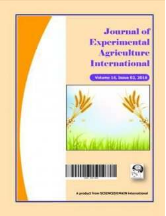

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Application of Compost, Lime and P Fertilizer on Selected Soil Properties and P Use Efficiency of Maize in Acidic Soil of Assosa, Western Ethiopia

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Authors' contributions

This work was carried out in collaboration between all authors. Author BT designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors TT, ND and TNS contributed in the design, analyses and write up of the study. All authors read and approved the final manuscript.

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ABSTRACT

Soil fertility loss due to soil acidity is a major constraint for crop production in western Ethiopia. A study was conducted in the acidic soil of Assosa for two main growing seasons (2014 and 2015) to assess the effect of integrated application of compost, lime and phosphorus on selected properties of soil and P use efficiency of maize. The treatments were factorial combinations 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}) in randomized complete block design with three replications. The combined analysis of the two season data showed, significant (P<0.01) interaction effects of season with compost and season with P on soil pH; compost with P; and lime with P on apparent P recovery and utilization efficiency; season, lime and P on exchangeable acidity; and interactions of season, compost, lime and phosphorus on the available P. The highest soil pH (6.23) was observed due to compost (5 t ha^{-1}) in the first season (2014) and the highest reduction in exchangeable Al (0.05 cmol$_c$ kg^{-1}) was due to lime (3 t ha^{-1}) in

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the first season (2014). The highest P apparent recovery (6.29%) and utilization efficiencies (169.12 kg kg^{-1}) were observed due to combination of compost (5 t ha^{-1}) with P (20 kg P ha^{-1}). The exchangeable acidity was highly reduced due to combination of lime at 1.5 t ha^{-1} with P at 40 kg P ha^{-1} in the first season; while the highest available P (15.04 and 14.65 cmolc kg^{-1}) was observed due to combination of compost at 5 t ha^{-1}, lime at 1.5 t ha^{-1} and P at 40 and 20 kg P ha^{-1} in the first season. Therefore, combination of compost with P or combination of compost, lime with P could be helpful treatments in reducing the exchangeable acidity and increase the available P use efficiency, respectively.

Keywords: Available P; exchangeable acidity; maize; P use efficiency; soil pH.

1. INTRODUCTION

Decline in soil fertility is still heading forward as a major crop production problem, exhibiting itself through loss of soil nutrients, depletion of soil organic matter and plant toxicity. The depletion in organic matter (OM) is 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 the remaining nutrients [1].

In addition to OM depletion, about 40% of the cultivated soils have got acidity problem in Ethiopia, which ranges from slightly acidic to strongly acidic conditions; the magnitude of the latter being about 15% [2]. Soil acidity status in western and central Ethiopia, carried out in three Zones (East, West Wellega and West Showa) also showed all samples collected from the three study Zones were acidic. The degree of soil acidity in this region varied among study Zones, districts, and peasant associations, showing a trend of soil acidity development due to poor soil management practice [3]. In some highland parts of western Ethiopia, the inherent available phosphorus (P) has become deficient due to soil acidity resulting in stunted growth and reduced yield of crops [4,5]. In these acidic soils, availability of nutrients like nitrogen (N), zinc (Zn), copper (Cu) and molybdenum (Mo) in addition to P are too low to support good crop production [2]. Nutrient deficiencies are not the only problems in these soils; but toxicity of Al and manganese (Mn) constrain crop production through interfering with active nutrient uptake of roots [6].

High yielding maize varieties that are adapted to differing agro ecologies of the country have been produced to ensure food security of the country since the famine of 1984 [7,8]. Among these, maize varieties breed to mid altitude areas like BH540 and BH541 had the highest productivity of 10 and 11 t ha^{-1} on research fields and 6.5 and 7 t ha^{-1} on farm researches, respectively [9]; however their productivity on farmers field in Western Ethiopia is only about 3 t ha^{-1} [10] due to constraints related to soil acidity among the others.

Application of organic matter (compost, manure) to such acidic soils would have multifaceted benefit like stabilization of soil aggregates and reduction in further depletion of nutrients that could occur through soil erosion [11]. Since organic matter is prepared from plant residues and animal manures, it can replace plant nutrients to the soil and improve the availability of soil deficient nutrients, like P, magnesium (Mg), sulfur (S), Mo and Zn [12]. On the top of these, OM has a potential liming effect in acidic soils, due to the high molecular weight humic substance constituting about 70-80% of the organic residue. This humic substance can form complexes with monomeric species of aluminum (Al^{+3}, $Al(OH)^{+2}$, $Al(OH)_2^{+}$) to reduce the interference of Al in the active uptake of P in root surfaces [13]. The organic acids in compost or manure also raise 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 [13]. For instance [14] reported, increase in soil pH from 4.00 to 5.6 for increasing rate of vermicompost in the rate between 0-70 t ha^{-1}, and a lime substitution potential of 60 t ha^{-1} vermicompost for 2 t ha^{-1} lime.

On the other hand application of lime ($CaCO_3$) can be used to reduce 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 Al hydroxide [15]. Lime applied at rate of 2 t ha^{-1} with 88 kg P ha^{-1} in form of single super phosphate (SSP) significantly increased the soil pH from 4.83 to 7.13 [16]. But, if an acid soil is to be reclaimed by full dose of lime, it may require larger sum of money, which could not be afforded by smallholder farmers. However, integration of lime with locally available materials like the compost might be helpful in achieving the required yield and economic efficiency.

