# Lime Application Rates on Selected Soil Chemical Properties of Acidic Soils

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**Abstract**:
Liming has been recently started to amend acidic soils in the study area but meager information is available about effects of Dejen lime on soil properties. The objective of this study was to investigate the application dose effect of locally available liming material on selected chemical properties of *Dystric Nitisol.* Soil samples received 0, 1.1, 2.2, 3.3 and 4.4 t ha$^{-1}$ Dejen lime and incubated for one month at constant moisture and temperature. Finally, its pH, exchangeable acidity, Al, Ca, Mg, K, Na, Mehlich 3 and water soluble P were estimated. Lime rates significantly ($p < 0.01$) increased soil pH, exchangeable Ca, Mehlich 3 and water soluble P but exchangeable acidity and Al significantly ($p < 0.01$) decreased. Application of 2.2 t ha$^{-1}$ Dejen liming material increased soil pH and available P by 0.6 units and 9.2 mg kg$^{-1}$, respectively but exchangeable acidity decreased by 0.72 cmol $_{(+)}$ kg$^{-1}$. Thus, application of $\geq$ 2.2 t ha$^{-1}$ lime alleviate acidity related problem of the soil for crop growth but supplementary nutrient (mainly P) is required for optimum crop yield. Application of 2.2 t ha$^{-1}$ Dejen liming material substantially improves soil acidity related problems but supplementary soil nutrient is essential to increase crop yield in the study area.

**Keywords:** Dejen, exchangeable acidity, lime incubation, *Nitisol*
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## 1. Introduction

Soil acidity is the major limiting factor for sustainable agricultural production in many parts of the world (Sumner and Noble, 2003). Low phosphorus (P) availability and a high P fixation by huge quantities of aluminum (Al) and iron (Fe) oxides are characteristic of highly weathered acid soils in the tropics (Keerthisinghe *et al*., 2001). Large amount of iron and aluminum oxides rapidly react with applied phosphate and make it less soluble in the acidic soils (Bolan *et al.*, 2003). Acid soil infertility is related with toxicities of Al and manganese (Mn) and deficiencies of calcium and magnesium (Foy, 1984; Bolan *et al.*, 2003). The pH of acidic soils is commonly buffered by Al-oxide which dissolves upon further acidification and gradually cation exchange sites of the soils are saturated with exchangeable Al.

Soils of Gozamin and Senan Districts of Eastern Gojam zone and Awi zone in Amhara region, Nedjo, Diga, Gimibi and Bedi of Oromia region, Chencha, Sodo and Endibir of South Nation and Nationality People (SNNP) are intensively affected by soil acidity (Minstry of Agriculture and Rural Development, 2006). Soil pH negatively affects the solubility and availability of P and Mo. Moreover, Al and Mn become highly soluble in low pH soils and can reach toxic level which inhibits nutrient uptake. Manganese minerals are highly soluble when soil pH drops below 5.2 (Upjohn *et al.,* 2005).

Crop growth is negatively affected on strongly and moderately acidic soils (FAO, 2006). Furthermore, decomposition of organic matter is highly reduced in strongly acidic soils, thus the availability of plant nutrients is highly affected (Whitehead, 2000; Bolan *et al.*, 2003). As much as 45% of the cultivated lands of Amhara National Regional State are moderate to strongly acidic in their reaction (IOANRS, 2006). In tropical areas, soil acidity is a major problem to improve wheat and maize yield due to aluminum toxicity and phosphorus deficiency (Agriculture Information Center, 2002; Kisinyo *et al.,* 2005; Upjohn *et al.,* 2005). Similarly, wheat productivity of the Amhara region is lower than the national average due to intensive chemical degradation of soils and frequent drought, (CSA, 2005; 2006; 2007; Ashenafi, 2008).

Phosphorus is the main essential plant nutrient after nitrogen; it has a function in energy transfer as ATP, regulation of enzymatic reactions, transferring genetic materials, synthesis of nucleic acids and phospholipids (Wissuwa, 2003; Devers, 2011; Marschner, 2012). However, most plants which grow in acidic soils are P deficient and show low yield response to fertilization since P availability is determined by reactions on the sorption sites of soil regulating the P concentration in soil solution and adsorption–desorption reactions (Agbenin, 1996; Holford, 1997; Sato, 2003). Most soils of Ethiopian highlands are depleted in their basic cations but rich in sesquioxides, thus they strongly adsorb P and reduce its availability (Tekalign and Haque, 1991; Solomon *et al.*,2002; Birru and Heluf, 2003). Similarly, Birru and Heluf (2003) disclosed that 56% of northwestern Ethiopian highlands soils are being categorized as having high P sorption capacity and requiring more than 150 mg P kg$^{-1}$ soil to reach an adequate P level for crops. This P amount corresponds to about 300 kg ha$^{-1}$ in a 15-20 cm plough layer. About 70 to 75% of agricultural soils of Ethiopian highlands are phosphorus deficient, 36% of Ethiopian highlands soils were categorized under moderately P fixing while 1% of them had a high P fixation capacity (Buresh *et al.*, 1997;

Miressa and Robarge, 1999).

