Effect of Lime and Phosphorus Fertilizer on Acid Soil Properties and Sorghum Grain Yield and Yield Components at Assosa in Western Ethiopia

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Acidic soils limit the production potential of sorghum crop because of low availability of basic cations and excess of hydrogen (H⁺) and aluminium (Al³⁺) in exchangeable forms at Assosa. Experiments were conducted to evaluate the response of acid soil properties and sorghum to lime and Phosphorus fertilizer around Assosa area during 2012-2015 cropping seasons. Five levels of lime (0, 1.88, 3.76, 5.64 and 7.52 t ha⁻¹) and four levels of P (0, 23, 46 and 69 kg ha⁻¹) laid out in randomised complete block design with three replications. Analysis of variance revealed that the interaction effect of lime and phosphorus fertilizer significantly (P≤0.05) affected head weight, straw and grain yield of sorghum. The highest grain yield of sorghum was obtained from 5.65 t lime ha⁻¹ with application of 23, 46 and 69 kg P₂O₅ ha⁻¹ and 7.54 t lime ha⁻¹ with application of 0, 23 and 46 kg P₂O₅ ha⁻¹ treatments. The partial budget analysis also indicted that 1.88 t lime ha⁻¹ along with 23 kg P₂O₅ ha⁻¹ gives higher net benefits. Therefore, the management of P- deficient acid soils of Assosa area requires combined applications 1.88 t lime ha⁻¹ with application of 23 kg P₂O₅ ha⁻¹.

Key words: soil acidity, sorghum, lime, Phosphorus fertilizer, yield

INTRODUCTION

Sorghum is the dominant and one of the primary staple food crops next to teff and maize in many regions of the country (CSA, 2016). It provides more than one third of the cereal diet and is almost entirely grown by subsistence farmers to meet needs for food, income, feed, brewing and construction purposes in Ethiopia (McGuire, 2007). Sorghum grain is mostly used for domestic markets and most of the sorghum produced in Ethiopia is consumed at household levels. It is the second most important crop for injera quality next to teff (Asfaw, 2012). The grain is also used for the preparation of other traditional foods and beverages like tella and areke.

Ethiopia is the third largest producer of sorghum in Africa next to Nigeria and Sudan with a contribution of about 12% of annual production (Wani et al. 2011) and the second after Sudan in the Common Market for Eastern and Southern Africa (COMESA) member countries (USAID, 2010). While sorghum took the largest cultivated land, the productivity per unit area is very low. The national average productivity of sorghum in Ethiopia is 2331 kg/ha (CSA, 2016) which is far below the global average of 3200 kg/ha (FAO, 2005). Several production constraints were identified as hindrance for sorghum production and productivity enhancement. The major constraints include soil fertility decline (soil acidity), Striga, insect pests (stalk borer, midge, and shoot fly), disease (grain mold, anthracnose and smut), birds (Quelea quelea), inadequate adoption of the existing improved varieties, limited number of high yielding and farmer preferred sorghum varieties. Soil acidity is considered to be one of the major bottlenecks to barley production in the highlands of Ethiopia.

In Ethiopia, acidity-related soil fertility problems are the main production constraints, reducing productivity of major crops grown in the country (Paulos, 2001; IFPRI, 2010). About 41% of the total land area of the country has acidic...
reaction while, 33% of the soils in these areas have Al toxicity problem (Schlede, 1989). Soil nutrient depletion, erosion and leaching of basic cation are also very widespread crop production constraint in Western Ethiopia (Taye, 2001). In the western part of the country such as Assosa, Illubabor and Wollega, soil acidity is a well-known problem limiting crop productivity.

Soil acidity is one of the most important soil factors which affect plant growth and ultimately limit crop production and profitability (Mesfin, 2007). The problem is common in all regions where precipitation is high enough to leach appreciable amounts of exchangeable bases from the soil surface (Achalu et al., 2012). when soil pH is < 5.5, it affects the growth of crops due to high concentration of aluminum (Al) and manganese (Mn), and deficiency of P, nitrogen (N), sulfur (S) and other nutrients (Abreha, 2013). Several agricultural practices have been recommended to overcome the problem of tropical acid soil infertility worldwide. Amongst them, the most common and widely used method is liming, which is defined as the application of ground calcium and/or magnesium carbonates, hydroxides and oxides aiming at increasing the soil pH, modifying its physical, chemical and biological properties (Edmeades and Ridley, 2003). Because of its great ameliorative effect, lime is commonly called the foundation of crop production or ‘workhorse’ in acid soils (Fageria and Baligar, 2008).