Integrated soil fertility management (ISFM) is one best option as it utilizes available organic and inorganic inputs to build ecologically-sound and economically viable farming system [17]. Integrated soil fertility management refers to a set of soil fertility management practices that necessarily include the use of inorganic fertilizer, organic inputs, and improved varieties combined with the knowledge on how to adopt these practices to suit the local conditions, aiming at maximizing agronomic use efficiency of the applied nutrients and improving crop productivity [18].

In this regard, a study by [19] 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. [20] also reported that 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.

Nutrient use efficiency is also a factor that can be used as index to observe the yields of a crop under nutrient deficient condition. In situation where sufficient amount of the desired nutrient is taken up by the plant tissue (internal efficiency) and the crop have high utilization efficiency; the yield increment approaches the potential yield [21]. P utilization efficiency under acidic soil condition goes low due to soil factor, even with high yielding varieties that are responsive and nutrient efficient [20]. Thus, increasing yield and nutrient utilization efficiency, should be the way to respond to resource poor farmers under nutrient deficient condition [21]. Therefore, this research was conducted with the general objective of determining the effect of integrated application of compost, lime and inorganic P fertilizers on physicochemical properties of the soils and P use efficiency of maize.

2. MATERIALS AND METHODS

2.1 Description of the Study Site

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 Centre), which is located in the Assosa District, western Ethiopia. The study site is situated at an altitude of 1550 meters, with longitude and latitude of 34°34’15.4’’E and 10°2’27.6’’N, respectively. The rainfall distribution of the area is bi-modal occurring in months between March and October; and the long rainfall months are May, July, August and September, while the short rainfall months are November and December. 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 the 2014 growing season due to weather change by ‘El Nino’ in 2015. The highest mean maximum and minimum temperatures of 2015 were 33.4 and 17.4°C, respectively. The soil texture of the study site is heavy clay having a pH of 5.4 (strongly acidic) with low soil organic matter and low soil N, P and K (Table 1).

2.2 Soil and Compost Sampling and Analysis

Soil samples were taken from the whole field at five points before applying the treatments and after crop harvesting from each plot at three points diagonally to a depth of 0-30 cm by grid sampling methods and samples were composited. The soil texture and soil chemical properties were analysed at Assosa soil laboratory following standard methods.

The soil texture was determined using density method proposed by [22]; the soil pH was measured using soil to water ratio of 1:2.5 by pH meter (potentiometric analysis) [23]; the percent organic carbon content (% OC) was measured using wet potassium dichromate oxidation method [24]; cation exchange capacity (CEC) was determined using ammonium acetate extraction at pH 7 and titration with ammonium counter ion [25]; the exchangeable acidity and exchangeable aluminium were determined by 1 mol L^{-1} potassium chloride (KCl) extraction method [15]; exchangeable K by flame photometer; total N by kjeldal digestion [23]; and available P by Olsen extraction method [26], all before planting of maize and after harvesting of maize in the two growing seasons.

The compost was made by combining various locally available organic materials like maize leaves and stalks, kitchen scraps, tree leaves, broad leaved weeds, grass weeds, livestock manure and saw dust, which was composted in a rotating bin. The ready mature compost was taken out of rotating bin, homogenized and samples were taken from six points in all sides of the pile and composited. Then it was air dried in the laboratory, sieved and analyzed for pH by using soil to water ratio of 1:2.5 and measured, the bulb in the paste [23], while % OC, available P, available potassium (K), exchangeable acidity and exchangeable Al were determined following the same procedure as the soil described above.

2.3 Soil and Compost Properties before Treatment Application

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, which was strongly acidic [29]. The soil was low in organic carbon (1.7%) as the optimum soil organic carbon is in the range of 2 to 4.5% [30]; [31], which could be due to regular burning of forests, bush lands and grass lands with consequential washing up of the left over ash by runoff [1]. The soil had very low available P (4.75 mg kg^{-1}) compared to the sufficient range of 10 to 15 mg kg^{-1} [32]. The reason for low available P might be complex formation of phosphate with monomeric forms of Al and Fe. Consistent to this result, [4] reported that the available Olsen P in north western Ethiopia was in range between 2.0 to 24 mg kg^{-1}, which was in the range of very low to low soil available P. The soil had also very low available potassium (1.42 mg kg^{-1}) as compared to the optimum potassium saturation for crops, which is in the range of 190 to 600 mg kg^{-1} [30] or 100 to 250 mg kg^{-1} [33]; the available K is low in this soil probably due to leaching caused by high precipitation. The soil has relatively low percent of acid saturation (5.12%). While the compost used had a pH of 7.8, OC (35.12%), total N (4.75%), available P (56.9 mg kg^{-1}) and available K (67.18 mg kg^{-1}) (Table 1).

