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# Investigating the Synergetic Effect of Lime and NP Fertilizers on Maize Productivity and Selected Soil Chemical Properties of Acidic Soils of Western Ethiopia

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**Abstract:** Land and crop productivity are declining while soil acidity is increasing in Ethiopia. Decline in soil fertility may also occur because of nutrient depletion and mining, which should be partly attributed to complete removal of crop residues from farm lands. A five-years field study was conducted at Gute kebele, Wayu Tuka ditrict of western Oromia Regional National State during 2012-2016 cropping seasons to investigate the combined effect of lime and NP on maize grain yield and some chemical properties of soil and to identify sparingly viable mixes of lime and NP fertilizer in improving maize productivity, acidic properties and nutrient content of the soil. The experiment involved four levels of lime (1.86, 2.79, 3.72 and 4.65 t $ha^{-1}$) and four NP rates (27.5/11.5, 55/ 23, 82.5/34.5 and 110/46 kg $NP_2O_5$) combined in factorial arrangement with two positive and one absolute/control, constituting a total of nineteen treatments laid out in RCBD with three replications. The results of the study showed that seed yield was affected by the interactions of lime by NP fertilizer application in which the highest grain yield (7.29 tons $ha^{-1}$) was recorded from the use of 110/46 kg $NP_2O_5$ of NP fertilizer and 4.65 t $ha^{-1}$ (125% lime recommended). In other perspective, the soil laboratory analytical result after harvest showed that the highest soil pH (5.79) was recorded from the combination of 4.65 t $ha^{-1}$ of lime and 82.5/34.5 kg $NP_2O_5$. In similar manner, the exchangeable acidity was significantly reduced to 0.78 cmol (+) $kg^{-1}$ due to application of the above mixes of lime and NP that improved the potential acidity level of the soil by 242%. The highest soil available P (20.11 mg $kg^{-1}$ of soil) was recorded from the plot that received 3.72 t $ha^{-1}$of lime by 110/46 kg $NP_2O_5$. Eventually, the result of the study inferred that liming intervention should be made at optimal level with recommended $N/P_2O_5$ fertilizer to keep soil acidity and soil nutrient level in check for sustainable maize production in acid prone areas of the country.

**Key words:** Acid Soil・Exchangeable Acidity・Nutrient Content・Grain Yield

## INTRODUCTION

Maize is cultivated globally as one of most important cereal crops and ranks third next to wheat and rice. The total world production of maize is 1, 107.38 MT, with the United States producing 366.29 MT, China 257.33 MT, Brazil 96.0 MT, European Union 63.0 MT, South Africa 11.0 MT and Ethiopia harvesting 7.1 MT of the total production of maize [1]. In Ethiopia by 2017/18 main cropping season, out of the total grain crop area (12, 574, 107.3 hectare (ha)) 80.7% was under cereals of which maize share 16.8% [2]. Regarding total annual production, cereals contributed 87.4% (25, 384, 723.96 tons (t)) in which maize ranked first 27.4% (8, 395, 887.24 t) [2]. However, national average yield in Ethiopia is still as low as 3.94 t $ha^{-1}$ (CSA, 2018) compared to that of the developed world 11.07 t $ha^{-1}$ [1].

Land and crop productivity are declining while soil acidity is increasing in Ethiopia. Mono-cropping, removal of basic cations by crops and leaching, continual and inappropriate use of acid forming inorganic fertilizers and soil erosion have been threats to soil fertility and has been drastically reducing maize crop yields [3]. Decline in soil fertility may also occur because of nutrient depletion and mining, which should be partly attributed to complete removal of crop residues from farm lands for

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their competitive use as fuel-wood, construction etc. These factors lead to progressively lower crop yields, increased costs of production and may end up with land abandonment [4].

