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The Response of Maize (*Zea mays*) Yield and Soil Physico-Chemical Properties to Different Inorganic Phosphorus Fertilizer Sources under Limed and Unlimed Acidic *Nitisols* Soil

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Abstract

Phosphorus is often the limiting nutrient in a system and farming practices, by their very nature, remove P from the soil. As a result, P needs to be restored to maintain productivity. Plant available phosphorus levels can undergo gradual decline where losses through crop removal exceed input through fertilizers. Phosphorus is continuously taken up by maize from the seedling stage to maturity, with its maximum uptake during the third and sixth week of growth. Currently there are different types of inorganic phosphorus fertilizers sources are utilized for agricultural soil fertility to overcome the limitation of soil phosphorus deficient. The field experiment was conducted from 2016-2018 cropping years at MetuHurumu on maize crop to evaluate the effects of different phosphorus fertilizer sources with lime application on maize yield and soil chemical properties under acidic Nitisols soil. The treatments were arranged in split plot design with three replications. The treatments were consists of two lime rates as main plot and eight different phosphorus sources as sub plots Control, 2/3 Recommended P from(GPAPR 20 +Zn + B), Recommended P from (GPAPR 20 +Zn + B), 2/3 Recommended P from (MOHP +Zn +B), Recommended P from (MOHP +Zn +B), 2/3 Recommended P NAFAKA (NPK +CaO + S +MgO + Zn +B), Recommended P NAFAKA (NPK +CaO + S +MgO + Zn +B) and NPSZnB (positive control). Initial and after harvest soil sample was collected prepared and analysed based on standard soil laboratory procedures. The result revealed the combined three year (2016-2018) mean analysis data showed there was significant difference among lime and different phosphorus sources. The maximum grain yield 7036.80 kg/ha and biomass yield 17.38 ton/ha was recorded from the Lime*NPSZnB (positive control). There was also the maximum grain and biomass yield was obtained from different phosphorus sources under limed treated plots as compared with unlimed and negative control treatments but statically not significant. In general, from the evaluated different inorganic phosphorus fertilizer sources NPSZnB (positive control) with lime treated plot gave the maximum mean grain and biomass yield as well as enhanced the available phosphorus of soil.

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Keywords

Available P, exchangeable acidity, maize yield, phosphorus fixation.

Introduction

Phosphorus is one of the major essential elements in maize production (Kaya, 2020). It is the most commonly limiting nutrient element in the tropics after water and nitrogen. Many tropical soils have extremely high capacities to immobilize phosphorus. In the maize plant, phosphorus principally stimulates early root formation and growth, hastens crop maturity and affects the grain yield (Muys *et al.,* 2021). The phosphorus is taken up from the soil in H_2PO4 - and $HPO4^{2-}$ forms by plants, and unless the soil contains adequate phosphorus or it is supplied from external sources, plant growth is restricted (Yadav and Verma, 2012). Plant available Phosphorus levels can undergo gradual decline where losses through crop removal exceed input through fertilizers. Phosphorus is continuously taken up by maize from the seedling stage to maturity, with its maximum uptake during the third and sixth week of growth (Nadeem *et al.,* 2011). As soils become more acidic, the reaction of iron and aluminium increases and the relatively soluble calcium phosphate are converted into less soluble aluminium and iron phosphates. These processes are slow enough to permit considerable quantities of calcium phosphates to be present in acid soil with pH values below 5.5. In highly weathered soils, most of the inorganic phosphorous is in the occluded or reductant – soluble form because of the formation of iron and aluminium oxide coatings. In acidic soils aluminium and iron are most abundant and react with phosphorus to form relatively insoluble aluminium and iron phosphates (Bromfield, 1965). According to Negese *et al.,* (2020), soil acidity severely affects the yields of many crops in the western, south-western and southern parts of high rainfall areas of Ethiopia. The infertility of soils in these areas is attributed to excessive concentration of aluminum (Al), iron (Fe) or manganese (Mn) on one hand; and to deficiencies of phosphorus and other essential nutrients reduces the plant phosphorus uptake (Pavlovic *et al.,* 2021). To mitigate phosphorus fixation in acid soils, lime is used to reduce phosphorus sorption sites. This amendment have also been used to increase phosphorus uptake and crop productivity in phosphorus deficient acid soils by rising soil pH and reducing soil acidity which causes the toxicity of Al and Fe. Therefore, the main objectives of this study were to investigate the effects of different phosphorus fertilizer sources with lime application on maize yield and soil chemical properties under acidic soil.

