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Effect of Compost, Lime and P on Selected Properties of Acidic Soils of Assosa

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Abstract
A three-factor-experiment was conducted in the acidic soil of Assosa for two main growing seasons (2014-2015) to identify the effect of integrated application of compost, lime and phosphorus on selected chemical and physical properties of soil using maize as a test crop. The treatments consisted of compost (0 and 5 t ha^{-1}), lime (0, 1.5 and 3 t ha^{-1}) and phosphorus (0, 20 and 40 kg P ha^{-1}). Randomized complete block design with three replications was used. The analysis showed that there was significant ($p<0.01$) difference due to main and interaction effects of treatments on soil pH, OC, CEC and available P, total N, exchangeable acidity and exchangeable Al. Thus, the first season compost applied at 5 t ha^{-1} increased the soil pH to 6.23, while the main effect of lime at 3 t ha^{-1} increased the pH to 5.95. The interactions of the first season compost at 5 t ha^{-1}, lime at 1.5 t ha^{-1} and P at 40 kg P ha^{-1} showed the highest available P (15.04 cmolc kg^{-1}). The interactions of the first season lime (1.5 t ha^{-1}) with P at (40 kg P ha^{-1}) reduced the exchangeable acidity (0.36 cmol$_c$ kg^{-1}) the highest, while the exchangeable Al was highly reduced by the main effect of compost at 5 t ha^{-1} (0.32 cmol$_c$ kg^{-1}) and interaction of first season with lime at 3 t ha^{-1} (0.05 cmol$_c$ kg^{-1}). The study suggested compost was as important as lime in increasing the soil pH and reducing exchangeable Al.
Keywords: soil pH, available P, exchangeable acidity exchangeable Al

1 Introduction

Decline in soil fertility still takes the forefront as a crop production problem, exhibiting itself through loss of soil nutrients, depletion of soil organic matter and phyto-toxicity. The depletion of soil organic matter in the west Ethiopia is mainly caused by burning of forests, bush lands and grass lands with consequential washing up of the left over ash by runoff leading to depletion of remaining nutrients (Vaje, 2007). Since there was washing of the ash, its effect on reversing soil acidity become lower, hence about 40% of the cultivated soils have got acidity problem in the country, ranging from slightly acidic to strongly acidic conditions; the magnitude of the latter being about 15%. In these acidic soils availability of nutrients such as the phosphorus (P), nitrogen (N); zinc (Zn), copper (Cu) and molybdenum (Mo) becomes too low to support good crop production (Abebe, 2007). Nutrient deficiencies are not the only problems in these acidic soils, but toxicity of aluminum (Al) and manganese (Mn) are the other significant problems constraining crop production by interfering with active nutrient uptake by roots (Kochian, 1995).

An inventory of soil acidity status in western and central Ethiopian, carried out in three zones (East, West Wellega and West Showa) showed all samples collected from the three study zones were acidic while the degree of acidity varying among study zones, districts and peasant associations (Abdenna *et al.*, 2007). It was also reported that in some highland parts of Western Ethiopia, the inherent available P has become deficient due to soil acidity resulting in stunted growth and reduced yield of crops (Chimdi *et al.*, 2012). Thus, soil acidity is so a widespread problem in Ethiopia that needs due attention to be addressed by different coping mechanisms (Abebe, 2007).

High yielding maize varieties that are adapted to differing agro ecology of the country have been produced to ensure food security of the country since the famine of 1984 (Abate *et al.*, 2015; Negassa *et al.*, 2007). Such that maize varieties breed to mid altitude area (BH540 and BH541) have the highest productivity of 10 and 11 t ha^{-1} on research fields and 6.5 and 7 t ha^{-1} on farm research, respectively (EARO, 2004); however their productivity on farmers field in West Ethiopia is only about 3 t ha^{-1} (CSA, 2015) due to constraints related to soil acidity among the others.

Application of organic matter (compost, manure) to this soil would have multifaceted benefit; such as in soil aggregate stabilization through binding the soil particle; reduce the impact of erosion preventing further depletion of soil nutrients (Eyasu, 2002). Since OM is prepared from plant residues and animal manure it can replenish plant nutrients to the soil and improve the availability of deficient nutrients, like P, magnesium (Mg), sulfur (S), Mo and Zn (Amlinge *et al*., 2007). On the top of these, it has potential liming effect; the high molecular weight humic substance, which constitute 70-80% of the organic residue can forms complexes with monomeric species of aluminum (Al^{+3}, Al $(OH)^{+2}$ Al $(OH)_2^{+}$) and reduce the interference of aluminum in the active uptake of phosphorus in root surfaces or in the soil solution (Haynes and Mokolobate, 2001). The organic acids in compost or manure also raises the soil pH, and reduce the exchangeable forms of Al through oxidation of organic acid anions, chelation, ammonification, specific ion adsorption and reduction reactions of metal oxides like FeO (OH) and MnO_2 (Haynes and Mokolobate, 2001).