Acid soil infertility which has become a serious threat to crop production in most highlands of Ethiopia specifically in western part of the country caused by leaching of exchangeable cations ($Ca^{2+}$, $Mg^{2+}$, $K^{+}$) and accumulation of high concentration of Al and other soil fertility degradation attributes are the main factors that adversely affect maize production in the country [5]. Different researchers reviewed those reddish-brown soils of the Ethiopian highlands are highly deficient in phosphorus (P) which is induced by the acidic nature of the soil. Gupta *et al*. [6] reported that poor fertility of acid soil is due to a combination of mineral toxicities (Al, Mn and Fe) and nutrient deficit caused by leaching of P, Ca, Mg and micronutrient such as Mo, Zn and B. Considerable grain yield reductions of maize under low soil pH have been reported in numerous studies. Hayati *et al*. [7] noted that grain yield reduction in acid soils varied from 2.8 to 71%. Also, Tandzi *et al*. [8] found maize yield reduction under acid soils to be up to 69%.

Acidic unproductive soils can be corrected by liming to reduce its acidity to attain its production potential. This makes the soil environment better for crop and beneficial microorganisms as well as increase availability of essential plant nutrients by raising its pH and precipitating exchangeable Al [9]. The amount of lime required adjusting the pH of the soil and its change over time in response to lime application depends upon the soil type, initial pH value of the soil and lime quality [10]. The other factor that determines lime rate of the soil is the exchangeable acidity of the soil. Thus, the purpose of the present study was to investigate the combined effect of lime and commercial NP fertilizers on soil and maize crop productivity on acidic soils of western Ethiopia.

## MATERIALS AND METHODS

**Site Description:** The study was conducted at Gute kebele, Wayu Tuka ditrict of western Oromia National Regional State for five years starting from 2012 cropping seasons. The experimental field is located at Latitude: 9.003 N and Longitude: 36.63 and at an altitude of 2030 m above sea level (Figure 1). The location has warm humid climate with annual mean minimum and maximum air temperatures of 11.9 and 24°C, respectively. The study area has an average ambient humidity of 60%, wind speed of 96 km/hr., sunshine of 6 hours/day and radiation of 17.8 $MJ/m^2/day$. The area received average annual rainfall ranging from 886 to 1635 mm which extends from May to September with maximum precipitation being received in the months of June to August (Bako Agricultural Research Center Metrological Station). The soil of the experimental site was reddish-brown; Nitisol, which is very strongly acidic in reaction with a pH range of 4.5-5.4 according to the rating by Jones [11]. The area is a mixed farming zone and is one of the most important maize (*Zea mays* L.) growing belts in Ethiopia, in which cultivation of soybean (*Glycine max* L.), finger millet (*Eleusine coronata*), common bean (*phoseolus vulgaris* L.), sesame (Sesamum indicum) and to some extent tef (*Erograstis tef*), are common.

**Soil Sampling and Analysis:** Soil samples were collected (0–20 cm) from the whole experimental field before lime application and from every experimental unit after each harvesting season randomly in zigzag pattern using an auger. Soil samples were air-dried; gravels and non-decayed plant debris were removed and were ground to pass through 2 mm screen prior to analysis. Soil particle size distribution was analyzed by the hydrometer method [12]. Soil pH was determined potentiometrically using pH meter with combined glass electrode in a 1:2.5 soil to water supernatant suspension [13]. The base titration method which involves saturation of the soil sample with 1 M KCl solution and titrating with sodium hydroxide was employed to determine exchangeable acidity as described [14]. Available soil phosphorus was extracted by the Bray II procedure [15] and determined calorimetrically by spectrophotometer.

**Lime Rating and Fertilization:** The chief source of disorder in soil health and soil nutrient balance brought about by the major causative agents of soil acidity is illustrated by the resultant elemental toxicity effect of the acidic cations (Ex. Aluminum and Ex. Hydrogen). In effect, the essence of lime and other amendments are primarily aims at the elimination or suppression of these cations from the soil medium [16].

In accordance to this perception, the amount of lime was determined based on the soil's exchangeable acidity ($Al^{+3}$ plus $H^{+1}$) and bulk density with in 0.15m depth of the soil (Eq. 1) adapted from [17] for liming acid mineral soils assuming that one mole of exchangeable acidity would be neutralized by equivalent mole of $CaCO_3$.

$$LR, CaCO_3\ (kg/ha) = \frac{cmolEA/kg\ of\ soil * 0.15\ m * 10^4\ m^2 * B.D.(Mg/m^3) * 1000}{2000} \qquad \text{(Eq. 1)}$$