Although P is known to be the master key to agriculture, lack of available P in the soil limits the growth of both cultivated and uncultivated plants (Foth and Ellis, 1997). In these soils, the amount of readily available phosphorus (P) in the soil is very low compared with the total amount of P. Tropical and subtropical soils are predominantly acidic with high P fixation capacities and often are extremely P deficient (Mamo, 2011). Most soils of the highlands are characterized by soil acidity and high P fixation due to intensive weathering and leaching attributed to high rainfall. In the past, soil acidification affected large areas of Ethiopian highlands and this situation now has the potential to worsen in the country (EATA, 2013). Particularly, soil acidity is becoming a serious threat to crop production in the areas of the western, southern and central highlands of Ethiopia (Wassie et al., 2009). This low availability of P under most soils of Ethiopia is due to the impacts of P fixation by acidic cations, abundant loss of P by crop harvest, erosion and the inherent P deficiency of the soils by application of little or no P source fertilizers (Asmare, 2014). Numerous studies demonstrated the synergetic effect of lime and P fertilizers. However, there is no or scarce investigation that has been carried out on major crops grown on acid soils of Benishagul Gumuz. Therefore, putting the above points in view, the present study was initiated to evaluate the response sorghum to lime and P fertilizer rate and its effect on acid properties of the soil around Assosa area.

MATERIALS AND METHODS

Description of the study area

This experiment was conducted at Assosa District during the main rainy season of 2012 to 2015. The study sites are found in the altitude ranging between 1300-1470 m.a.s.l. with mean minimum and maximum temperatures of 14.38 and 28.55 °C, respectively. The area receives an average annual rainfall of 1291.2 mm of which 1041.7 mm were received between May and October during the cropping season.

Figure 1. Map of the study area.
Treatments and Experimental Design

The experiment consisted of factorial combination of five levels of lime (0, 1.88, 3.76, 5.64 and 7.52 t ha⁻¹) and four levels of P (0, 23, 46 and 69 kg ha⁻¹) laid out in randomised complete block design (RCBD) with three replications. The site exchangeable acidity of the area was 2.36 which is above the critical permissible level. The amount of lime is determined on the basis of the mass of soil per 20 cm hectare-furrow-slice, soil bulk density, and exchangeable Al³⁺ and H⁺ as described in Eq. 1 below. It has been assumed that one mole of exchangeable acidity is neutralized by equivalent mole of CaCO₃. The full dose of lime was applied at once in the first year according to the rate. Lime was uniformly broadcasted by hand and incorporated into the soil one month before planting. The recommended rate of N was applied uniformly to all treatments. Urea and triple super phosphate were used as the source of N and P, respectively. Application of urea was in two split while the entire rate of phosphorus was applied at sowing in band. The plots were kept permanent for the duration of the experiments to observe the carry-over effects of the lime.

\[
LR, \text{ CaCO}_3, (kg/ha) = \frac{cmolEA/kg of soil \times 0.15 \times 10^4 \times m^2 \times B.D. (Mg/m^3) \times 1000}{2000}
\]

Eq. 1

Soil sampling and analysis

Initially one composite soil sample from the experimental site was collected before lime application and subjected to analyses of soil acidity attributes and other soil physico-chemical properties. Samples were randomly collected from surface layer of the experimental field i.e. 0-20 cm soil depth to form composite and analyzed for the soil pH, bulk density, exchangeable acidity, exchangeable aluminum, available P, calcium, magnesium, potassium, sodium, CEC and acid saturation. The pH of the soil was determined according to FAO (2008) using 1:2.5 (weight/volume) soil sample to water solution ratio using a glass electrode attached to digital pH meter. Available phosphorus was determined by the Bray method. The cation exchange capacity (CEC) was measured after saturating the soil with ammonium acetate (NH₄Ac) and displacing it with NaAc (Chapman, 1965).