2.4 Treatments and Experimental Procedure

The treatments consisted of three-factor-factorial combinations of compost (C), lime (L) and phosphorus (P) fertilizer. The rates of lime were calculated from the lime requirement using the Shoemaker McLean Pratt (SMP) buffer pH method [27] and with incubation experiment for check up. Then 0, 50% and 100% of the lime requirements 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

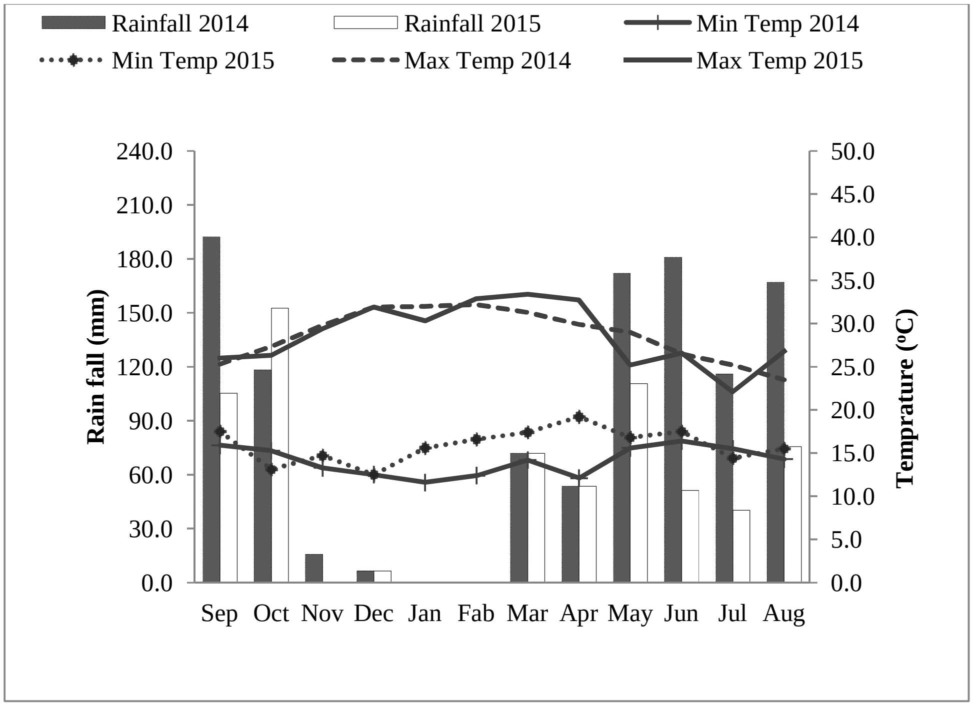

Fig. 1. Mean monthly rainfall (mm), max and min temperatures (℃) of 2014 and 2015

Table 1. Selected physico-chemical properties of soil and compost before treatment application

Chemical properties	Compost	Soil	
		2014	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

69 kg N ha^{-1} as per the recommendation for the crop in the area. Treatments were replicated 3 times in complete randomized block design (CRBD) in factorial arrangement on gross plot of 3 m × 3 m (9 m^2) and net plot size of 4.5 m^2.

A land with pH of less than 5.5 was selected for the experiment and land preparation was done 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 site selected was ploughed and harrowed using tractor and manually levelled in to good seed bed with final make up of the desired number of plots. The treatments of compost and lime were applied according to the randomization set before sowing of maize; and were 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 for compost. 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 rates P fertilizers were applied. The remaining two third rate of nitrogen was applied at knee height stage of maize. After harvest of maize soil samples were taken for physico-chemical analysis.

2.5 Measure of P Use Efficiencies

The P use efficiencies considered were: the agronomic efficiency (AE), the apparent recovery efficiency (ARE) and utilization efficiencies (UE) of phosphorus by maize. The agronomic efficiency was described as the ratio of grain yield to P fertilizer applied, which was calculated as: AE (kg yield kg^{-1} P applied) = $\frac{(\mathrm{Gf - Gu})}{\mathrm{Pa}}$; where G_f is the grain yield of the fertilized plot (kg), G_u is the grain yield of the unfertilized plot (kg), and P_a is the quantity of P applied (kg).

The apparent recovery efficiency is the quantity of phosphorus uptake per unit of P applied, which was calculated as: ARE (%) = $\frac{(\mathrm{Pf-Pu})}{\mathrm{Pa}} \times 100$; where P_f is the P uptake (grain plus straw) of the fertilized plot (kg), P_u is the P uptake (grain plus straw) of the unfertilized plot (kg) and P_a is the quantity of P applied (kg).

The physiological efficiency (PE) was used to calculate the utilization efficiency and described as the biomass yield obtained per unit nutrient uptake, which was calculated as: PE (kg kg^{-1}) = $\frac{(\mathrm{BYf-BYu})}{(\mathrm{Pf-Pu})}$; where BY_f is biomass yield of fertilized plot and BY_u is biomass yield of unfertilized plot, Pf is the P uptake (grain plus straw) of the fertilized plot (kg) and Pu is the P uptake (grain plus straw) of the unfertilized plot (kg). And the utilization efficiency (UE) was obtained as: ARE×PE.

2.6 Statistical Analysis

The experiment was done for two seasons and 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 GLM model using year as random effect. The treatment effects were separated using Tukey's mean separation test using SAS version 9 [28].

3. RESULTS AND DISCUSSION

3.1 Soils Chemical Properties after Harvest of Maize

3.1.1 Soils pH

The combined analysis of the two seasons' data showed significant (*P<0.01*) main effects of season, compost, lime and P and significant interaction effects of season with compost and season with P on the soil pH (Table 2). Accordingly application of lime significantly increased the soil pH showing higher soil pH (5.95) at lime rate of 3 t ha^{-1}, which exceeded the control by 0.24 pH units and the soil before treatment application by 0.55 pH units, without significant difference to lime applied at 1.5 t ha^{-1} (Table 3). Lime having calcium in it might have increased the soil pH by replacing the exchangeable forms of Al and Fe, which reacts with hydroxide ion released from water in the soil solution to arrest Al and Fe in to insoluble hydroxide forms [34]. Similar result was reported by [16] wherein application of lime (2 t ha^{-1}) alone or in combination with phosphorus 88 kg P ha^{-1} in form of single super phosphate (SSP) significantly raised the soil pH relative to the control.