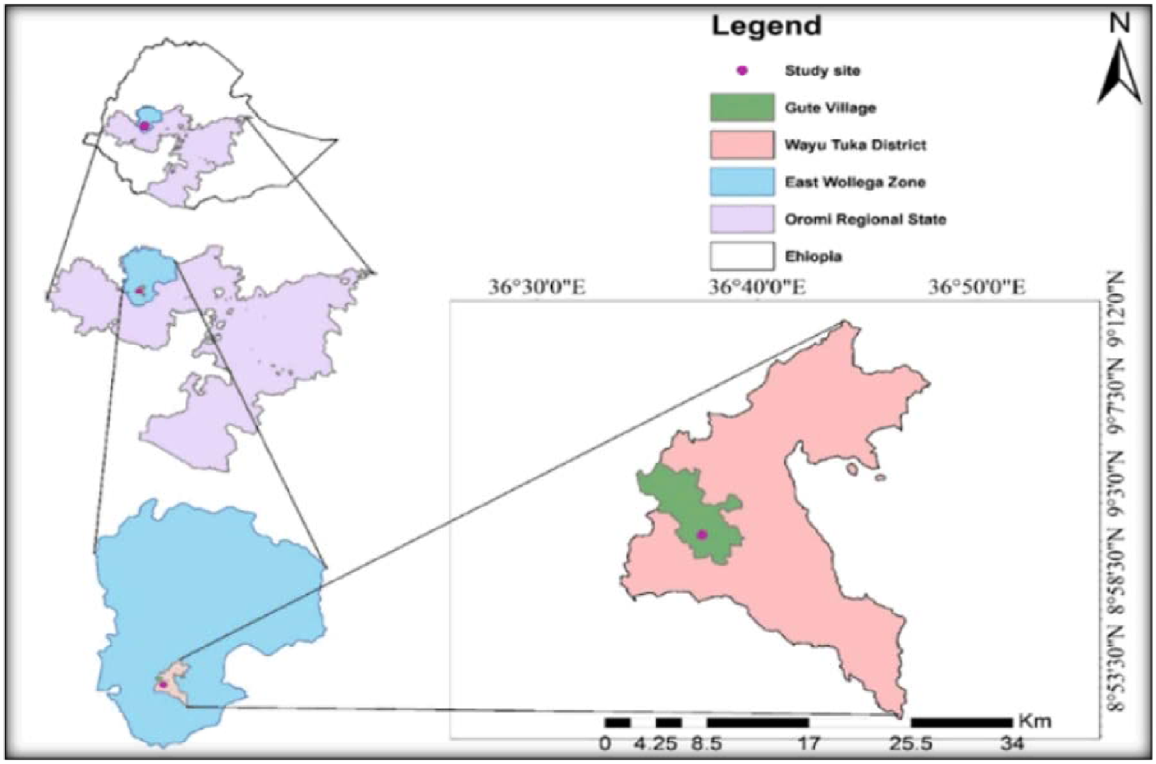


Fig. 1: Location map of the study area: Gute sub-site of BARC

Soil acidity ameliorant used in the experiment was calcite limestone ($CaCO_3$) obtained from Senkele limestone crushing factory found in western Oromia, while, the N and P fertilizer sources were Urea and DAP (Di-ammonium Phosphate).

**Experimental Design, Treatments and Procedures:** The experiment comprised four levels of lime (1.86, 2.79, 3.72 and 4.65 t $ha^{-1}$) which represented 50%, 75% 100% and 125% recommended amount of lime respectively and four NP rates (27.5/11.5, 55/23, 82.5/34.5 and 110/46 kg N/$P_2O_5$ respectively) combined in factorial arrangement, two independents positive controls (full lime rate with no fertilizer and 110/46 kg $NP_2O_5$ with no lime) and one absolute control, altogether constituting of a total 19 treatments which was laid out in RCBD with three replications. The fertilizer rate was fixed on the basis of the result of the fertilizer trials conducted on different varieties of maize over years by the agronomy research case team of Bako Agricultural Research Center (BARC). The linear model for the two Factor Randomized Complete Block Design (RCBD):

$$Yijk = \mu + \alpha I + \beta I + \Upsilon k + \alpha\Upsilon ik + \varepsilon ijk \qquad \text{(Eq. 2)}$$

where, $Y_{ijk}$ – the value of the response variable; μ - Common mean effect; $\alpha_I$ – Effect of factor A; $\beta_I$ – Effect of block; $\Upsilon_k$ – Effect of factor B; $\alpha\Upsilon_{ik}$ – Interaction effect of factor A & factor B and $\epsilon_{ijk}$ – Experiment error (residual) effect.