On the other hand application of lime ($CaCO_3$) reduces soil acidity through dissociation in to calcium (Ca^{+2}) cation and hydroxide (OH^-) anion, which do their job in sequence, when the Ca^{+2} displaces the H^+ and Al^{+3} ions from the soil exchange surfaces, the OH^- ion binds with the two acid cations to form water and insoluble form of aluminum hydroxide (Pansu and Gautheyrou, 2006). Liming materials are of different types and calculation of the calcium carbonate equivalent (CCE) and the fineness is required to know the effectiveness of the materials (Pansu and Gautheyrou, 2006). However, if an acid soil is to be reclaimed by full dose of lime application, it may require larger sum of money, which could not be afforded by small holding farmers. But integration of lime with locally available materials like the compost might be helpful in achieving the required yield and economic efficiency.

In regard to this, a study by Serafim *et al.* (2013) showed that combined application of manure, lime and phosphorus (TSP) significantly reduced the exchangeable acidity more than combination of manure with phosphorus or manure with lime. Onwonga *et al.* (2013) also reported, combinations of manure (5 t ha^{-1}), lime (3 t ha^{-1}) and phosphorus (60 kg P ha^{-1}) significantly increased the soil available P than treatment combinations of manure and phosphorus. The reduction in exchangeable acidity and increase in available P can improve the yield of crops; thus, a study reported by Laekemariam and Gidago (2012) showed, integration of compost and inorganic fertilizer highly increased the dry biomass and grain yields of maize; where application of compost at rate of 5 t ha^{-1} with 100 kg DAP ha^{-1} and 50 kg urea ha^{-1} resulted in significantly higher maize yield than sole application of compost 5 t ha^{-1} and the control. Ayalew (2011) also reported a higher yield of maize due to application of 1.8 t lime ha^{-1} with 20 kg P ha^{-1} and 69 kg N ha^{-1} fertilizers. Therefore, this research was conducted with a general objective of investigating the integrated application of compost, lime and inorganic P fertilizer on selected properties of the soils.

2 Materials AND Methods

2.1 Description of the Study Area

The experiment was conducted for two main growing seasons in 2014 and 2015, in the outskirts of Assosa town, about 5 km distant (Assosa Research Center in Amba twelve kebele), which is located in the Assosa Woreda, in Benishagul-Gumuz region, western Ethiopia. The study site is situated at an altitude of 1550 m.a.s.l, with longitude and latitude of 34°34'15.4''E and 10°2'27.6''N, respectively. During the two seasons of the study, the rainfall distribution was bi-modal occurring in months between March to October. However, in the 2015 growing season there was a drop in the annual rainfall to about 667.2 mm compared to 1063.6 mm of 2014 growing season (Figure 1). There was also a rise in mean maximum temperature from 32.2 °C in February 2014 to 33.5 °C in March 2015 due to weather change by 'El Nino'. The soil texture of the study site is heavy clay having a pH of less than 5.5, indicating it was strongly acidic that possessed low soil organic matter with low soil nutrient status (N, P and K) (Table 1).

2.3 Treatments and Experimental Design

The study consisted of a three-factor-factorial combination of treatments, which included compost (C), lime (L) and P fertilizer. The two factors, *i.e.* lime and P fertilizer had three rates of application, while compost had two rates of application. The rates of lime were calculated from the lime requirement using the Shoemaker McLean Pratt (SMP) buffer pH method (Shoemaker *et al.,* 1961) and were confirmed by incubation experiment. Then 0, 50% and 100% of the lime requirement were taken at 0, 1.5 and 3 t ha^{-1}, respectively. The rates of compost were 0 and 5 t ha^{-1} and that of P fertilizer were 0, 20, 40 kg P ha^{-1}; while N fertilizer in form of urea (46% N) was applied uniformly to all treatments at rate of 69 kg N ha^{-1}. Treatments were replicated 3 times in randomized complete block design (RCBD) in factorial arrangement.

2.4 Experimental Procedure

A land with pH of less than 5.5 was selected for the study and land preparation took place well in advance of sowing of maize, as compost and lime need certain incubation period to bring change in physico-chemical properties of the soil. The seed bed was prepared by plowing and harrowing using tractor and then leveled manually and plots were laid out. The treatments of compost and lime were applied according to the randomization set before sowing of maize; and incorporated in to the soil to a soil depth of 15 cm and were left for two months of incubation period for lime and one month of incubation period for compost, *i.e.* compost was applied one month later than lime. After two months, furrows were made on each plot and seeds of maize (var. BH-543) were sown on the side of the ridge (two seed per hill) maintaining inter and intra-row spacing of 75 cm and 30 cm, respectively. At the same time one third of N fertilizer (69 kg N ha^{-1}) and the whole P rates were applied. The remaining two third rate of nitrogen was applied at knee height stage of maize. After post harvest of maize soil samples were taken for physico-chemical analysis.

2.4.1 Soil and Compost Sampling and Analysis

Soil samples were taken before applying any of the treatments from the whole field at 5 points and after crop harvesting from 3 points of each plot diagonally to a depth of 0-30 cm by grid sampling methods and samples were composited. Determination of soil physico-chemical properties like soil texture and soil dry bulk density, accompanied by chemical properties were determined following standard methods: The soil texture was determined using density method proposed by Bouyoucos (2003); the dry bulk density was measured by core sampling method of Black (2003); the soil pH was measured using soil water ratio of 1:2.5 by pH meter (potentiometric analysis) (Jackson, 2003); the percent organic carbon content (% OC) was measured using wet potassium dichromate oxidation method (Walkley and Black, 2003); cation exchange capacity (CEC) was determined using ammonium acetate extraction at pH 7 and titration with ammonium counter ion (Amma, 2003); the exchangeable acidity and exchangeable aluminum were determined by 1 mol L^{-1} potassium chloride (KCl) extraction method (Pansu and Gautheyrou, 2006); exchangeable K by flame photometer; total N by kjeldal digestion (Jackson, 2003); and available P by Olsen extraction method (Barker and Pilbeam, 2007).