Statistical Analysis

All the generated data were subjected to analysis of variance (ANOVA) using SAS computer software version 9.3 (SAS, 2002) and the least significant difference between means (LSD) used to separate the treatment means at statistical significance level of p ≤ 0.05. Partial budget analysis was carried out following CIMMYT (1988) procedure based on local market price.

RESULTS AND DISCUSSION

Analysis of selected soil physico-chemical properties

Before Planting: Analysis of soil physico-chemical properties before planting and after harvesting is presented in table 1 and 2. Soil sample analysis before planting indicated that the bulk density was 1.06 g/cm³ which is low according to (Barauah and Barthakul, 1997), according to Bruce and Rayment (1982) soil pH (H₂O) was strongly acid (5.02), available Ca²⁺, Mg²⁺, K⁺ and Na⁺ analysis results were 2.63 (Low), 0.78 (Low), 0.06 (very low) and 0.08 (very Low), respectively (Metson, 1961); cation exchange capacity was 8.25 Cmolkg⁻¹ which was low according to Metson (1961).

Table 1. Soil sample result before planting

<table>
<thead>
<tr>
<th>pH(1:2.5 H₂O)</th>
<th>Exch. acidity</th>
<th>Exch. Al</th>
<th>Av. P (ppm)</th>
<th>Ca%</th>
<th>Mg%</th>
<th>K%</th>
<th>Na%</th>
<th>CEC</th>
<th>% AS*</th>
<th>BD</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.02</td>
<td>2.27</td>
<td>2.48</td>
<td>3.2</td>
<td>2.63</td>
<td>0.78</td>
<td>0.06</td>
<td>0.08</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*AS=Acid saturation

After harvesting

1. Soil pH

Effect of lime application on soil pH after significantly increased due to lime application as compared to control. The higher soil pH was obtained when soil is limed while the lowest soil pH was observed at control (0 level of lime). The reductions in exchangeable Al and percent Al saturation of the soils were related to the increased soil pH. These changes of soil pH of soil might be attributed to the neutralizing of acid soil due to application of lime at increasing rates (Tisdale et al., 1993). Responses of pH to lime application were also observed in tropical soils in several regions of the world (Caires et al., 2006) and in Ethiopia by Alemayehu (1999) and Desta (1987). These results are similar to those reported by Peter (2017), Brown., et al. (2008), Anetor et al. (2007), Hue (2004) and Caires et al. (2002) who reported that liming at various levels had highly significant effects on increasing soil pH. The increase in soil pH following application of lime can be attributed to the release of organic acids which in turn may have suppressed Al content in the soil through chelation (Onwonga et al. 2008; Okwuagwu et al. 2003). Moreover, lime when applied in the soil reacts with water leading to the production of OH⁻ ions and Ca²⁺ ions which displace H⁺ and Al³⁺ ions from soil adsorption sites resulting in an increase in soil pH (Kisinyo et al., 2012). This is in agreement with Anetor and Ezekiel (2007) who
indicated that lime increased pH. Liming of acid soils raises soil pH, which in turn releases phosphate ions precipitated with Al and Fe ions thus making P available for plant uptake (Achalu et al., 2012). The findings observed on soil pH changes in soil agree with the findings of Kayitare (1989), Hartmann (1993) and Ruganzu (2009) who reported the increase of soil pH after lime application in acidic soils. This is might be due to the hydroxyl concentration is increased, and the H+ concentration in the soil solution is decreased by the application of materials to correct acidity; consequently, the soil pH is increased (Castro & Crusciol, 2013). Similar observation was made by Shen et al. (1998) and Bardgett et al. (1995) who reported that reclaiming acid soils by lime increased the soil pH which is mainly due to the neutralization of Al ion in the soil solution by hydroxyl (OH-) ion furnished by the hydrolysis reaction of the agricultural liming material added to the soils.