Lime was surface applied and incorporated in the soil by hand 45 days before planting in the initial year of the experiment. The test crop was a maize variety BH-660, planted at intra and inters spacing of 75*30 cm in gross plot area of 5.1*4.5 m. The P fertilizer was band applied at planting in rows while the N fertilizer was applied in two splits where one half was applied at planting and the remaining was supplemented when the plant reached to knee height.

Net plot area of 12.8 $m^2$ was used for crop data collection at harvesting when 95% of the plants reached harvestable maturity. At physiological maturity, grain yield was recorded from each net plot area where the moisture content of the seed was determined for each treatment and adjusted to 12% moisture content, a standard as recommended by Biru [18] using the formula:

$$ASW(g) = (RSW * 100 - M) / (100 - D) \quad \text{(Eq. 3)}$$

where: RSW- Adjusted seed weight, RSW- Recorded seed weight, M is the measured moisture content and D is the standard moisture content (12%) for cereal crop [19].

**Statistical Analysis:** Data were analyzed using SAS version 9.3 [20]. Computer software and were subjected to ANOVA to determine significant differences among factors and their interactions. Means were separated using LSD test at 0.05 significance level.

## RESULTS AND DISCUSSION

**Selected Soil Properties Before Lime Amendment:** The results for soil analysis before treatment application are indicated in Table 1. According to the laboratory analytical result, the soil of the study area was sandy clay loam in texture, very strongly acidic in reaction as rated by Tekalign *et al.* [21] and low in Available P which is probably attributed to high P fixing capacity of the soil at the area. Finally, the acidic nature of the soil which can be toxic to plants and hence can depress their growth and the lower proportion of P that can potentially affect crop performance signifies that the soil needs acidity adjustment and requires application of P fertilizer source to sustain crop production.

The interaction effect of lime and NP fertilizer on selected chemical property of the soil

**Soil pH, Exchangeable Acidity and Exchangeable Aluminum:** Soil laboratory test result analyzed after harvest is depicted in Table 2. The result showed that the combined use of lime and NP fertilizer increased soil pH and exchangeable acidity. The highest soil pH (5.79) was recorded from the combination of 4.65 t $ha^{-1}$ lime and 82.5/34.5 kg $NP_2O_5$ which exhibited an increment of 21.63% over the absolute control. Conversely, the exchangeable acidity was significantly reduced to 0.78 $cmol_{(+)}$ $kg^{-1}$ due to application of slightly over optimal dose of lime (4.65 t $ha^{-1}$) and three quarter of recommended NP (82.5/34.5 kg $NP_2O_5$) that improved the potential acidity level of the soil by 242%. The exchangeable Al of the soil before the lime treatment application have dropped from 1.80 $cmol_{(+)}$ $kg^{-1}$ to 0.36 $cmol_{(+)}$ $kg^{-1}$ showing an improvement of 400% in suppressing the elemental toxicity of this acidic cation. This is to be expected because lime is universally known to influence soil chemical properties: the exchangeable Al and $H^+$ that dominated the soil's exchange site drastically reduced, the soil pH increased, these all contributed to raises available P, CEC and Ca. The result of this study is in agreement with Anetor and Akinrinde [22] who indicated that lime at various levels had a significant effect on soil properties, where Soil pH, extractable acidity (EA), available P, increased, whereas exchangeable acidity (Ac) and exchangeable Al (exAl) decreased significantly with an increase in lime application.