Materials and Methods

Description of the study area

The experiment was conducted at Hurumuworeda, Illu Aba Bor zone, South Western Ethiopia. The site is geographically located 8^0 10' 30'' latitude and 35^0 50' 0'' longitudes. The altitude is 1550 m above sea level. The mean annual temperature of the woreda ranges from 17.6-25ºC and the average annual rainfall is about 1300 mm per year The dominant soils of the area was *Nitisols* which are sesquioxidic and moderately to strongly acidic (Figure 1).

Description of the experiment and managements

The field experiment was conducted from 2016-2018 cropping years at MetuHurumuon maize crop. The treatments were arranged in split plot design with three replications. The treatments were consists of two lime rates as main plot and eight different phosphorus sources as sub plots (Table 1)Control, 2/3 Recommended P from(GPAPR 20 +Zn + B), Recommended P from (GPAPR 20 +Zn + B), 2/3 Recommended P from (MOHP +Zn +B), Recommended P from (MOHP +Zn +B), 2/3 Recommended P NAFAKA (NPK +CaO + S +MgO + Zn +B), Recommended P NAFAKA (NPK +CaO + S +MgO + Zn +B) and NPSZnB (positive control). Maize variety BH 660 was used as test crops. Maize seeds were sown in 80 cm x 50 cm with two seeds per hill. The amount of lime $CaCO_3$(calcium carbonate) that was applied at each level was calculated on the basis of the mass of soil per 0.15m hectare-furrow-slice, soil sample density and exchangeable acidity methods. The recommended nitrogen fertilizer 92 kg/ha was uniformly applied for all treatments from UREA source. For appropriate uses of nitrogen fertilizer application of urea was made in two splits, half at sowing and half at knee height; while the entire rate of different phosphorus source fertilizers at the rates of 69 kg/ha were applied once at the time of sowing.

Soil analysis

Representative soil samples were collected from the experimental field before sowing and after harvesting. The collected soil samples were then air dried, and ground and sieved with a 2 mm size sieve, in preparation for analysis of the envisaged soil physicochemical properties. The soil samples were further ground to pass a 0.5 mm size sieve for the determination of organic carbon and total N contents. The pH of the soil was determined at 1:2.5 (weight/volume) soils to water dilution ratio using a glass electrode attached to digital pH meter (Page, 1982).The exchangeable acidity was determined by saturating the soil samples with 1N KCl solution and titrating with NaOH. The Walkley and Black (1965) wet digestion method was used to determine soil carbon content and percent soil OM was obtained by multiplying percent soil OC by a factor of1.724 following the assumptions that OM is composed of 58% carbon. Total N was analyzed using the Kjeldahl digestion, distillation and titration method as described by Bremner (1965). Available phosphorus was extracted using Bray-II method (Bray and Kurtz, 1945).

Data collected

Ten plants from central rows of each plot were taken at harvest; then chopped and sun dried for eight days and the weight was recorded by using sensitive balance and above ground biomass was measured. Grain yield (kg/ha) was measured with bulk grain yield per net plot was weighed after drying the grain yield by using sensitive balance and the weight was adjusted to 12.5% by using grain moisture tester All the relevant data was summarized and subjected to analysis of variance (ANOVA) using the General Linear Model of SAS 9.3 version. Treatment means were separated using LSD test at 5% probability level for significantly different parameters.