In the first season (2014), compost applied at 5 t ha^{-1} gave the highest pH of 6.23, and it was significantly higher than all combination of the treatments. The first season treatment without compost was the second highest in pH (6.02), which in turn was significantly higher than second season compost applied at 5 t ha^{-1} (5.60) (Table 4).

The first season, compost application raised the soil pH more than compost applied in the second season, probably due to high soil moisture status and low temperature of the first season (Fig. 1), which in turn could lower the release of soil organic carbon, increasing the effect of compost to increase the soil pH. In line to this result, [35] showed, increase in soil pH in line with increase in the available water holding capacity of the soil and increasing rate of compost (0-20 t ha^{-1}). On the other hand, the acid saturation of the soil in the second season was higher than in the first season (Table 1),

Table 2. Mean squares of ANOVA for selected properties of soil after maize harvest and P use efficiency of maize due to season, compost, lime and P

Source of variation	DF	Soil pH	Available P	Exch. acidity	Exch. Al	Dry bulk density	P recovery efficiency	P utilization efficiency
Season (S)	1	8.89***	978.85***	0.59**	7.30***	0.0002 ns	60.92***	33926.01***
Compost (C)	1	0.62***	22.41***	2.53***	0.97***	0.014*	92.10***	70465.88***
Lime (L)	2	0.54***	44.21***	6.07***	1.25***	0.0004ns	33.07***	15562.54***
Phosphorus (P)	2	0.09**	133.428***	0.29^{ns}	0.10^{ns}	0.005ns	210.56***	132768.15***
S x C	2	0.09*	11.68*	0.04 ^{ns}	0.09^{ns}	0.008ns	31.79**	3172.22^{ns}
S x L	2	0.05^{ns}	0.96^{ns}	1.72***	0.24*	0.002ns	1.68^{ns}	1860.67^{ns}
S x P	2	0.14**	15.49**	0.68***	0.11^{ns}	0.0002ns	40.89***	10241.30**
C x L	2	0.01^{ns}	2.14^{ns}	0.60**	0.16^{ns}	0.002ns	4.14^{ns}	809.94^{ns}
C x P	2	0.02^{ns}	1.06^{ns}	0.57**	0.15^{ns}	0.001ns	28.57***	27002.21***
L x P	4	0.02^{ns}	16.59***	0.56***	0.02^{ns}	0.0001ns	15.21**	5005.91*
S x C x L	2	0.01^{ns}	29.99***	0.04^{ns}	0.08^{ns}	0.006 ns	3.56^{ns}	437.97^{ns}
S x C x P	2	0.03^{ns}	2.04^{ns}	0.05^{ns}	0.04^{ns}	0.002ns	8.88^{ns}	2470.23^{ns}
S x L x P	4	0.01^{ns}	15.42***	0.80***	0.16^{ns}	0.0002ns	6.62^{ns}	1107.97^{ns}
C x L x P	4	0.04^{ns}	1.23^{ns}	0.27*	0.16^{ns}	0.0002ns	4.05^{ns}	1031.90^{ns}
S x C x L x P	4	0.04^{ns}	8.34**	0.16^{ns}	0.07^{ns}	0.003 ns	1.00 ^{ns}	178.53^{ns}
Error	68	0.02	2.52	0.09	0.08	0.003	3.53	4359.42

Where, DF: degree of freedom; Exch.: exchangeable; ^{ns}: non-significant difference; *, **, and *** significantly difference at probability level of 5, 1, and 0.1%, respectively

Table 3. The main effects of season, compost, lime and P on selected soil chemical properties and P use efficiencies of maize

Treatments	Soil pH	Available phosphorus (mg kg^{-1})	Exchangeable acidity (cmol$_c$ kg^{-1})	Exchangeable Al (cmol$_c$ kg^{-1})	Recovery efficiency (%)	Utilization efficiency (kg kg^{-1})
Season						
2014	6.13^{a}	10.48^{a}	0.94^{b}	0.68^{a}	3.51^{a}	51.17^{b}
2015	5.55^{b}	4.46^{b}	1.09^{a}	0.16^{b}	2.21^{b}	86.62^{a}
Compost (t ha^{-1})						
0	5.76^{b}	7.02^{b}	1.18^{a}	0.51^{a}	1.84^{b}	43.35^{b}
5	5.92^{a}	7.93^{a}	0.87^{b}	0.32^{b}	3.68^{a}	94.44^{a}
Lime (t ha^{-1})						
0	5.71^{c}	6.43^{c}	1.49^{a}	0.63^{a}	2.79^{ab}	69.61^{ab}
1.5	5.86^{b}	8.64^{a}	0.85^{b}	0.28^{b}	3.69^{a}	89.32^{a}
3	5.95^{a}	7.34^{b}	0.72^{b}	0.35^{b}	1.78^{b}	47.76^{b}
Phosphorus (kg P ha^{-1})						
0	5.79^{b}	5.62^{c}	0.96^{a}	0.36^{a}	0.00^{b}	0.00^{b}
20	5.83^{ab}	7.34^{b}	1.13^{a}	0.47^{a}	4.51^{a}	114.66^{a}
40	5.89^{a}	9.46^{a}	0.98^{a}	0.42^{a}	3.77^{a}	92.03^{a}
CV (%)	2.52	21.17	30.62	6.59	68.07	65.41