Acidic soils are lower in water and nutrient retention capacities thus reduce uptake of moisture and nutrient and low biotic activity (Kinraide, 2003, Pinkerton and Simpson, 1986). Furthermore, A1 and Mn ions toxicity of acidic soil restrict root growth (Foy, 1984; Pinkerton and Simpson, 1986). On the other hand, phosphorus deficiency is a major limiting factor for crop production in acidic soils of tropical highlands where soils adsorb large quantity of P and increase the fertilization requirement of crops (Sanchez *et al*., 1997; Sato, 2003). Therefore, P deficiency of resource-poor farmer dominant fields could not be corrected by sole application of mineral fertilizer because of high P requirement of the soils and inflated price of the fertilizer (Sahlemedhin and Ahmed, 1983; Weil, 2000; Horst *et al*., 2001; Keerthisinghe *et al*., 2001; Nziguheba *et al*., 2002; Singh and Lal, 2005; Nziguheba, 2007). Furthermore, the global phosphate resource is predicted to be depleted within the next 50–100 years. Unfortunately in this era, high amount of P fertilizers are needed to produce more food and fiber to sustain the growing population (Gilbert, 2009).

Liming improves physicochemical properties of acidic soils. It raises pH, thus decrease Al, Mn and heavy metal toxicities but increases the availability of P and calcium (Ca) thereby it creates favorable soil environmental conditions for growth of plant (Foy, 1984; Haynes, 1984; Naidu *et al.,* 1990; Lungu *et al*., 1993; Holford *et al*., 1994; Slattery *et al*., 1995; Curtin and Syers, 2001; Bolan *et al*., 2003; Wildey, 2003; Rajkishore, 2005; Sato and Comerford, 2005; Mesfin, 2007; Fageria and Santos, 2008; Kisinyo *et al*., 2012). Similarly, crops respond positively to the application of lime through increasing soil pH, exchangeable Ca and available P (Bolan *et al*., 2003; Henning, 2008). However, excess liming decrease crop yield that can be attributed to the effect it might have on the nutrient availability (mainly P) and imbalances (Ca: Mg and Ca: K ratios) (Melakeberhan *et al*., 2001). Furthermore, excess liming increases pH to 5.6 to 6.2 which favors the incidence of take-all infection and reduces wheat grain yield (Thomason *et al*., 2001).

Dejen liming material is readily available and affordable in northwestern Ethiopian highlands. Moreover, there is extensive and thick Mesozoic limestone and gypsum sequences found in the Blue Nile River valley. However, meager information is available about the application rate effects of Dejen liming material on selected chemical properties of acidic soil. Therefore, this experiment was conducted to quantify the effect of Dejen lime on soil pH, exchangeable acidity, Al, Ca, Mg, K, Na, available P and water soluble P.

## 2. Materials and Methods

### 2.1. Experimental Materials

Pit was opened at Enerat Kebele at geographical coordinate of $10^0$23’44’’ N and $37^0$44’31’’ E to describe the morphological feature of the experiential soil as per World Reference Base (WRB) system (FAO, 1998). Moreover, three composite surface soil samples were collected at root depth from the cultivated land of. The samples were air dried and ground to pass through 2 mm sieve. The liming material was Dejen lime with 1.06% moisture content, 52% fineness factor, 91% purity and with neutralizing value of 50%.

The bulk density was estimated from undisturbed soil using the core sample method (Blake, 1965). Soil pH was measured in water (1:2.5 soil: water ratio). Exchangeable acidity was extracted with 1M KCl solution and then titrated with 0.02M NaOH while exchangeable Al was determined from the same solution by adding 0.02 M HCl and 10 ml 1M NaF solution and then titrated with 0.02 M HCl (Sahlemedhin and Taye, 2000). Exchangeable bases (Ca, Mg, Na and K) were extracted with 1M $NH_4OAc$ at pH 7 and then Ca and Mg were determined by atomic absorption spectrophotometer, while K and Na values were determined using flame photometer (Sahlemedhin and Taye, 2000). Effective cation exchange capacity (ECEC) was estimated through summation of exchangeable Al and basic cations.