Ready mature compost was taken out of rotating bin, homogenized on smooth surface covered with plastic sheet and samples were taken from 6 points in all sides of the pile and composited. The sample was air dried in the laboratory, sieved and analyzed for % OC, available P, available K, exchangeable acidity and exchangeable aluminum following same method described above.

2.5 Statistical Analysis

The experiment was done for two seasons; taking the assumption that the random effects of two seasons could have different variances, the homogeneity test was made using the F-test. Since the test showed homogeneity of variance for all the data, combined analysis was made using mixed and GLM models. And treatment effects were separated using Tukey mean separation test using SAS version 9 (SAS, 2002).

3 Result and Discussions

3.1 Soil and Compost Properties before the Study

Laboratory analysis indicated that soil texture was heavy clay and has a mean dry bulk density of 1.08 g cm^{-3}. The average soil pH was 5.4 indicating it was strongly acidic (Hazelton and Murphy, 2007). The soil was low in % OC (1.57%) (Charman and Roper, 2007) and very low in available P (3.23 mg kg^{-1}) compared to the sufficient range of 10 to 15 mg kg^{-1} (Fassil and Yamoah, 2009); and low in available potassium (1.35 mg kg^{-1}), the optimum potassium saturation for crops being 20,000 to 50,000 mg kg^{-1} (Fageria, 2009); the soil has relatively low percent of acid saturation (5.12%). The compost applied also had pH of 7.8, OC of 35.12%, total nitrogen of 4.75%, available P of 56.9 mg kg^{-1} and available potassium of 67.18 mg kg^{-1} (Table 1)

3.2 Lime Requirement

The amount of lime required to attain the desired soil pH of 6.4 for suitable growth of maize (Fageria, 2009) was determined by the SMP model: The lime requirement (LR) in cmol$_c$ kg^{-1} = 1.69 (20 *A*) – 0.86 = 33.8 *A* – 0.86 in field units at a depth of 20 cm, where A is the acidity, thus LR in t ha^{-1} = 45.5 *A* – 1.16 (Shoemaker *et al.,* 1961). Using the data of the water pH (5.4) and the buffer pH 6.6 in the first buffer reading (pH$_1$) and 5.9 in the second buffer reading (pH$_2$) the extent of acidity (A) was determined as A=0.0917 and: LR t ha^{-1} = 45.5 A – 1.16 = 3 t ha^{-1} or 3000 kg ha^{-1}. The second method used as cross reference to SMP method was the lime calibration methods. From the calibration experiment the data was fitted to simple regression model and there was significant ($p < 0.01$) difference with R^2 value of 0.93 giving the parameter estimates as in the equation: Lime t ha^{-1} = 4.79 pH-28.07. To bring the soil from pH 5.4 to about 6.4 it required lime at 2.58 t ha^{-1}. Therefore a lime requirement in the two methods was found to be comparable and the two methods can determine the lime requirement as precisely as equal.

3.3 Soils Chemical Properties

3.3.1 Soils pH

The analysis of the two seasons showed, the main effects of season, compost, lime, phosphorus ($p<0.01$) and the interaction effects of season with compost and season with phosphorus significantly ($p<0.05$) affected the soil pH (Table 2). Accordingly, the first season compost (2014) applied at 5 t ha^{-1} gave the highest pH of 6.23 with significant difference to all treatments, while the first season (2014) without compost was the second highest (6.02), which in turn was significantly higher than the second season (2015) with compost at 5 t ha^{-1} (5.60) and without compost (5.51). Thus, application of compost at rate of 5 t ha^{-1} improved the soil pH by 0.21 in first season and by 0.11 in second season compared to the respective controls(Table 3)

The interaction of season with phosphorus also increased the soil pH, where the first season (2014) P applied at 40 kg P ha^{-1} showed the highest soil pH (6.24) with significant difference to all treatments with the exception of the first season P applied at 20 kg P ha^{-1} (6.13), however the second season P applications showed no significant difference with the lowest record of soil pH. Thus, the first season P applied at rate of 40 kg P ha^{-1} increased the soil pH by 0.22 units compared to its respective control (Table 3)

The main effect of lime significant affected the soil pH, where the highest increase was observed at lime application rate of 3 t ha^{-1} exceeding the control by 0.25 pH units. But it showed no significant difference to lime application rate of 1.5 t ha^{-1} (Table 4)

3.3.2 Soils Organic Carbon (% OC)

Soil organic carbon was significantly ($p<0.01$) affected by the main effects of season, compost and interactions of season, compost with lime and season, lime with phosphorus (Table 2). The interaction of second season (2015) compost at 5 t ha^{-1} with lime at 3 and 1.5 t ha^{-1} showed the highest organic carbon (2.14 and 2.13%, respectively) with significant difference to the first season (2014) without compost and without lime (Table 5).