The observed decline in soil pH and the associated soil acidity attributes pertaining to the fertilizer only treatment in the study site could be attributed to the addition of $H^+$ ions from ammonium containing mineral fertilizers. This is in agreement with the study of Zeleke *et al.* [23] and corroborates with findings of Mugendi *et al*. [24], Mucheru-Muna *et al*. [25] who reported a general reduction in pH after application of mineral fertilizer. However, it is inconsistent with other studies that reported P can reduce exchangeable acidity by precipitating the Al in solution [26]. The result of this study is in conformity to the observation of Buni [27] who reported that soil pH increased from 5.03 to 6.72 and exchangeable acidity (Ac) reduced due to the application of 3.75 t $ha^{-1}$ lime on Nitisol with an inherent property of high P fixation in southern Ethiopia. A concordant examination was done by Desalegn *et al.* [28] which showed that Application of 0.55, 1.1, 1.65 and 2.2 t lime $ha^{-1}$ decreased $Al^{3+}$ by 0.88, 1.11, 1.20 and 1.19 $cmol_{(+)}$ $kg^{-1}$soil and increased soil pH by 0.48, 0.71, 0.85 and 1.1 units, respectively. Furthermore, Geremew *et al*. [29] studied the effect of lime and P on acidic Nitosls of welmera district and indicated that applied lime neutralized the acidity and increased pH, lowered the exchangeable acidity and Al. The findings observed on soil pH and the exchangeable Al changes in soil from this study agree with the findings of many authors [30- 32] who reported the increase of 0.4 to 0.9 units of soil pH and the reduction of exchangeable Al and Al saturation was observed after lime application in acidic soil.

**Soil Available Phosphorus:** The result of the current study has shown that soil available P was affected by the interaction of lime and NP fertilizers (Table 3). The highest soil available P (20.11 mg $kg^{-1}$ soil) was recorded from the plots treated with recommended lime (3.72 t $ha^{-1}$) and 100 % recommended NP (110/46 kg $NP_2O_5$). However, not statistically different from the rest of NP applied treatments. While the lowest soil available P (11.64 mg $kg^{-1}$ soil) content was recorded from the absolute control (Table 3). This sizeable increase in available P could have been caused by quick action of lime in improving soil acidity and enhancing microbial activity for mineralization of soil available organic P when pH increased [9].

Table 1: Some physicochemical properties of the soil of the site before commencement of the experiment

| Parameters | Test Result |
|---|---|
| pH $H_2O$ (1:2.5) | 4.65 |
| Available phosphorus (ppm) | 7.52 |
| Sand (%) | 48.3 |
| Clay (%) | 36.4 |
| Silt (%) | 15.4 |
| Textural Class | Sandy clay loam |
| Bulk density(g/cm$^3$) | 1.33 |
| Exchangeable acidity (cmol$_{(+)}$kg$^{-1}$ soil) | 2.8 |

Table 2: Mean soil acidity attributes as affected by the interaction of lime and NP fertilizer applied

| Treatments | | | | |
|---|---|---|---|---|
| Lime (t ha$^{-1}$) | N/$P_2O_5$(kg ha$^{-1}$) | pH-$H_2O$ (1:2.5) | Ac (cmol $_{(+)}$kg$^{-1}$) | ExAl. (cmol $_{(+)}$kg$^{-1}$) |
| 0 | 0 | 4.76 | 2.67 | 1.8 |
| 3.72 | 0 | 5.51 | 0.94 | 0.62 |
| 0 | 110/46 | 4.83 | 2.37 | 1.43 |
| 1.86 | 27.5/11.5 | 4.97$^{c-e}$ | 1.34c-f | 0.79de |
| | 55/ 23 | 4.95$^{de}$ | 2.06ab | 0.81bc |
| | 82.5/34.5 | 5.05$^{b-e}$ | 1.56cd | 0.92bc |
| | 110/46 | 4.89$^{e}$ | 2.41a | 1.18a |
| 2.79 | 27.5/11.5 | 5.24$^{b-e}$ | 1.52c-e | 0.95cd |
| | 55/ 23 | 5.30a-e | 1.09d-g | 0.81d-f |
| | 82.5/34.5 | 4.98c-e | 1.60bc | 0.83b |
| | 110/46 | 5.14a-e | 1.23fg | 0.75f-h |
| 3.72 | 27.5/11.5 | 5.57a-e | 1.08d-g | 0.82f-h |
| | 55/ 23 | 5.41a-c | 0.84g | 0.74gh |
| | 82.5/34.5 | 5.33a-e | 1.05e-g | 0.76e-g |
| | 110/46 | 5.19a-e | 1.14fg | 0.65 e-g |
| 4.65 | 27.5/11.5 | 5.33a | 0.82g | 0.30gh |
| | 55/ 23 | 5.54$^{ab}$ | 0.81g | 0.32gh |
| | 82.5/34.5 | 5.79$^{ab}$ | 0.78g | 0.36h |
| | 110/46 | 5.37$^{a-d}$ | 0.79g | 0.39f-h |
| CV (%) | | 6.83 | 36.7 | 23.41 |
| LSD (0.05) | | 0.25 | 0.5 | 0.17 |