Results and Discussion

Initial soil results

Results of soil properties before establishment of the experiment showed that the soil was highly acidic with pH of 4.41 and the soil also had exchangeable acidity (Al^{+3}+H^{+}) of 2.95 cmol kg^{-1}(Figure 2).Soil with such pH is classified as very acidic (Landon, 1991).Exchangeable acidity occurs when acidic H^{+} ion occurs in the soil solution to a greater extent and when an acid soluble $Al3^{+}$ reacts with water (hydrolysis) and results in the release of H^{+} and hydroxyl Al ions into the soil solution (Fageria and Baligar, 2008). Nadeem (2011) stated that during soil acidification, protonation increases the mobilization of Al and Al forms serve as a sink for the accumulation of H^{+}. The level of organic matter was 1.05 %, while nitrogen and phosphorus were 0.02 % and 4.85 mg kg^{-1}, respectively (Figure 2).The low available P could be explained by the low pH levels or acidity of the soils that leads to P fixation into unavailable forms (Yadav and Verma, 2012). The results implied thatsoil at the experimental site in this study had highly deficient in phosphorus and other essential nutrients.

Effects of lime and different phosphorus sources in soil chemical properties

Based on after harvesting soil chemical properties results indicated that soil pH changed from 4.41 very strongly acidic to 5.73 slightly acidic (Tekalign, 1991) through the application of Lime*NPSZnB (positive control) treatment. Soil reaction is one of the most important physiological characteristics of the soil solution because solubility of many essential elements for plants and nutrient uptake rates are pH dependant. Correcting soil pH to a suitable value requires the removal of excess hydrogen (H^{+}) ions produced by various processes in soil, by applying liming materials such as agricultural lime (calcium carbonate), dolomite (magnesium carbonate plus calcium carbonate), or other materials containing basic cations capable to replace excess H^{+} (Fageria and Baligar, 2008). In addition, liming can also cause the aluminum (Al) and manganese (Mn) to move from the soil solution back into solid (non-toxic) chemical forms. According to the result indicated from (Figure 2) the pH value is regarded to be suitable for maize production (Muys *et al.*, 2021). Liming reduces Al3+ and H+ ions as it reacts with water leading to the production of OH- ions, which react with Al3+ and H+ in the acid soil to form Al(OH)3 and H2O. The precipitation of Al3+ and H+ by lime causes the pH to increase, enhances microbial activity and nutrient availability (Kaya *et al.*, 2020). Exchangeable acidity (EA) showed a highly affected by lime and different P sources (Figure 2). The minimum and maximum EA values were recorded from treatments that received Lime*Control (Negative Control) and Lime*NPSZnB (positive control), and with magnitudes of 2.28 and 0.06 cmolkg^{-1} of soil, respectively. However, the exchangeable acidity under limed plots was decreased as compared with the unlimed treatments. This is to be expected because lime is known to increase the soil pH, hence precipitating Al as $Al(OH)_3$ (Negese *et al.*, 2020).

This has the effect of reducing exchangeable acidity which comprises Al^{3+} and H^{+}. Exchangeable acidity (EA) showed a decreasing trend with limed treated plots which agreed with findings of Getachew *et al.*, (2017) The available phosphorus ranged from 6.72 (ppm) Unlimed*Control (Negative control no lime and phosphorus) treatment to 10.56 (ppm) (Lime*NPSZnB (positive control), 9.82 (ppm) Lime*Recommended Phosphorus from NAFAKA + (NPK+CaO+S+ MgO+Zn+B) and 9.85 (ppm) Lime* Recommended Phosphorus from (MOHP +Zn +B) treated plots respectively. This is in agreement with the findings of Buni (2014) who indicated that increase in soil pH due to lime application reduced phosphorus fixation. Similarly, the findings of Chimdi *et al.*, (2012) reported that the application of lime and chemical phosphorus fertilizer in sole or combination had significantly positive effect on soil pH and available P in acid soils.