Interaction among season, lime and phosphorus affected the organic carbon of the soil where the second season (2015) lime applied at 3 t ha^{-1} with phosphorus at 40 kg P ha^{-1} gave the highest OC (2.28%) showing significant difference to second season without lime and wihtout phosphorus, while it was significanlty higher than most of the first season (2014) application of compost with lime; the treatments without lime and P at rate of 40 kg P ha^{-1} in the first season were the least in OC (Table 6).

3.3.3 The Cation Exchange Capacity (CEC)

The analysis of the two growing seasons showed, the main effects of season, compost, lime and phosphorus and interaction among season, compost with lime, season, compost with phosphorus and season, lime with phosphorus showed significant ($p<0.01$) difference on the CEC of soil (Table 2). The second season compost applied at 5 t ha^{-1} with 3 t ha^{-1} lime showed the highest CEC with significant difference to all first season treatments and to the second season treatments without compost and lime (Table 5);

showing the interaction of compost with lime made an improvement in the CEC of the soil to some extent. The higher CEC in the first season was due to a two digit difference in the original CEC of the soil, which might have contributed in high nutrient (P) uptake by maize in the first season.

The interaction between season, lime with phosphorus also affected the CEC of the soil where the first season (2014) lime at 3 t ha^{-1} with P at 40 kg ha^{-1} showed the highest CEC of the soil (37.16 $cmol_c\,kg^{-1}$) with significant difference to all second season treatments and the first season lime at 0, 1.5 and 3 t ha^{-1} without phosphorus, showing a CEC of 34.18, 34.59 and 34.28 $cmol_c\,kg^{-1}$, respectively (Table 6).

3.3.4 Total Nitrogen

The main effects of season, compost, phosphorus and interactions of season with compost and season with phosphorus significantly ($p<0.01$) affected the total nitrogen of the soil (Table 2). The first season (2014) with compost applied at 5 t ha^{-1} showed the highest residual total nitrogen (0.98%) with significant difference to all treatments. The first season (2014) without compost showed the second highest total nitrogen (0.66%) without significant difference to the second season (2015) compost applied at 5 t ha^{-1} (0.43%), see (Table 3).

The interactions of season with phosphorus also affected the total nitrogen of the soil, where the first season (2014) applied P at 40 kg P ha^{-1} showed the highest total nitrogen (1.04%) with significant difference to all the second season (2015) P treatments and the first season treatment without P(Table 4)

. The first season P applied to result in higher total nitrogen might be due to higher initial nitrogen content of the soil in the first season (Table 1)

3.3.5 Available Phosphorus

The available phosphorus of the soil after crop harvest was significantly ($p<0.01$) affected by main effects of season, compost, lime, phosphorus and interactions of season with compost, season with phosphorus, compost with lime, lime with phosphorus, season with compost with lime, season with lime with phosphorus and season with compost with lime and phosphorus (Table 2). Considering only the interaction effects, the first season (2014) treatments of compost at 5 t ha^{-1} with lime at 1.5 t ha^{-1} and P at 40 kg P ha^{-1} showed the highest soil available P (15.03 mg kg^{-1}) with significant difference to all second season treatments and all first season (2014) compost and lime without P(Table 7)

. Application of compost with intermediate rate of lime and high rate of P increased the residual available P the highest of all.

3.3.6 Exchangeable Acidity

The exchangeable acidity was significantly ($p< 0.01$) affected by the main effects of season, compost, lime and interaction effects of season with lime, season with P, compost with lime, compost with P, lime with P, season, lime with P and compost with lime with P ($p<0.05$) (Table 2). Focusing on the interaction effects of season with lime with P and compost with lime with P; the second season (2015) treatment without lime and with P at rate of 20 kg P ha^{-1} showed the highest exchangeable acidity (2.44 cmol$_c$ kg^{-1}), while the first season (2014) treatment without lime and without P was the second highest (1.59 cmol$_c$ kg^{-1}). The first season lime at 1.5 t ha^{-1} with P at 40 kg P ha^{-1} showed the least exchangeable acidity (Table 6).

The interaction of compost, lime and phosphorus also affected the exchangeable acidity of the soil where the treatment without compost, without lime and without P showed the highest exchangeable acidity (2.41 cmolc kg^{-1}) with significant difference to all treatments. Application of compost (5 t ha^{-1}) with lime (3 t ha^{-1}) with and without P showed lower exchangeable acidity. The treatment with compost at 5 t ha^{-1}, lime at 3 t ha^{-1} without P reduced the exchangeable acidity by 1.90 cmolc kg^{-1} compared to the control (Table 8).

3.3.7 Exchangeable Aluminium

The exchangeable aluminum was significantly affected by the main effects of season, compost, lime ($p<0.01$) and interaction of season with lime ($p<0.05$) (Table 2). Therefore, compost applied at rate of 5 t ha^{-1} showed lower exchangeable aluminum (0.32 cmolc kg^{-1}) compared to the treatment without compost (0.51 cmolc kg^{-1}), decreasing the exchangeable Al of the soil by 0.19 cmolc kg^{-1} (Table 4).