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

constraining the effect of compost to increase the soil pH in the second season. In this regard, [5] reported, higher increase in soil pH on soils (land use systems) that had lower acid saturation for same rate of lime applied (0-10 t ha^{-1}). In support to this result, [14] reported, increase in soil pH from 4.00 to 5.6 for increasing rate of vermicompost in the rate between 0-70 t ha^{-1}, and there was a lime substitution potential of 60 t ha^{-1} vermicompost for 2 t ha^{-1} lime.

The interaction of season with phosphorus affected the soil pH such that in the first season, P applied at 40 kg P ha^{-1} showed the highest soil pH (6.24) with significant difference to all combination of treatments except P applied at 20 kg P ha^{-1} (6.13) in the first season. Thus, the first season P applied at rate of 40 kg P ha^{-1} increased the soil pH by 0.22 units compared to the control (Table 4). The higher increase in soil pH due P in the first season might be related to the high rainfall in the season (Fig. 1), which could increase the solubility of P applied in the form of triple super phosphate (TSP), in turn increasing the formation of insoluble aluminium (Al) and iron (Fe) phosphate [36]. Similar to this result, [37] reported, the existence of fertilizer-induced soil pH increase and soil bioactivity, with increasing rate of P (0-80 kg P ha^{-1}) applied.

3.1.2 Available phosphorus

The available P of the soil after crop harvest was significantly (*P<0.01*) affected the four way interactions of season, compost, lime and phosphorus (Table 2).

Table 4. Interaction effects of season with compost and season with P on soil pH after maize harvest

Treatment interactions			Soil pH
Season	Compost (t ha^{-1})	P applied (kg ha^{-1})	
2014	0	-	6.02^{b}
	5	-	6.23^{a}
2015	0	-	5.51^{c}
	5	-	5.60^{c}
2014	-	0	6.02^{b}
	-	20	6.12^{ab}
	-	40	6.24^{a}
2015	-	0	5.54^{c}
	-	20	5.55^{c}
	-	40	5.56^{c}
CV (%)			2.52

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

Thus, in the first season treatments applied as combination of compost at rate of 5 t ha^{-1}, lime at 1.5 t ha^{-1} and P at rate of 40 kg P ha^{-1} showed the highest soil available P (15.04 mg kg^{-1}) which was significantly higher than all the second season treatments of compost, lime with P and all first season treatments of compost and lime without P (Table 5). There was a 68.38% increase in available P relative to the soil before treatment application. In this study, P application was the major source of the residual available P since it became lower for all combination of compost and lime without P, and it became higher for increasing rate of P [38]. The higher residual P for combinations of compost, lime and P in the first season compared to the second season might be due to higher initial P of the soil in the first season. The second most likely reason might be due to the nature of triple super phosphate (TSP), which needs long period of soil moisture for dissolution depending on the rock phosphate of which it was made [39]. Hence, the higher annual rainfall (1063 mm) in the first season compared to the second season rainfall (667 mm) (Fig. 1) might have resulted in higher chance of dissolving the TSP while improving the soil available P. The interactions of compost, lime and P also increase the residual available P due to desorption effects of lime and compost, which frees the dissolved P from being chemically bound to the Al and Fe compounds, such that lime forms the insoluble Al and Fe hydroxide and compost forms Al and Fe organic acid complex [34,13]. In agreement to this, [20] showed that combinations of manure (5 t ha^{-1}), lime (3 t ha^{-1}) and phosphorus (60 kg P ha^{-1}) has significantly increased the residual available P than combinations of manure with P.

3.1.3 Exchangeable acidity

The exchangeable acidity showed significant (*P<0.01*) difference due to three way interaction effects of season, lime with P and compost with lime with P (Table 2).

The interaction effects of the second season treatment without lime and P at rate of 20 kg P ha^{-1} showed the highest exchangeable acidity (2.44 cmol$_c$ kg^{-1}), while the first season treatment without lime and without P showed the second highest exchangeable acidity (1.59 cmol$_c$ kg^{-1}). In the first season (2014) lime at 3 t ha^{-1} with P at 40 kg P ha^{-1} showed the least exchangeable acidity (0.36 cmol$_c$ kg^{-1}), reducing the soil exchangeable acidity before the treatment application by 56.63% (Table 6). The higher exchangeable acidity in treatment combinations of the second season compared to the first season might be related to the higher initial acid saturation of the second season (Table 1); a soil with higher acid saturation would give higher exchangeable acidity after application of similar rate of lime [5]. Moreover, due to higher rainfall in the first season (Fig. 1), the soil reaction due to lime and P might have highly reduced the exchangeable acidity inducing the formation of Al and Fe hydroxides [34]. Regardless of seasons, application of lime with P also decreased the exchangeable acidity. In agreement to this result, [16] reported that lime applied at rate of 2 t ha^{-1} with 88 kg P ha^{-1} in form of single super

Table 5. Interaction effects of season, compost, lime and P on the available P (mg kg^{-1}) of the soil after maize harvest