Table.1 Treatment combination

No	Treatments
1	Lime*Control (Negative control no phosphorus only lime)
2	Lime*2/3 Recommended Phosphorus from(G PAPR 20 +Zn + B)
3	Lime*RecommendedPhosphorus from (G PAPR 20 +Zn + B)
4	Lime*2/3 Recommended P from (MOHP +Zn +B)
5	Lime* Recommended Phosphorus from (MOHP +Zn +B)
6	Lime*2/3 RecommendedPhosphorus from NAFAKA (NPK+CaO+S+MgO+Zn+B)
7	Lime* RecommendedPhosphorus from NAFAKA + (NPK+CaO+S+MgO+Zn+B)
8	Lime*NPSZnB (positive control)
9	Unlimed*Control (Negative control no lime and phosphorus)
10	Unlimed*2/3 RecommendedPhosphorus from(GPAPR 20+Zn +B)
11	Unlimed*Recommended Phosphorus from (GPAPR 20 +Zn + B)
12	Unlimed*2/3 RecommendedPhosphorus from (MOHP+Zn+B)
13	Unlimed* RecommendedPhosphorus from (MOHP+Zn+B)
14	Unlimed*2/3 RecommendedPhosphorus NAFAKA+ (NPK+CaO+S+MgO+Zn+B)
15	Unlimed* RecommendedPhosphorus from NAFAKA+ (NPK+CaO+S+MgO+Zn+B)
16	Unlimed*NPSZnB (positive control)

Table.2 The main effects of lime and different p source on grain and biomass yield of maize at Metu (Hurumu)

Treatment	2016		2017		2018	
	GY/kg/ha	BY/t/ha	GY/kg/ha	BY/t/ha	GY/kg/ha	BY/t/ha
T1	2480.30d	7.53d	5148.00bdc	9.36dec	4055.70c	8.96f
T2	5759.30a	15.30c	6141.10bac	11.40bdac	7258.70ba	14.73bedc
T3	4911.30c	15.24c	6232.30bac	12.13bac	6611.70ba	17.50ba
T4	5756.00a	16.98bac	5948.60bac	11.73bac	6612.70ba	14.00edc
T5	5152.00bac	16.88bac	5178.40bdc	9.90dec	5857.70b	16.80bc
T6	5176.70bac	17.92a	4813.60edc	9.63dec	6282.30b	15.00befc
T7	5192.00bac	15.58bc	5897.90bac	11.56bdac	7109.70ba	16.36bdc
T8	5317.70bac	17.78a	7418.00a	14.60a	8166.70a	19.96a
T9	2956.70d	8.74d	3171.90e	6.403e	3582.00c	7.40f
T10	5515.30ba	17.02bac	5593.90bac	10.53bdac	6615.00ba	13.36ed
T11	5711.70ba	17.51ba	5401.30bdc	10.03dec	6115.70b	13.10e
T12	5628.30ba	16.88bac	4965.60edc	9.00dec	5871.70b	12.73e
T13	5279.00bac	17.40bac	4641.30edc	8.00de	5692.00b	13.66edc
T14	4638.30c	16.24bac	3506.30ed	6.53e	6360.30b	12.50e
T15	4931.30bac	16.18bac	4540.00edc	8.70dec	6896.30ba	14.46bedc
T16	5525.70ba	17.57a	6972.10ba	14.03ba	7958.70a	16.9bac
LSD	844.07	1.98	1937.8	3.69	1592.5	3.0972
CV	10.15	7.59	21.78	21.7	15.16199	13.09895