LSD-Least Significance Difference, Ac - Exchangeable Acidity, ExAl - Exchangeable Aluminum. Means within a column followed by the same letter (s) are not significantly different.

Table 3: Available soil Phosphorus (ppm) as affected by the interaction of lime application and NP fertilizer

| | Lime rate (ton ha$^{-1}$, % recommendation) | | | | |
|---|---|---|---|---|---|
| Fertilizer rate N $P_2O_5$ Kg ha$^{-1}$, (% recommendation) | 1.86 (50%) | 2.79 (75%) | 3.72 (100%) | 4.65 (125%) | No lime |
| 27.5, 11.5 (25%) | 17.03c | 16.75c | 17.61a-c | 16.82c | |
| 55, 23 (50%) | 17.90a-c | 18.50a-c | 17.56a-c | 17.36bc | |
| 82.5, 34.5 (75%) | 16.51c | 17.68a-c | 18.19a-c | 19.16ab | |
| 110, 46 (100%) | 17.17c | 17.14c | 20.11a | 18.76a-c | 18.04 |
| No fertilizer | | 15.74 | 11.64 | | |
| CV (%):19.06 | | | | | |
| LSD (5%): 2.7 | | | | | |

LSD (0.05) = Least Significance Difference at 5% of Probability level, Av. P = Available Phosphorus. Means within a column followed by the same letter (s) or with no letter are not significantly different

The observed increase in soil P levels through use of liming materials which could be attributed to reversal effect of acidic soils that are deficient in available P since significant portions of applied P are immobilized in low pH levels due to precipitation of P as insoluble Al phosphates. Similar observations were reported by Derib [33] indicating that fertilizer and lime resulted in higher soil P availability than where either of them was applied alone.

Kisinyo *et al*. [34] attributed this to reduced P sorption by lime making both the native and P fertilizer available for plant absorption. Increasing lime rates relatively increased soil pH and exchangeable bases thereby reducing the magnitude of soil acidity, exchangeable acidity and Al saturation [32].

The response observed with application of the fertilizers (with or without lime) confirms that both N and P are deficient at the study area and fall under the category of responsive soils [35]. The increase in P associated with pH with an increase in lime rate might be due to an increase in hydroxide ions that in turn supported greater microbial activity resulting in greater decomposition and increased mineralization of soil organic matter releasing humic acids and reduced P associated with Al and Fe and their oxyhydroxides. The trends observed in this study, at low soil pH there is no significant increase in P, followed by an increase as pH increases due to liming, are in agreement with the results of Haynes [36], Miles and Farina [37].

Another reason for this scenario might be the effect of P fertilizer which is better extricated from fixation as insoluble phosphates due to the lime conditioned environment of the soil. Similar observation was made by Girma and Zeleke [38] that implies application of the recommended amount of p fertilizer builds-up the soil P critical value and maintains its concentration at optimal level. In line with this result, Kisinyo *et al*. [39] pointed out that both lime and P fertilizer applications are important to enhance soil available P in acid and P deficient soil. Similarly, Fageria *et al.* [40] reported an increase of soil P as pH increased due to liming from 5.0 to 6.5, due to release of P ions from Al and Fe oxides, which are responsible for P fixation. Anetor and Akinrinde [22] reported that unamended soil remained acidic (pH 4.8), but liming raised pH (6.1-6.6) and resulted in maximum P release (15.1-17.3 mg $kg^{-1}$) compared to un-amended soil (4.2-7.1 mg P $kg^{-1}$).

