^{3+} ions by Ca^{2+} ions from the lime (CaO) and TSP fertilizer. When liming material (CaO) is added to the acid soils, it reacts with carbon dioxide and water to yield Ca bicarbonate which reacts with the exchangeable and residual acidity with consequent replacement of the H^+ and Al^{3+} on the colloidal complex by Ca^{2+} [33,34]. The adsorption of the calcium ions lowers the percentage acid saturation of the colloidal complex and the pH of the soil solution increases hence increased adsorption of bases on the exchange complex [35,36]. Similar results have been reported [37-40].

The lower pH values in soils treated with DAPL as compared to LP could be attributed to the H^+ produced during biological oxidation of ammonium (nitrification) into nitrates for plant uptake. Similar observations and trends were reported [41,42]. Mwangi [42] observed that the topsoil pH of soils supplied with 23:23:0/CAN or DAP / CAN gradually decreased over the years while the pH of soils where TSP/CAN were applied remained constant. Similarly, Manoharan [41], working on pastures in New Zealand, observed that soil acidification was more pronounced in DAP treated plots, and this led to significantly low soil pH, exchangeable Ca, and Ca saturation, and increased soluble Al and exchangeable acidity.

Increased soil extractable P on Plough-DAPL and Plough-LP interactions as compared to other interactions can be attributed to stimulation of soil organic P mineralization by tillage and lime [43]. Ploughing the soils might have disrupted soil aggregates resulting in concomitant organic matter oxidation; increased aeration and porosity hence increased the microbial activities and net mineralization of P from soil organic P [44,45,15]. Comparing effects of P alone and lime alone, the significant increase of soil available P after application of P alone as compared to lime alone could be attributed to the provision of starter P to the soils which have very low soil solution P. Antoniadis [45] reported similar findings in a greenhouse experiment and concluded that P alone was more beneficial than lime alone when soils had low initial P levels while lime alone was beneficial when the soils had moderate initial P levels.

The significant increase of soil pH, extractable P, Ca, CEC, and reduction of exchangeable Al by plough tillage compared to other tillage methods can be attributed to enhanced rate of soil reactions due to improved soil porosity resulting from deep turning and mixing of the soil, lime and P fertilizer [45]. Similar findings have been reported by [46,47].

5. CONCLUSIONS

Interaction between lime, phosphorus and tillage methods significantly increased soil pH, extractable P, exchangeable Ca, CEC, and reduced exchangeable Al. Combining plough tillage with Phosphorus in form of TSP and lime application was observed to significantly increase soil pH, P, CEC, Ca and Mg, and reduced exchangeable Al while combination of plough tillage, phosphorus in form of DAP and lime application was observed to significantly increase extractable P, CEC and AL. Combination of strip tillage, lime and Phosphorus in form of TSP on the other hand, increased exchangeable Ca in the soils. It can be concluded that integrating ploughing with either LP or DAPL can be possible options in the management of soil pH, available P, calcium, magnesium, Aluminium and CEC in acidic soils. Further studies are, however, required to ascertain the long-term effects of the tillage methods on such soils for sustainable soil health and productivity.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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