GY=grain yield, BY=biomass yield

Fig.1 Map of the study area

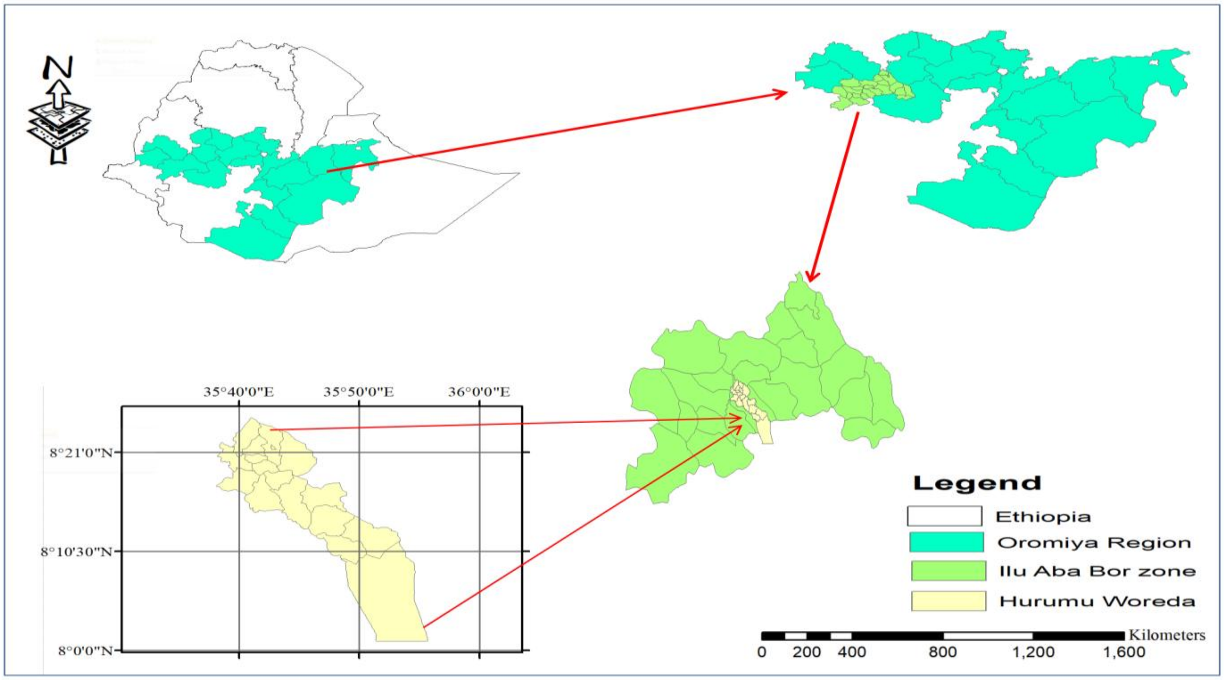


Fig.2 Initial soil results

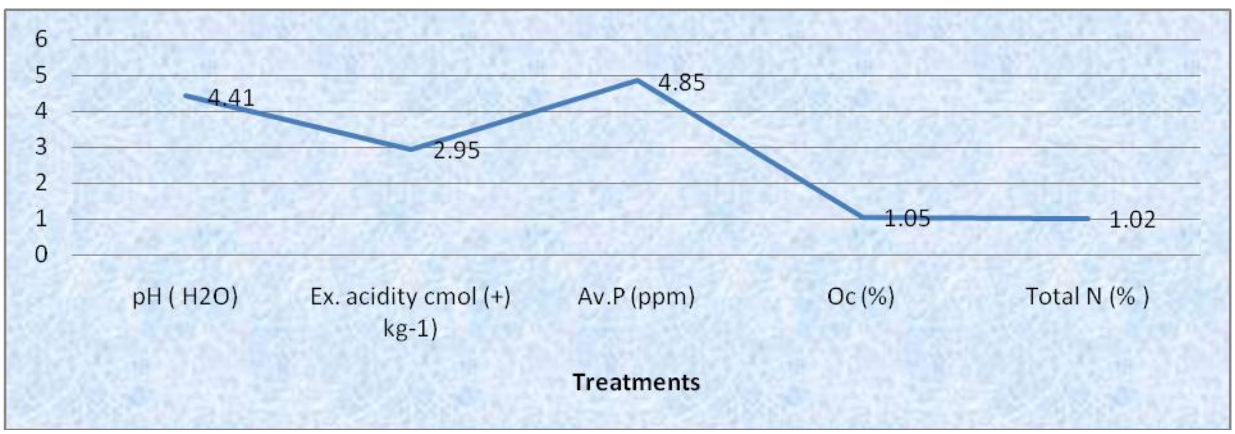


Fig.3 Effect of lime and different Phosphorus source fertilizers on chemical properties of soil on maize crop farm