Treatments					
Season	**Compost (t ha^{-1})**	**Lime (t ha^{-1})**	**P applied (kg P ha^{-1})**		
			0	**20**	**40**
2014	0	0	6.68^{defghij}	8.63^{cdefgh}	9.92^{abcde}
	0	1.5	9.02^{cdefg}	9.81^{bcdef}	12.15^{abc}
	0	3	8.63^{cdefgh}	11.09^{abc}	12.15^{abc}
	5	0	8.35^{cdefghi}	11.98^{abc}	12.19^{abc}
	5	1.5	9.18^{cdefg}	14.65^{ab}	15.04^{a}
	5	3	9.36^{cdefg}	10.35^{abcde}	10.30^{abcde}
2015	0	0	1.5^{k}	3.16^{jk}	3.50^{ijk}
	0	1.5	3.70^{hijk}	4.30^{ghijk}	11.90^{abc}
	0	3	1.70^{jk}	3.16^{jk}	5.30^{efghijk}
	5	0	2.90^{jk}	4.70^{fghijk}	2.90^{jk}
	5	1.5	4.30^{ghijk}	2.30^{jk}	8.90^{cdefg}
	5	3	2.10^{jk}	4.70^{fghijk}	9.30^{cdefg}
CV (%)			21.17		

Means in columns and rows followed by different letters are significantly different at 0.05 levels, according to Tukey's mean separation test phosphate (SSP) significantly increased the exchangeable acidity through raising the soil pH from 4.83 to 7.13.

The interaction of compost, lime and phosphorus also affected the exchangeable acidity wherein the treatment without compost, without lime and without P showed the highest exchangeable acidity (2.41 cmolc kg^{-1}) with significant difference to all treatment combinations. And compost applied at 5 t ha^{-1} with lime at 3 t ha^{-1} with and without P showed lower exchangeable acidity, indicating, application of compost with higher rate of lime could significantly reduce the exchangeable acidity without much regard to the rate of P applied. The treatment with compost at 5 t ha^{-1}, lime at 3 t ha^{-1} without P reduced the exchangeable acidity by 1.90 cmol$_c$ kg^{-1} compared to the control (Table 6). The acidity reduced by lime and compost was synergistic having a mechanism that calcium from lime replaces the exchangeable forms of Al and Fe, which reacts with hydroxide ion released from water in the soil solution forming insoluble Al and Fe hydroxides [34]; while compost forms insoluble Al and Fe organic acid complex bounding to the exchangeable Al and Fe without interfering with the effect of lime [13]. Similar study by [19] showed that combined application of manure, lime and phosphorus (TSP) significantly reduced the exchangeable acidity more than combination of manure with P or manure with lime.

The main effects of season, compost, lime and interaction effects of season with lime showed significant (*P<0.05*) difference on the exchangeable aluminium (Table 2). Therefore, compost applied at rate of 5 t ha^{-1} showed the lowest exchangeable aluminium (0.32 cmolc kg^{-1}) compared to the treatment without compost (0.51 cmolc kg^{-1}) (Table 3). Application of compost decreased the exchangeable Al of the soil by 0.19 cmolc kg^{-1} compared to the control, which might be due to the depressing effect of compost on the exchangeable Al through formation of Al organic acid complex [13]. In agreement to this result, [40] reported that application of manure at 10 t ha^{-1} reduced the exchangeable aluminium by 8.91 cmolc kg^{-1} compared to the control, due to release in calcium, reduction in solubility of Fe compounds when the soil pH was raised and chelation of exchangeable Al during decomposition of manure. Similarly, [41] reported that application of 1.2 g compost applied to 20 g soils reduced the exchangeable Al better than the control.

Lime application affected the exchangeable Al, where in the first season treatment of lime at 3 t ha^{-1} reduced the exchangeable Al the highest (0.05 cmolc kg^{-1}) (Table 7), this reduction in exchangeable Al was accounted to 90.79% of the soil exchangeable Al before application of treatment. The second season lime applied at 3 t ha^{-1} showed relatively higher exchangeable Al (0.44 cmolc kg^{-1}), which might indicate increased rate of lime was more effective in reducing soil exchangeable Al in a season that had adequate rainfall (soil moisture) (Fig. 1). The higher exchangeable Al in the second season could also be due to higher initial Al saturation of the

Table 6. Interaction effects of season, compost, lime and P on the exchangeable acidity (cmol$_c$ kg^{-1}) of soil after maize harvest

Treatment interactions					
Season	**Compost (t ha^{-1})**	**Lime (t ha^{-1})**	**P rate (kg P ha^{-1})**		
			0	20	40
2014	-	0	1.59^{b}	1.14^{bcde}	1.09^{bcde}
	-	1.5	0.66^{def}	0.48^{ef}	0.36^{f}
	-	3	0.67^{def}	1.06^{bcde}	0.97^{bcdef}
2015	-	0	1.24^{bcd}	2.44^{a}	1.44^{bc}
-	-	1.5	1.04^{bcdef}	0.92^{bcdef}	1.16^{bcde}
-	-	3	0.56^{def}	0.72^{def}	0.87^{cdef}
-	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}
CV (%)			30.62		

Means in columns and rows followed by different letters are significantly different at 0.05 levels, according to Tukey's mean separation test soil compared to the first season (Table 1). Similar result was reported by [40] where application of lime at rate of 2.5 t ha^{-1} increased the exchangebel Al up to 8.91 cmolc kg^{-1} across different sites compared to the control, due to precipitation of Al in to Al hydroxide when the soil pH was raised above six. [41] also reported higher reduction in exchangeable Al, when lime at rate of 80 mg to 20 g soil, but with further increase in lime rate there was no further reduction in exchangeable Al.