2. Exchangeable Acidity

The application of lime significantly reduced the exchangeable acidity compared to the treatments (Figure 2). This decrease might be ascribed to the increased replacement of Al by Ca in the exchange site and by the subsequent precipitation of Al as Al(OH)3, as the soil was limed (Havlin et al., 1999). Moreover, an increase in soil pH results in precipitation of exchangeable and soluble Al as insoluble Al hydroxides thus reducing concentration of Al in soil solution (Ritchie, 1989). Elsewhere, studies conducted revealed also that lime application lead to decreased soil exchangeable acidity (The et al., 2001; Nekesa et al., 2005). The reduction of soil exchangeable acidity is associated with the presence of basic cations (Ca2+ and Mg2+) (Fageria et al., 2007) and anions (CO32-) in lime that are able to exchange H+ from exchange sites to form H2O + CO2. Effiong and Okon (2009) reported that incubation of acidic soils with various liming materials for one month generally reduced exchangeable acidity among which CaCO3 used as a liming material showed up to 68% reduction of exchangeable acidity of the soils. The effects observed on exchangeable Al are corroborated by the findings of Crawford and Su (2008) who reported reduction of exchangeable Al and Aluminum saturation to adequate levels following application of lime in acidic soil. Other authors such as Conyers et al. (2003), Caires et al. (2008) and Awkes (2009) have reported a decrease of exchangeable Al following liming of acidic soils.

![Figure 2. Soil pH as affected by applications of lime. Similar letters above the vertical bars with same letters denote no significant difference at p≤0.05. Lime rates (0, 1.88, 3.76, 5.64 & 7.52).](image)

**Figure 2.** Soil pH as affected by applications of lime. Similar letters above the vertical bars with same letters denote no significant difference at p≤0.05. Lime rates (0, 1.88, 3.76, 5.64 & 7.52).

**Effect of Lime and Phosphorus on yield and yield component of Sorghum**

**Plant Height**

The analysis of variance showed that plant height of sorghum was significantly (P≤ 0.05) influenced by main effect of lime while there is not significantly influenced by phosphorous rate. Plant height significantly increased with the increase in lime rates from control (0 lime kg ha-1) to 7.52 t ha-1 lime applied (Table 3). The highest plant height (1.13m) was obtained from the maximum lime rates and the lowest (0.99m) from the control. There was a mean plant height increase of 14.1% due to the application of 7.52 t ha-1 lime over the control. The increase in plant height with increasing lime rates on acidic soils is highly likely related to the increase in soil fertility and reduction of the toxic concentration of acidic cations. Liming might have reduced the detrimental effect of soil acidity on plant growth due to high concentration of H+ and Al3+ ions in the acid soils (Achalu et al., 2012). Corroborating the results of this study, Oluwatoyinbo et al. (2005) reported that plant height was significantly increased by the application of lime. Activities of exchangeable basic (Ca2+, Mg2+ and K+) cations; orthophosphate (H2PO4-), nitrate (NO3-) and sulfate (SO42-) anions with soil organic matter content and their availability to plant roots might be hampered by acidifying ions (Thomas and Hargrove, 1984). With the neutralization of part of the soil acidity by lime application, negative charges of the soil exchange complex are released, and then occupied by basic cations (Haynes and Mokolobate, 2001). This improves soil fertility and gives favorable condition for agricultural production such as; increased plant height observed in this study.
Table 3. Plant height (m) of sorghum as influenced by mean effect of lime and Phosphorus Fertilizer

<table>
<thead>
<tr>
<th>Lime level (L) (t ha(^{-1}))</th>
<th>Plant height (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0.99(^{c})</td>
</tr>
<tr>
<td>1.88</td>
<td>1.17(^{a})</td>
</tr>
<tr>
<td>3.76</td>
<td>1.07(^{bc})</td>
</tr>
<tr>
<td>5.64</td>
<td>1.12(^{ab})</td>
</tr>
<tr>
<td>7.52</td>
<td>1.13(^{ab})</td>
</tr>
<tr>
<td>LSD (0.05)</td>
<td>0.09</td>
</tr>
</tbody>
</table>

Phosphorus rate (kg P\(_{2}\)O\(_{5}\) ha\(^{-1}\))

| 0                           | 1.06            |
| 23                          | 1.08            |
| 46                          | 1.12            |
| 69                          | 1.12            |
| LSD \(0.05\)                | NS              |
| CV (%)                      | 14.31           |