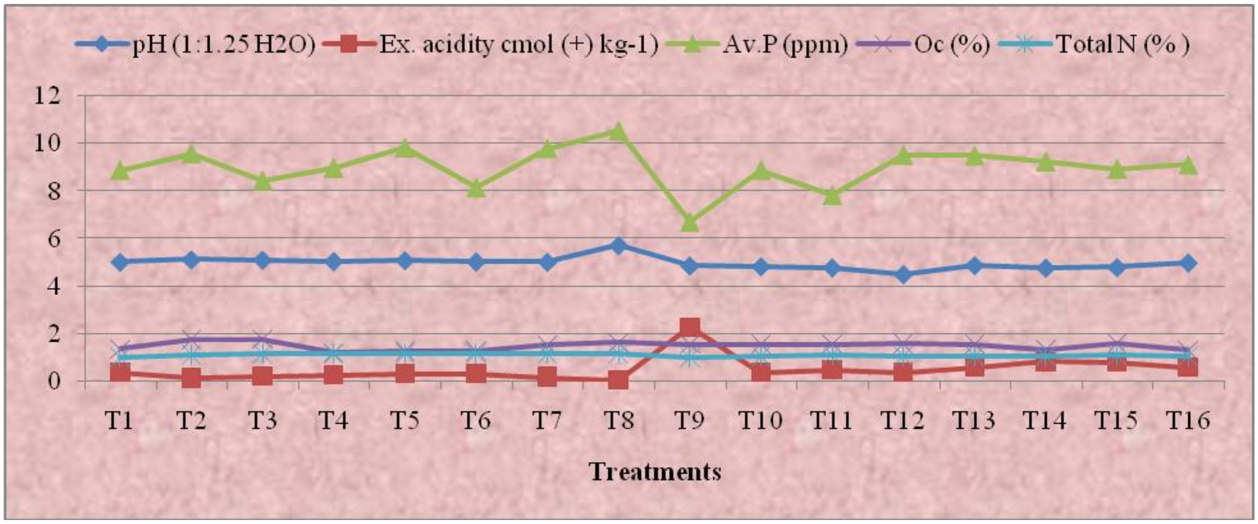
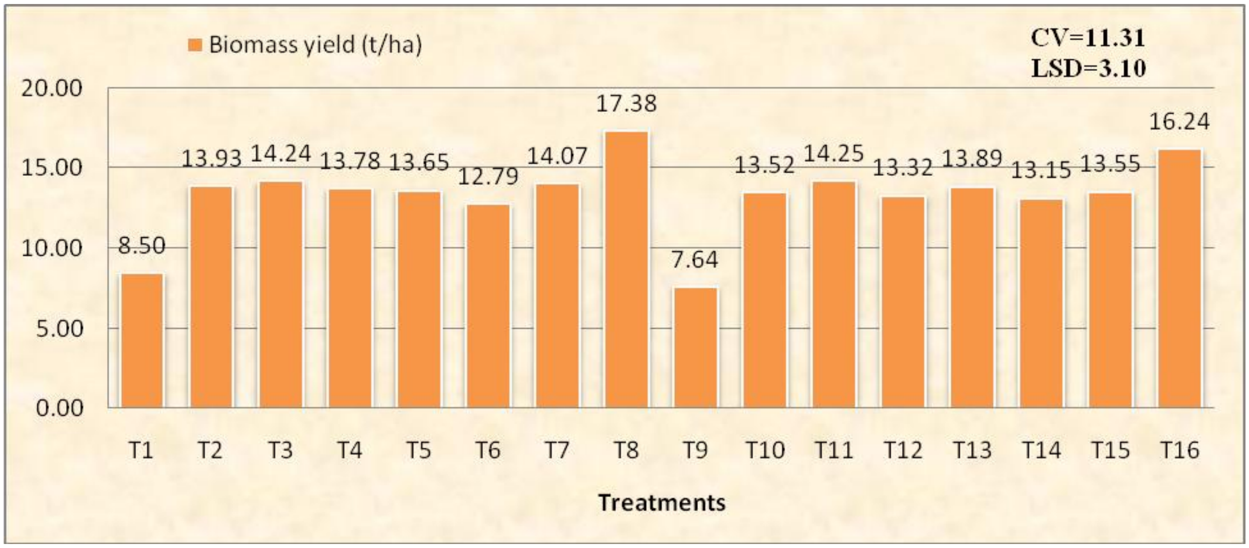