The second season (2015) treatment without lime showed the highest exchangeable Al (0.94 cmol$_c$ kg^{-1}), and the second season treatment with lime at rate of 3 t ha^{-1} was the second highest in exchangeable Al, while the least exchangeable Al was recorded in the first season lime applied at 3 t ha^{-1} (Table 3).

3.4 Soils Physical Property

3.4.1 Dry Bulk Density

The dry bulk density was significantly ($p<0.05$) affected due to compost alone (Table 2). Application of compost at rate of 5 t ha^{-1} increased the dry bulk density to 1.09 g cm^{-3} compared to control (1.07 g cm^{-3}). The soil test before the study was described as heavy clay having lower dry bulk density with intermediate proportion of silt (Table 1), which might contributed to low dry bulk density, but with application of compost, it increased probably due to the aggregation of the silt in to good soil structure. Similar study by (Onwudiwe *et al.*, 2014) showed that increasing rate of municipal solid waste from 0 to 2 t ha^{-1} with increasing rate of NPK from 0 to 200 kg ha^{-1} resulted in increasing tendency of the soil dry bulk density.

4 Discussions

There was higher Soil OC and higher exchangeable acidity in the second season, while higher soil pH and residual total N in the first season. The reason for higher soil organic carbon and exchangeable acidity in the second season, while higher total N in the first season might be due to higher OC, total N during the initial soil test before the study, while the higher exchangeable acidity in second season was due to higher acid saturation as soil with higher acid saturation would end up with higher exchangeable acidity after application of similar rate of lime (Chimdi *et al,* 2012) and the interaction systems capable of sustaining them after harvest of maize. Apart from the initial soil test the soil pH increased by the interactions of compost and P in the first season might be due to high rain fall and low temperature of the first season, which in turn relate to increased liming effect of the compost as there would be less release of organic carbon due to relative weather effects; while there would be increased solubility of applied P in form of triple supper phosphate (TSP), which highly relies on the soil moisture for dissolution to about 80% (Syers *et al.*, 2008), thus the soil organic carbon and the dissolved P acting on the exchangeable Al and Fe forming soluble and insoluble phosphates raising the soil pH. Similar study by Yagi *et al.* (2003) showed a substitution effect of vermicompost to lime where vermicompost at 60 t ha^{-1} showed a substitution effect of 2 t ha^{-1} lime rate, while increasing the soil pH. Grant (2011) on the other hand reported the existence of fertilizer-induced soil pH increase and bioactivity of the soil with increasing rate of P from 0 to 80 kg P ha^{-1}.

The increase in soil organic carbon by interactions of compost (5 t ha^{-1}) with lime (1.5 and 3 t ha^{-1}) might be due to addition of OC by compost and due to their effect on improvement of the soil physical property (enhancing clay organic bond) and proliferation of soil microorganism. In agreement with this result, Malhi (2012) showed significant improvement in the residual soil organic matter by annual application of compost at rate of 20 t ha^{-1} compared to the control. The probable reason for high increase in OC due to interactions of increasing rate of P with increaseing rate of lime might be due to improved soil structure, prolifration of soil microorgnisms and clay organic carbon bond with incresing rate of lime (Paradelo *et al.*, 2015) and due to improvement of soil OC through production of higher biomass and soil biota with higher rate of P (Grant, 2011).

The increase in CEC by the interaction between compost and lime might relate to the contribution in soil surface charges (functional groups) during the composting process compost (Yagi *et al.*, 2003) and due to increase in soil pH by lime leading to deprotonation of pH dependent charge sites of the soil increasing the CEC of the soil (Edmeades, 1982). Similar study by Kisić *et al.* (2004) showed interactions of hydrated lime (4 and 8 t

ha^{-1}) with different sources of orgainci fertilizers increased the CEC of the soil at increasing rate of orgnic fertilizer and hydrated lime. The interaction of increasing rate of lime with P also showed increasing tendency in the soil CEC; as P fertilizer applied to the soil first change to orthophosphate in the soil solution, having negative surface charges when weakly adsorbed to the soil contribute to the surface charge (ionic strength) of the soil increasing the CEC. This property might have enabled the P to protect applied N from leaching loss through providing adsorption surface charge (Grant, 2011; Pansu and Gautheyrou, 2006). Then higher residual total nitrogen due to application of compost (5 t ha^{-1}) with P (40 kg P ha^{-1}) might relate to the supply of N by compost as it can significantly increase the total nitrogen, NH_4^+ nitrogen and NO_3^- nitrogen (Khoi *et al*., 2010) in addition to applied P effects on N.

There was synergistic interaction between lime and compost in reducing the exchangeable acidity, as the calcium from lime replaces the exchangeable forms of Al and Fe, which reacts with hydroxide ion released from water in the soil solution to form gibbsite (Buni, 2015); while compost might have reduced the exchangeable Al and Fe having different mechanism during its decomposition process with formation of insoluble Al and Fe hydroxide or soluble Al organic complex (Haynes and Mokolobate, 2001) without interference to lime. This effect of compost and lime might have reduced the role of P in reducing the exchangeable acidity, letting the P in its available form, but when P was with lime alone it reduced the exchangeable acidity having a share of adsorption of on clay aluminum surfaces (Haynes and Mokolobate, 2001). In support to this study, Serafim *et al.* (2013) showed significant reduction in the exchangeable acidity by the interactions of manure with lime.