Head Weight

The head weight of sorghum was significantly (\(P \leq 0.05\)) influenced by interaction effect of lime and phosphorous rate (Table 4). The highest head weight was obtained from 3.76 and 5.65 t lime ha\(^{-1}\) with application of 69 kg P\(_{2}\)O\(_{5}\) ha\(^{-1}\) and 7.54 t lime ha\(^{-1}\) with applications of 46 and 69 kg P\(_{2}\)O\(_{5}\) ha\(^{-1}\) treatments. However; the lowest head weight was obtained from the control treatment (0/0 lime and phosphorus fertilizer) and 23 kg P ha\(^{-1}\) alone. The increase in the head weight of sorghum due to liming of acidic soils may be attributed to the reduction in ion toxicity (H, Al, or Mn) and reduction in nutrient deficiency of Ca and P (Curtin and Syers, 2001). Rahman et al. (2002) reported that application of lime influenced the nutrient availability of soil, resulting increased the yield and yield components of crops. Increasing of the straw yield by improving soil acidity through the application of lime and P fertilizers (Oluwatoyinbo et al., 2005).

Straw Yield

The straw yield of sorghum was significantly (\(P \leq 0.05\)) influenced by interaction effect of lime and phosphorous rate (Table 5). The highest straw yield was obtained from 5.65 t lime ha\(^{-1}\) with application of 46 and 69 kg P\(_{2}\)O\(_{5}\) ha\(^{-1}\) and 7.54 t lime ha\(^{-1}\) with applications of 0, 23 and 46 kg P\(_{2}\)O\(_{5}\) ha\(^{-1}\) treatments. However; the lowest straw yield (1223 kg ha\(^{-1}\)) was obtained from the control treatment (0/0 lime and phosphorus fertilizer). The increase in the straw yield of sorghum due to liming of acidic soils may be attributed to the reduction in ion toxicity (H, Al, or Mn) and reduction in nutrient deficiency of Ca and P (Curtin and Syers, 2001). Rahman et al. (2002) reported that application of lime influenced the nutrient availability of soil, resulting increased the yield and yield components of crops. Increasing of the straw yield by improving soil acidity through the application of lime and P fertilizers (Oluwatoyinbo et al., 2005).

Table 4. Head weight (kg plant\(^{-1}\)) of sorghum as influenced by interaction effect of lime and Phosphorus Fertilizer

<table>
<thead>
<tr>
<th>Phosphorus Lime level (L) (t ha(^{-1})) rate (kg P(<em>{2})O(</em>{5}) ha(^{-1}))</th>
<th>0</th>
<th>1.88</th>
<th>3.76</th>
<th>5.64</th>
<th>7.52</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0.67(^{h})</td>
<td>1.25(^{gh})</td>
<td>1.45(^{g})</td>
<td>1.11(^{f})</td>
<td>1.69(^{de})</td>
<td>1.23</td>
</tr>
<tr>
<td>23</td>
<td>0.93(^{l})</td>
<td>1.31(^{gh})</td>
<td>1.73(^{de})</td>
<td>1.76(^{de})</td>
<td>1.85(^{bde})</td>
<td>1.52</td>
</tr>
<tr>
<td>46</td>
<td>1.20(^{hi})</td>
<td>1.37(^{gh})</td>
<td>1.74(^{de})</td>
<td>1.82(^{de})</td>
<td>2.01(^{abc})</td>
<td>1.62</td>
</tr>
<tr>
<td>69</td>
<td>1.58(^{hi})</td>
<td>1.32(^{gh})</td>
<td>1.97(^{de})</td>
<td>2.1(^{ab})</td>
<td>2.27(^{a})</td>
<td>1.76</td>
</tr>
<tr>
<td>Mean</td>
<td>0.99</td>
<td>1.31</td>
<td>1.71</td>
<td>1.70</td>
<td>1.95</td>
<td></td>
</tr>
<tr>
<td>LSD (0.05)</td>
<td>L(^{*})PR =0.27</td>
<td>CV (%)=15.62</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 5. Straw yield (kg ha\(^{-1}\)) of sorghum as influenced by interaction effect of lime and Phosphorus Fertilizer