Table 7. Interaction effects of season with lime on exchangeable aluminium of soil after maize harvest

Treatments		Exchangeable Al (cmol$_c$ kg^{-1})
Season	**Lime (t ha^{-1})**	
2014	0	0.32^{cd}
	1.5	0.11^{d}
	3	0.05^{d}
2015	0	0.94^{a}
	1.5	0.66^{ab}
	3	0.44^{bc}
CV (%)		6.59

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

3.2 Soil Physical Property (Dry Bulk Density)

The dry bulk density was significantly (*P<0.05*) different due to the main effect of compost only while the other main effects and interactions are not significant (Table 2). Application of compost at rate of 5 t ha^{-1} showed significantly higher dry bulk density (1.09 g cm $^{-3}$) than treatment without compost (1.07 g cm^{-3}). The physical property of the soil before the study was described as heavy clay having low dry bulk density (1.1 g cm^{-3}) with medium proportion of silt (Table 1), which might have contributed to low dry bulk density of the soil, but with application of compost the dry bulk density showed no significant change compared to the dry bulk density before the study, while the control treatment showed lower dry bulk density. The addition of organic matter to sandy soil could decrease the dry bulk density of the soil, while on clay soil that have lower dry bulk density application of organic matter could increase the dry bulk density; it might increase the dry bulk density by improving the soil macropors. In agreement to this, [42], showed a decrease in soil dry bulk density when compost and peat are applied to compacted soil and soil with texture of sandy loam, while compost applied at 10% of the soil volume of, un-compacted clay loam soil, the dry bulk density increased from 1.26 to 1.3 g cm^{-3}.

3.3 Phosphorus Use Efficiency of Maize

3.3.1 Apparent recovery efficiency

The apparent recovery efficiency of P was significantly (*P<0.01*) affected by the interaction effects of season with compost; season with phosphorus; compost with phosphorus and lime with phosphorus (Table 2). Thus, interaction effects of season with compost increased the apparent recovery efficiency wherein the first season (2014) compost applied at 5 t ha^{-1} showed the highest recovery efficiency (4.98%) followed by second season (2015) with compost at 5 t ha^{-1} (2.39%), which showed no significant difference, to the remaining treatments (Table 8). The highest apparent recovery with compost application in the first season might be attributed to better moisture status of the soil for P uptake (Fig. 1), since recovery efficiency depended on the uptake. In agreement to this, [20] reported that there is an interaction between farm yard manure (5 t ha^{-1}) and phosphorus (0, 60 kg P ha^{-1}) in improving nutrient uptake and P apparent recovery of maize.

The interaction between season with phosphorus also affected the apparent recovery where P applied at 20 kg ha^{-1} in the first season (2014) gave the highest P recovery (6.48%) and the treatment in first season with P at rate of 40 kg P ha^{-1} showed the second highest P recovery efficiency (4.05%) without significant difference to the rest of the treatments (Table 8). The apparent recovery was highest at the intermediate P rate, which might be related to the decrease in P uptake for additional unit of P applied beyond 20 kg P ha^{-1}, decreasing the apparent recovery efficiency for increased rate of P due to soil acidity and plant factors, which suggested the P uptake increments for additional unit of P applied decreased, beyond certain level of P applied, decreasing the apparent recovery efficiency [43].

Interaction of compost with phosphorus affected the apparent recovery efficiency significantly (*P<0.01*), such that compost at rate of 5 t ha^{-1} with P at 20 kg P ha^{-1} showed the highest apparent recovery efficiency (6.29%) without significant difference to compost at 5 t ha^{-1} with P at 40 kg P ha^{-1} (4.76%). The treatment having P at 20 kg P ha^{-1} without compost showed the least apparent recovery (2.73%). The observed recovery efficiency was lower compared to the attainable apparent recovery efficiency (33%) of rice in Brazilian acidic soil [44], which might arose from the combined effect of leaf blight of maze and soil acidity. Application of P at 20 kg ha^{-1} with compost (5 t ha^{-1}) significantly increased the apparent recovery efficiency compared to the two rates of P (20 and 40 kg P ha^{-1}) in the absence of compost (Table 8). This indicated intermediate rate of P is more important in presence of compost than higher rate of P without compost in increasing the apparent recovery efficiency P, due to enhanced availability of P by the liming effect of compost. Similar result was reported by [45] that half dose of farm yard manure (5 t ha^{-1}) with phosphorus (30 kg P ha^{-1}) significantly improved the P uptake and P apparent recovery efficiency.

Lime and phosphorus showed significant (*P<0.01*) interaction effect on the apparent recovery efficiency; and the treatment combination of 1.5 t ha^{-1} lime with 20 kg P ha^{-1} showed the highest recovery efficiency (5.97%) without significant difference to lime at 0 with P at 20 kg ha^{-1} (5.30%) and lime at 1.5 t ha^{-1} with P at 40 kg P ha^{-1} (5.12%). Lime at 3 t ha^{-1} with P at 40 and 20 kg ha^{-1} showed the least apparent recovery efficiency (Table 8). In this study intermediate rate of lime (1.5 t ha^{-1}) with intermediate rate of P (20 kg ha^{-1}) gave the highest apparent recovery efficiency; and the synergism was higher at intermediate rate of lime with P, because, at higher rate of lime the soluble form of P chemically precipitate after formation of the calcium phosphate [46], while reducing the P uptake and recovery efficiency. The interaction of lime with phosphorus was reported by [47] where lime (4 t ha^{-1}) with P (26 kg P ha^{-1}) highly improved the available P (P uptake) and the P use efficiency of different varieties of maize.