5 Conclusions

There was a change in the residual soil chemical and physical properties due to applications of compost, lime and phosphorus in the two seasons after harvest of maize. The soil pH, which was initially 5.4 was raised to pH of 6.02 due to applied compost (5 t ha^{-1}) in the first season (2014), while lime applied at 3 t ha^{-1} raised the pH to 5.95, showing the interaction between season and compost was higher than the main effect of lime. On the same hand, the interactions of the first seasons with P applied at 40 kg P ha^{-1} showed the highest soil pH (6.24) with the indication that there was phosphate precipitation due to soil acidity. The available phosphorus was highly enhanced by the interactions of first season, compost (5 t ha^{-1}) with lime (1.5 t ha^{-1}) and P (40 kg P ha^{-1}) giving the highest available P of 15.04 mg kg^{-1}. The exchangeable acidity was highly reduced by the interactions of compost (5 t ha^{-1}), lime (3 t ha^{-1}) without P, showing a tendency that increasing rate of lime with compost reduced the exchangeable acidity without much regard to the rate of P, but in the absence of compost, P applied at 40 kg ha^{-1} with lime at 1.5 t ha^{-1} highly reduced the exchangeable acidity. The interactions of first seasons with lime at 3 t ha^{-1} and compost at 5 t ha^{-1} highly reduced the exchangeable Al, showing a tendency that increasing rate of lime reduced the exchangeable Al in both seasons. Even though the exchangeable acidity and exchangeable Al were highly reduced by the highest rate of lime (3 t ha^{-1}), but the available P was highest due to intermediate rate of lime (1.5 t ha^{-1}) with compost and P; which might also suggest that the mechanism of compost in reducing soil acidity and P availability might be better than that of lime. Therefore interactions of compost (5 t ha^{-1}), lime (1.5 t ha^{-1}) and P (40 kg P ha^{-1}) could provide better nutrients with enhanced soil reactions.

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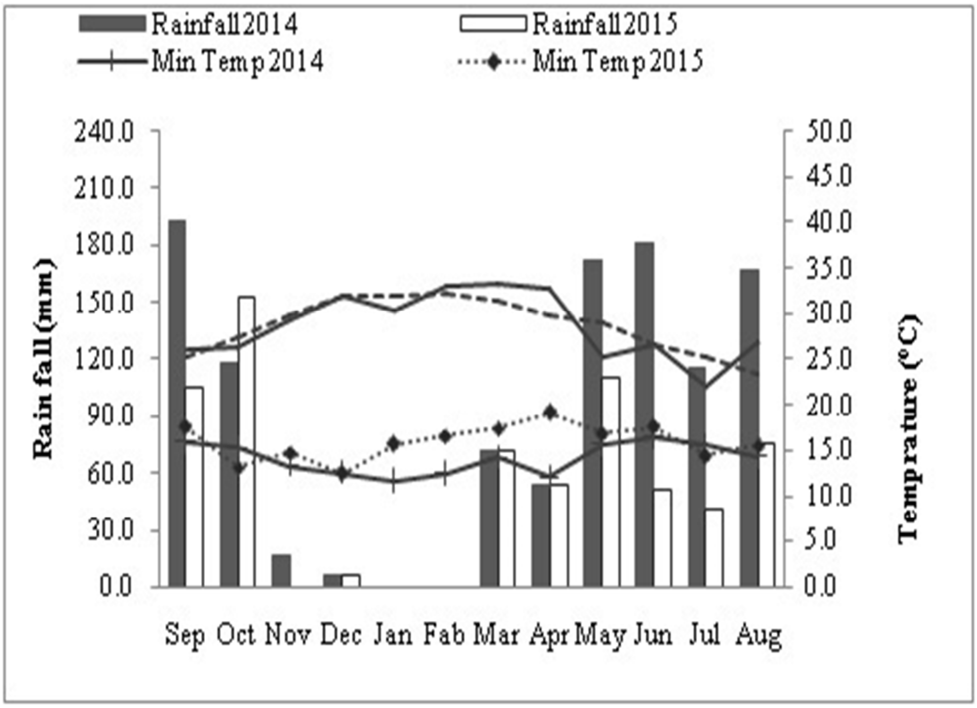

Figure 1: Mean Monthly Rain fall (mm), Max and Min Temperature (^oC) of 2014-15

Table 1: Selected physico-chemical properties of the soil and compost before planting of maize

Chemical properties	Compost	Soil 2014	Soil 2015
pH	7.8	5.40	5.40
OC (%)	35.12	1.57	1.94
Total N (%)	4.75	0.17	0.20
Available P (mg kg^{-1})	56.99	3.23	2.20
Available K (mg kg^{-1})	67.18	1.35	1.35
CEC (cmol$_c$ kg^{-1})	50.82	33.92	24.20
Exchangeable Acidity (cmol$_c$ kg^{-1})	0.83	1.30	1.24
Exchangeable Al (cmol$_c$ kg^{-1})	0	0.71	0.64
Percent Acid saturation (%)	1.63	3.83	5.12
Sand (%)	-	14.00	24.00
Silt (%)	-	23.00	10.00
Clay (%)	-	63.00	66.00
Texture	-	Heavy clay	Heavy clay
Dry bulk density (g cm^{-3})		1.1	1.1