<table>
<thead>
<tr>
<th>Phosphorus Lime level (L) (t ha(^{-1})) rate (kg P(<em>{2})O(</em>{5}) ha(^{-1}))</th>
<th>0</th>
<th>1.88</th>
<th>3.76</th>
<th>5.64</th>
<th>7.52</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1223(^{h})</td>
<td>2262(^{def})</td>
<td>2175(^{f})</td>
<td>2406(^{def})</td>
<td>4087(^{ab})</td>
<td>2430</td>
</tr>
<tr>
<td>23</td>
<td>1787(^{g})</td>
<td>2648(^{def})</td>
<td>2818(^{d})</td>
<td>3953(^{abc})</td>
<td>4187(^{ab})</td>
<td>3076</td>
</tr>
<tr>
<td>46</td>
<td>2139(^{g})</td>
<td>2535(^{def})</td>
<td>3511(^{c})</td>
<td>4288(^{ab})</td>
<td>4244(^{ab})</td>
<td>3343</td>
</tr>
<tr>
<td>69</td>
<td>2294(^{ef})</td>
<td>2555(^{def})</td>
<td>3827(^{bc})</td>
<td>4336(^{a})</td>
<td>3945(^{abc})</td>
<td>3391</td>
</tr>
<tr>
<td>Mean</td>
<td>1861</td>
<td>2500</td>
<td>3083</td>
<td>3746</td>
<td>4113</td>
<td></td>
</tr>
</tbody>
</table>

LSD L\(^{*}\)PR (0.05) =441 CV (%)=12.56

Grain yield of sorghum

The analysis of variance showed that grain yield of sorghum was significantly (\(P \leq 0.05\)) influenced by interaction effect of lime and phosphorous rate (Table 6). The highest grain yield of sorghum was obtained from 5.65 t lime ha\(^{-1}\) with application of 23, 46 and 69 kg P\(_{2}\)O\(_{5}\) ha\(^{-1}\) and 7.54 t lime ha\(^{-1}\) with applications of 0, 23 and 46 kg P\(_{2}\)O\(_{5}\) ha\(^{-1}\) treatments. However; the lowest grain yield (554.8 kg ha\(^{-1}\)) was recorded for control (no lime and no P\(_{2}\)O\(_{5}\)) application. Grain yield was increased with the increasing of levels of lime and phosphorus fertilizer. The observed increase in grain yield with increasing P rate, in treatments with no lime application, confirmed that P was limiting factor to sorghum production. The positive effect of lime on sorghum grain yield was therefore likely due to its effect in increasing the soil pH, increasing availability of nutrients and reducing exchangeable acidity. The increase in the grain yield of sorghum due to liming of acidic soils under different land use systems may be attributed to the reduction in acidity (H\(^{+}\) and Al\(^{3+}\)) ions and reduction in nutrient deficiency of Ca and P (Curtin and Syers, 2001). The improved soil environment due to the inputs, favours optimal functions of microbial activities such as mineralisation process (Jones et al., 2005; Harrison et al., 2008). Oluwatoyinbo (2005) also indicated the possibility of increasing crop yield by improving soil acidity through the application of lime, and P fertilizers. According to this author the increase in crop yield through the application of lime might be attributed to the neutralization of Al, supply of Ca and increasing availability of some plant nutrients.
Table 6. Grain yield of sorghum as influenced by interaction effect of lime and Phosphorus Fertilizer

<table>
<thead>
<tr>
<th>P2O5 rate (PR) (kg Lime level (L) (t ha⁻¹)</th>
<th>0</th>
<th>1.88</th>
<th>3.76</th>
<th>5.64</th>
<th>7.52</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>554.8a</td>
<td>1016.7cdef</td>
<td>726.2b</td>
<td>1292.7c</td>
<td>2236.5a</td>
<td>1197.4</td>
</tr>
<tr>
<td>23</td>
<td>856.3cdef</td>
<td>1536.2b</td>
<td>1089.3cdef</td>
<td>2193.2a</td>
<td>2323.9a</td>
<td>1559.9</td>
</tr>
<tr>
<td>46</td>
<td>944.1cdef</td>
<td>1361.9c</td>
<td>1815.5b</td>
<td>2469.1a</td>
<td>2237.5a</td>
<td>1725.6</td>
</tr>
<tr>
<td>69</td>
<td>1047.4cdef</td>
<td>1234.6c</td>
<td>1859.1b</td>
<td>2232.2a</td>
<td>1678.6b</td>
<td>1630.4</td>
</tr>
<tr>
<td>Mean</td>
<td>875.8</td>
<td>1287.3</td>
<td>1372.5</td>
<td>2046.8</td>
<td>2159.1</td>
<td></td>
</tr>
</tbody>
</table>