3.3.2 Utilization efficiency

Phosphorus utilization efficiency was significantly (*P<0.05*) affected by interaction effects of season with P; compost with P; and lime with P (Table 2). Thus, season with phosphorus increased the utilization efficiency such that P applied at 20 kg P ha^{-1} in the second season (2015) showed the highest utilization efficiency (134.25 kg kg^{-1}), without significant difference to the second season P applied at 40 kg ha^{-1} (125.61 kg kg^{-1}) (Table 8). Unlike P uptake and apparent recovery efficiency, where the first season P application showed the highest result, the utilization efficiency showed its highest result for P application in the second season; indicating the second season crop was more efficient in making its total biomass per unit P uptake, possibly due to reduced incidence of leaf blight of maize in the second season. It is known that crops with lower P content and higher yield are considered as highly nutrient efficient. In line to this, [43] reported a decrease in utilization efficiency with increasing rate of P (0 to 90 kg P_2O_5 ha^{-1}) having the highest utilization efficiency (182 kg kg^{-1}) observed at 30 kg P_2O_5 ha^{-1}.

Interaction effects of compost with P was also significant on the P utilization efficiency, where compost at 5 t ha^{-1} with P at 20 kg ha^{-1} had the highest utilization efficiency (169.12 kg kg^{-1}), while combination of P at 40 and 20 kg ha^{-1} in the absence of compost showed the least utilization efficiency (Table 8). The result indicated that intermediate rate of P (20 kg ha^{-1}) is more important in presence of compost than higher rate of P without compost in increasing the utilization efficiency. The increased utilization efficiency at intermediate rate of P might be due to improved availability of P as compost had a liming effect, which might have surpassed the sufficiency concentration at higher rate of P, but increased the dry biomass yield at the intermediate rate. In agreement to this result, [45] reported significant increase in P uptake and P utilization efficiency of maize due to half dose application of farm yard manure (5 t ha^{-1}) with phosphorus (30 kg P ha^{-1}).

Interaction between lime and phosphorus showed significant (*P<0.01*) effect on the utilization efficiency wherein the combination of 1.5 t ha^{-1} lime with 20 kg P ha^{-1} showed the highest utilization efficiency (146.74 kg kg^{-1}) without significant difference to lime at 0 with 20 kg P ha^{-1} (124.56 kg kg^{-1}) and lime at 1.5 t ha^{-1} with P at 40 kg P ha^{-1} (121.23 kg kg^{-1}). Lime at rate of 3 t ha^{-1} with P at 40 and 20 kg ha^{-1} showed the least utilization efficiency (Table 8). Intermediate rate of lime with intermediate rate of P gave the highest utilization efficiency, which might be due to increased availability of P at those rates. Higher rate of lime application might have decreased the availability of P due to formation of insoluble calcium phosphate [46]. The interaction of lime with P was reported by [47], where application of lime (4 t ha^{-1}) with P

Table 8. Interaction effects of season with P, compost with P and lime with P on P apparent recovery, utilization and agronomic efficiency of maize

Treatment interactions			Recovery efficiency (%)		Utilization efficiency (kg kg^{-1})	
Season	**Compost (t ha^{-1})**	**Lime (t ha^{-1})**	**Phosphorus (kg P ha^{-1})**			
			20	40	20	40
2014	-	-	6.48^{a}	4.05^{b}	95.06^{ab}	58.46^{b}
2015	-	-	2.54^{b}	3.48^{b}	134.25^{a}	125.61^{a}
-	-	-				
-	0	-	2.73^{b}	2.77^{b}	60.19^{c}	69.87^{bc}
-	5	-	6.29^{a}	4.76^{ab}	169.12^{a}	114.20^{b}
-	-	-				
-	-	0	5.30^{ab}	3.09^{bc}	124.56^{ab}	84.27^{b}
-	-	1.5	5.97^{a}	5.12^{ab}	146.74^{a}	121.23^{ab}
-	-	3	2.26^{cd}	3.09^{bc}	72.67^{b}	70.61^{b}
CV (%)			68.07		65.41	

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

(26 kg P ha^{-1}) increased the availability of P and thus increased the utilization efficiency of different maize varieties.

4. CONCLUSION

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 initial soil pH was highly raised, due to the main effect of lime and due to compost and phosphorus in the first season. The available P was highly enhanced by the interactions of compost with lime and phosphorus in the first season. The exchangeable acidity was highly reduced by the combined application of compost with lime and lime with phosphorus. Even though the exchangeable acidity and exchangeable Al were highly reduced by the highest rate of lime, but the available P was highest due to combination of intermediate rate of lime and with compost. The highest P apparent recovery and utilization efficiencies were recorded due to combination of compost with P; and relatively lower value of apparent recovery efficiency was due to soil acidity and maize leaf blight disease. Therefore, combined application of compost with low rate of lime and intermediate rate of P could provide better availability of nutrients with enhanced soil reactions.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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