**Combined Effect of Lime and NP Fertilizer on Maize Grain Yield:** The result of the combined effect of lime and NP fertilizer is depicted in Figure 2. The analysis result showed that grain yield of maize was significantly ($P<0.05$) affected by interaction of lime with NP fertilizer application. A combination of lime and NP fertilizer at the rate of 4.65 t $ha^{-1}$ and 110/46 kg $ha^{-1}$ $N/P_2O_5$, respectively resulted in higher grain yield than that with lime or $N/P_2O_5$ used independently. The highest significant grain yield (7.29 t $ha^{-1}$) was recorded from the use of optimal (100% rec.) amount of $N/P_2O_5$ with slightly over optimal (125% rec.) level of lime which have a grain yield advantage of 114% than the absolute control, where the lowest grain yield (3.40 t $ha^{-1}$) was recorded. This could be due to lime that reduced the exchangeable acidity (neutralizing the effect of $Al^{3+}$ and $H^+$) and raising the soil pH, enhanced maize growth performance, affected the solubility and availability of most of the plant nutrients (exchangeable base) and improved soil structure. The results of the present study is in compliance with the work of Opala *et al*. [41] who had reported the highest seed yield (7.15 t $ha^{-1}$) of maize from the combination of the recommended amount of lime and NP fertilizer. Analogous investigation on maize by Manoj *et al*. [42] illustrated that liming had beneficial effects on maize yield which suggest that liming along with integrated nutrient management practices, if adopted properly, can lead to more than three-fold increase in maize productivity on acidic soils of Meghalaya and other north-eastern states of India with similar soils.

The seed yield (4.55 t $ha^{-1}$) obtained from the experimental plot that received recommended lime alone (4.79 t $ha^{-1}$) was lower than that of the plot treated with sole recommended NP; however, the value was higher than that of the absolute control (3.40 t $ha^{-1}$), which showed an increment of 1.15 t $ha^{-1}$. Comparable discoveries have been reported by Kibet *et al*. [43] who found significant effects of lime and NP fertilizer on grain yields and indicated that treatments with sole lime performed better than the absolute control. The positive effects of lime on maize productivity could be due to liming which increased soil nutrient availability through mobilization of P and organic N mineralization by microbial activity in which more crop nutrient demands were met. Similar reports by Geremew *et al*. [29] indicated that crops responded to combined application of lime and fertilizers in acid soils. This result is also in concordance to the finding of Adane *et al*. [44], who reported that the mean grain yield of maize was significantly affected by application of blends of N and P fertilizers. Hengl *et al.* [45] also explained that a 26% increase in average yield was achieved form the inorganic NP fertilizer treatment alone, up to five times for the combined fertilizer and lime treatment and an increase of 48% was observed for the sole lime experimental unit, revealing that liming alone cannot serve to achieve the maximum potential of an acid soil. The other premise hypothesized prior to commencement of this field trials was that effects on yield could also be explained by a nutrient addition effect of lime at play, whereby the different treatments result in an increase in essential soil and plant macro and micronutrients which in turn improve maize yield [46].

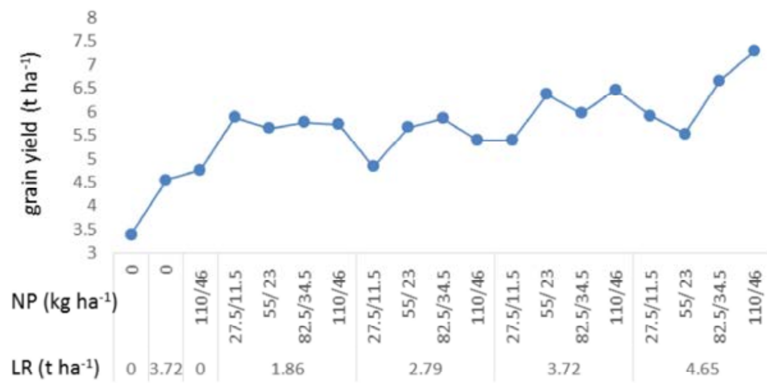


Fig. 2: The combined effect of lime and $NP_2O_5$ on maize grain yield

In the final analysis, the finding of this experiment postulates that the higher doses of these inputs increased maize seed yield, soil pH and available P and decreased exchangeable acidity and Al than lower ones, suggesting that liming intervention should be made at optimal level with recommended $N/P_2O_5$ fertilizer to keep soil acidity and soil nutrient level in check for sustainable maize production in such acidic soil belt areas of the country

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