LSD L*PR (0.05) = 328.04, CV (%) = 18.7

Table 7. Effects of lime and P on economic feasibility of sorghum grain yield at Assosa District

<table>
<thead>
<tr>
<th>L (t ha⁻¹)</th>
<th>P (kg P₂O₅ ha⁻¹)</th>
<th>AGYS (ETB ha⁻¹)</th>
<th>TVC (ETB ha⁻¹)</th>
<th>Revenue (ETB ha⁻¹)</th>
<th>Net Benefit (ETB ha⁻¹)</th>
<th>Value to cost ratio</th>
<th>Marginal Rate of Return (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>499.32</td>
<td>0</td>
<td>4493.88</td>
<td>4493.9</td>
<td>1.00</td>
<td>0.0</td>
</tr>
<tr>
<td>0</td>
<td>23</td>
<td>771.21</td>
<td>723.5</td>
<td>6940.89</td>
<td>6217.4</td>
<td>0.90</td>
<td>238.2</td>
</tr>
<tr>
<td>0</td>
<td>69</td>
<td>942.66</td>
<td>2170.5</td>
<td>8483.94</td>
<td>6313.4</td>
<td>0.74</td>
<td>6.6</td>
</tr>
<tr>
<td>1.88</td>
<td>23</td>
<td>1382.58</td>
<td>5385.9</td>
<td>12443.22</td>
<td>7057.32</td>
<td>0.57</td>
<td>102.8</td>
</tr>
</tbody>
</table>

The price of DAP ETB=14.47 kg⁻¹ N Urea ETB=13.87 kg⁻¹, lime ETB=2.48 kg ha⁻¹, Seed sorghum EB=9 kg⁻¹, AGYS=Adjusted Grain yield of sorghum (kg ha⁻¹) and TVC= Total variable cost.

3. Partial budget analysis

Partial budget analysis was carried out following Cimmyt (1988) procedure based on local market price. The study revealed that except 4 treatments on sorghum all the other treatments were dominated. Because these treatments have net benefits less than treatments with lower variable costs. Such dominated treatments were dropped from economic analysis. As a result, only marginal rate of return of 4 on sorghum was computed (Table 7). The highest net benefit of ETB 7057.3 ha⁻¹ & marginal rate of return 102.8 % and was obtained from application of 1.88 t lime ha⁻¹ along with 23 kg P₂O₅ ha⁻¹ for sorghum production. Therefore, combined application of 1.88 t lime ha⁻¹ along with 23 kg P₂O₅ ha⁻¹ for sorghum production are economical feasible

CONCLUSION

Lime increased soil pH and reduced exchangeable acidity resulting for high grain yield of sorghum. The highest grain yield of sorghum was obtained from 5.65 t lime ha⁻¹ with application of 23, 46 and 69 kg P₂O₅ ha⁻¹ and 7.54 t lime ha⁻¹ with application of 0, 23 and 46 kg P₂O₅ ha⁻¹ treatments. The partial budget analysis indicated that 1.88 t lime ha⁻¹ along with 23 kg P₂O₅ ha⁻¹ gives higher net benefits. From this result, it can be concluded that farmers of Assosa area need to apply 23 kg P and 1.88 t lime ha⁻¹ in order to improve the grain yield and yield components of sorghum on Nitosols under rain fed conditions. Thus, in the light of the significant response of Sorghum to both Lime and P fertilizers, further studies aimed at promoting acid-resistant cultivars, organic amendments i.e. compost and farm yard manure and gypsum rather than calcium carbonate would be used for maintaining production on acid soils are desirable.

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