Fig.4 Total mean grain yield kg/ha 2016-2018

Fig.5 Total mean biomass yield t/ha 2016-2018



Lime reduces the levels of exchangeable Al3+, Fe3+ and Mn4+ in acid soils and thus reduces P sorption. This makes both the native soil P and applied P fertilizers available for plant uptake (Fageria and Baligar, 2008).

Effects of lime and deferent Phosphorus source on grain and biomass yield

Maize grain yield in the cropping year 2016 was highly significantly (P<0.01) affected with the application of lime and different phosphorus sources. The maximum maize grain yield 5756.00kg/ha and 5756.00 kg/ha recorded from the treatments Lime*2/3 Recommended phosphorus from (G PAPR 20 +Zn + B) and Lime*2/3 Recommended P from (MOHP +Zn +B) respectively (Table 2).The analysis of variance indicated highly significant (P<0.01) biomass yield differences due to the application of lime and different phosphorus source at all cropping years (Table 2). In the cropping year of 2016 the maximum 5759.30 kg/ha 17.92 t/ha, 17.78 t/ha and 17.57 t/ha were recorded from Lime* Recommended Phosphorus from NAFAKA + (NPK +CaO +S +MgO +Zn +B), Unlimed*NPSZnB (positive control) and Lime * NPSZnB (positive control) treatments respectively (Table 2). The minimum maize biomass yield 7.53t/ha and 8.74 t/ha was recorded from Lime*Control (Negative control no phosphorus only lime) and Unlimed*Control (Negative control no lime and phosphorus) (Table 2).In the cropping year 2017 there was a significant (P<0.01) difference grain and biomass yield among the treatments. The maximum grain yield 7418.00 kg/ha and biomass yield 14.60 t/ha was recorded from Lime*NPSZnB (positive control) (Table 2). While the lowest maize grain yield 7418.00 kg/ha and biomass yield 6.403 t/ha was recorded from Lime*Control (Negative control no phosphorus only lime) (Table 2). Similarly in 2018 cropping year there is a significant (P<0.01) difference between the treatments. The maximum grain yield 8166.70kg/ha and 7958.70 kg/h and biomass yield 19.96 t/ha were recorded from the treatments Lime*NPSZnB (positive control) and Unlimed*NPSZnB (positive control) respectively (Table 2).

The combined three year (2016-2018) mean analysis data showed there was significant (P<0.01) difference among lime and different phosphorus sources. The maximum grain yield 7036.80kg/ha (Figure 4) and biomass yield 17.38 ton/ha (Figure 5) was recorded from the Lime*NPSZnB (positive control). The main plot treatments which was lime applied gave the maximum grain yield kg/ha as compared with unlimed treatments (Table 4 and 5).

Recommendation

The field experiment was conducted from 2016-2018 cropping years at MetuHurumu on maize crop to evaluate the effects of different phosphorus fertilizer sources with lime application on maize yield and soil chemical properties under acidic Nitisols soil. The result revealed the combined three year (2016-2018) mean analysis data showed there was significant difference among lime and different phosphorus sources. The maximum grain yield 7036.80 kg/ha and biomass yield 17.38 ton/ha was recorded from the Lime*NPSZnB (positive control). There was also the maximum grain and biomass yield was obtained from different phosphorus sources under limed treated plots as compared with unlimed and negative control treatments but statically not significant. In general, from the evaluated different inorganic phosphorus fertilizer sources NPSZnB (positive control) with lime treated plot gave the maximum mean grain and biomass yield as well as enhanced the available phosphorus of soil.

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