Table 2: ANOVA table of the chemical and physical properties of soil as affected by season, compost, lime and P

Source of variation	DF	Soil pH	% OC	CEC (cmol$^+$ kg^{-1})	Total N (%)	Available P (mg kg^{-1})	Exch. Acidity (cmol$^+$ kg^{-1})	Exch. Al (cmol$^+$ kg^{-1})	Dry bulk density (g cm^{-3})
Season (S)	1	8.89***	0.89***	3695.79***	4.45***	978.85***	0.59**	7.30***	0.0002^{ns}
Compost (C)	1	0.62***	0.31***	10.99***	0.78***	22.41***	2.53***	0.97***	0.014*
Lime (L)	2	0.54***	0.01^{ns}	7.35***	0.04^{ns}	44.21***	6.07***	1.25***	0.0004^{ns}
Phosphorus (P)	2	0.09**	0.02^{ns}	12.50***	0.67***	133.428***	0.29^{ns}	0.10^{ns}	0.005^{ns}
S x C	2	0.09*	0.01^{ns}	2.51^{ns}	0.62**	11.68*	0.04^{ns}	0.09^{ns}	0.008^{ns}
S x L	2	0.05^{ns}	0.03^{ns}	1.15^{ns}	0.04^{ns}	0.96^{ns}	1.72***	0.24*	0.002^{ns}
S x P	2	0.14**	0.09^{ns}	1.43^{ns}	0.56***	15.49**	0.68***	0.11^{ns}	0.0002^{ns}
C x L	2	0.01^{ns}	0.06^{ns}	2.83^{ns}	0.12^{ns}	2.14^{ns}	0.60**	0.16^{ns}	0.002^{ns}
C x P	2	0.02^{ns}	0.06^{ns}	11.64***	0.15^{ns}	1.06^{ns}	0.57**	0.15^{ns}	0.001^{ns}
L x P	4	0.02^{ns}	0.06^{ns}	5.92***	0.03^{ns}	16.59***	0.56***	0.02^{ns}	0.0001^{ns}
S x C x L	2	0.01^{ns}	0.22***	5.71**	0.13^{ns}	29.99***	0.04^{ns}	0.08^{ns}	0.006^{ns}
S x C x P	2	0.03^{ns}	0.07^{ns}	8.12***	0.17^{ns}	2.04^{ns}	0.05^{ns}	0.04^{ns}	0.002^{ns}
S x L x P	4	0.01^{ns}	0.24***	12.07***	0.03^{ns}	15.42***	0.80***	0.16^{ns}	0.0002^{ns}
C x L x P	4	0.04^{ns}	0.01^{ns}	0.17^{ns}	0.11^{ns}	1.23^{ns}	0.27*	0.16^{ns}	0.0002^{ns}
S x C x L x P	4	0.04^{ns}	0.03^{ns}	2.05^{ns}	0.11^{ns}	8.34**	0.16^{ns}	0.07^{ns}	0.003^{ns}
Error	68	0.02	0.03	1.18	0.07	2.51	0.09	0.08	0.003

Where, DF: degree of freedom; OC: organic carbon; CEC: cation exchange capacity; Exch.: exchangeable; ns: non-significant difference; *, **, and *** significant difference at probability level of 5, 1, and 0.1%, respectively.

Table 3: Interactions of season with compost, season with lime and season with P on the soil pH, total N and exchangeable Al

Treatments							
Interaction	Season	Compost (t ha^{-1})	Lime (t ha^{-1})	P applied (mg kg^{-1})	**Soil pH**	**Total N (%)**	**Exch. Al (cmol$_c$ kg^{-1})**
S*C	2014	0			6.02^b	0.66^b	
	2014	5			6.23^a	0.98^a	
	2015	0			5.51^c	0.41^c	
	2015	5			5.60^c	0.43^{bc}	
S*P	2014			0	6.02^b	0.53^b	
	2014			20	6.12^{ab}	0.89^a	
	2014			40	6.24^a	1.04^a	
	2015			0	5.54^c	0.40^b	
	2015			20	5.55^c	0.42^b	
	2015			40	5.56^c	0.43^b	
S*L	2014		0				0.32^{cd}
	2014		1.5				0.11^d
	2014		3				0.05^d
	2015		0				0.94^a
	2015		1.5				0.66^{ab}
	2015		3				0.44^{bc}
CV (%)					2.52	41.91	65.88

Table 4: The main effects of compost and lime on soil pH and exchangeable Al

Treatments	**Soil pH**	**Exchangeable Al (cmol$_c$ kg^{-1})**
Compost (t ha^{-1})		
0	5.76^b	0.51^a
5	5.92^a	0.32^b
Lime (t ha^{-1})		
0	5.71^c	0.63^a
1.5	5.86^b	0.28^b
3	5.95^a	0.35^b
CV%	2.52	65.88

Means in columns followed by different letters are significantly different at 0.05 levels, according to Tukey's mean separation test.

Table 5: Interactions of season, compost with lime on OC and CEC of the soil

Treatments		**Organic carbon (%)**			**CEC (cmol$_c$ kg^{-1})**		
Season	Compost t ha^{-1}	Lime applied (t ha-1)					
		0	1.5	3	0	1.5	3
2014	0	1.68^c	1.92^{abc}	1.91^{abc}	34.80^b	35.29^{ab}	35.36^{ab}
2014	5	2.05^{ab}	1.85^{bc}	1.98^{ab}	35.06^{ab}	36.41^{ab}	36.80^a
2015	0	2.11^{ab}	2.01^{ab}	1.98^{ab}	23.00^c	24.40^c	23.87^c
2015	5	2.09^{ab}	2.13^a	2.14^a	24.26^c	23.33^c	24.66^c

Means in columns followed by different letters are significantly different at 0.05 levels, according to Tukey's mean separation test.

Table 6: Interactions of season, compost with P and season, lime with P on OC, CEC and exchangeable acidity

Treatments				OC %			CEC			Exch. acidity (cmolc kg^{-1})		
Interaction	Season	Compost (t ha^{-1})	Lime (t ha^{-1})	Applied P (kg P ha^{-1})								
				0	20	40	0	20	40	0	20	40
S*C*P	2014	0	-				33.97^{b}	36.22^{a}	35.27^{ab}			
	2014	5	-				35.52^{ab}	36.20^{a}	36.56^{a}			
	2015	0	-				24.00^{cd}	24.60^{cd}	22.67^{d}			
	2015	5	-				23.00^{d}	24.07^{cd}	25.20^{c}			
S*L*P	2014	-	0	2.04^{abcd}	1.87^{bcd}	1.69^{d}	34.18^{c}	35.26^{abc}	35.36^{abc}	1.59^{b}	1.14^{bcde}	1.09^{bcde}
	2014	-	1.5	1.88^{bcd}	1.84^{cd}	1.92^{abcd}	34.59^{bc}	36.57^{abc}	36.40^{abc}	0.66^{def}	0.48^{ef}	0.36^{f}
	2014	-	3	1.86^{bcd}	2.07^{abc}	1.91^{bcd}	34.28^{bc}	36.80^{ab}	37.16^{a}	0.67^{def}	1.06^{bcde}	0.97^{bcdef}
	2015	-	0	1.88^{bcd}	2.07^{abc}	2.22^{ab}	22.5^{e}	24.10^{de}	24.30^{de}	1.24^{bcd}	2.44^{a}	1.44^{bc}
	2015	-	1.5	2.12^{abc}	2.22^{ab}	1.95^{abcd}	23.50^{de}	25.60^{d}	22.50^{d}	1.04^{bcdef}	0.92^{bcdef}	1.16^{bcde}
	2015	-	3	1.98^{abcd}	1.99^{abcd}	2.28^{a}	24.5^{de}	23.30^{de}	25.00^{de}	0.56^{def}	0.72^{def}	0.87^{cdef}
CV (%)				8.59			21.22			30.62		

Means in columns followed by different letters are significantly different at 0.05 levels, according to Tukey's mean separation test.

Table 7: Interactions of season, compost, lime with P on the available P of the soil

Treatments			Available P (mg kg^{-1})		
Season	Compost t ha^{-1}	Lime t ha^{-1}	Applied P (kg P ha^{-1})		
			0	20	40
2014	0	0	$6.68^{defghij}$	8.63^{cdefgh}	9.92^{abcde}
		1.5	9.02^{cdefg}	9.81^{bcdef}	12.15^{abc}
		3	8.63^{cdefgh}	11.09^{abc}	12.15^{abc}
	5	0	$8.35^{cdefghi}$	11.98^{abc}	12.19^{abc}
		1.5	9.18^{cdefg}	14.65^{ab}	15.04^{a}
		3	9.36^{cdefg}	10.35^{abcde}	10.30^{abcde}
2015	0	0	1.5^{k}	3.16^{jk}	3.50^{ijk}
		1.5	3.70^{hijk}	4.30^{ghijk}	11.90^{abc}
		3	1.70^{jk}	3.16^{jk}	$5.30^{efghijk}$
	5	0	2.90^{jk}	4.70^{fghijk}	2.90^{jk}
		1.5	4.30^{ghijk}	2.30^{jk}	8.90^{cdefg}
		3	2.10^{jk}	4.70^{fghijk}	9.30^{cdefg}

Means in columns followed by different letters are significantly different at 0.05 levels, according to Tukey's mean separation test

Table 8: Interactions of compost, lime with P on the exchangeable acidity of the soil

Treatments		Exchangeable acidity (cmol$_c$ kg^{-1})		
Compost (t ha^{-1})	Lime (t ha^{-1})	Applied P (kg P ha^{-1})		
		0	20	40
0	0	2.41^{a}	1.65^{b}	1.32^{bc}
	1.5	0.88^{cd}	0.81^{cd}	1.09^{bcd}
	3	0.72^{cd}	1.04^{bcd}	0.68^{cd}
5	0	1.19^{bcd}	1.16^{bcd}	1.22^{bcd}
	1.5	0.83^{cd}	0.59^{d}	0.94^{cd}
	3	0.51^{d}	0.75^{cd}	0.65^{cd}

Means in columns followed by different letters are significantly different at 0.05 levels, according to Tukey's mean separation test