The available P was extracted through Mehlich 3 method (Mehlich, 1984), the extracting solution with a pH of 2.5 containing 0.2 M $NH_4Cl$, 0.2 M acetic acid, 0.015 M $NH_4F$ and 0.012 M HCl. The extracted phosphorus was quantified colorimetrically using spectrophotometer. Water-soluble P was extracted by shaking a solution of 1g soil and 40 ml of deionized water for 1 hour (Curtin and Syers, 2001). The field water holding capacity of the soil was 27%. The experimental soil had bulk density of 1.17 g $cm^{-3}$, soil pH of 4.8, available P of 2.7 mg $kg^{-1}$ and 0.8 mg $kg^{-1}$ water soluble P. Besides, its exchangeable acidity, Al, Ca, Mg, K and Na were1.8, 1.5, 3.2, 2.75, 0.72 and 0.5 $cmol_{(+)}$ $kg^{-1}$, respectively.

### 2.2. Experimental Design and Procedures

Fifteen soil samples received 0, 0.627, 1.254, 1.881 and 2.508 g lime $kg^{-1}$ soil· equivalent to 0, 1.1, 2.2, 3.3 and 4.4 t $ha^{-1}$ lime each replicated thrice and arranged in a completely randomized design (CRD). The lime was thoroughly mixed with the soil through maintaining 90% of moisture content of the field capacity and then incubated for one month at constant room temperature and moisture. During experimental period, soil moisture loss due to evaporation was regularly compensated by adding equivalent amount of distilled water within four days interval and then mixed. After one month, the incubated soil samples were air dried and ground (< 2 mm). Soil pH, exchangeable basic cations, acidity and Al, available and water soluble P were determined.

### 2.3. Statistical Analysis

Values of the parameters were subjected to analysis of variance following the standard procedure of Gomez and Gomez (1984) using Statistical Analysis System (SAS) computer package v. 9.1 (SAS Institute Inc, 2002). Significant mean differences among treatments were delineated by least significant differences (LSD) at the probability level of 5%.

## 3. Results and Discussion

### 3.1. Morphological feature and category of the experimental soil

The experimental soil had *Nitic* substances at lower depth thus, it categorized under Nitisol (NT) which derived from intensively weathered basalt rock, mainly tuffs of volcanic origin (FAO, 1984). Clay loam in texture and strongly acidic in reaction. Its consistency is very friable which crushes under very gentle pressure therefore, susceptible to soil erosion. Under moist condition it was slightly sticky since adheres to both thumb and finger but comes off one or the other rather cleanly and while it was plastic breaks immediately if bent into a ring. Granular structure type shifted towards blocky at lower depth (Table 1).

**Table 1. Morphological description of the soil**

| Horizon | Depth (cm) | Profile description |
|---|---|---|
| Ap | 0-20 | Dark red (2.5YR 3/6) dry; dark reddish brown (2.5YR 3/4) moist; clay loam; weak to moderate, very fine to medium, granular; slightly hard, dry; very friable to friable, moist; slightly sticky and slightly plastic, wet; many, medium to coarse roots; clear and smooth boundary; non-calcareous (no effervescence with dilute HCl); pH ($H_2O$) 4.6. |
| Bt | 20-50 | Dark reddish brown (2.5YR ¾) dry; dusky red (2.5YR 3/2) moist; clay; moderate to strong, fine and medium, sub angular blocky; hard, dry; friable, moist; sticky and plastic, wet; common fine roots; gradual and wavy boundary; non-calcareous (no effervescence with dilute HCl); pH ($H_2O$) 4.8. |
| BC | 50-100 | Dark reddish brown (5YR 3/3) dry; dark reddish brown (5YR 3/2) moist; clay; medium to strong, medium to coarse, sub angular blocky; hard to very hard, dry; friable to firm, moist; slightly sticky and plastic, wet; very few fine roots; diffuse and irregular boundary; shiny ped faces; non-calcareous (no effervescence with dilute HCl); pH (H2O) 4.8. |
| C | 100-170 | Strong brown (7.5YR 5/6) dry; strong brown (7.5YR 5/6) moist; clay; strong, medium and coarse, sub angular blocky; very hard, dry; firm, moist; sticky to very sticky and very plastic, wet; no roots; diffuse and irregular boundary; shiny ped faces; slightly calcareous (audible effervescence with dilute HCl); pH (H2O) 4.8. |

### 3.2. Soil pH and Exchangeable Acidity

Application of one ton ha$^{-1}$ Dejen lime increased soil pH by 0.24 units on average (Table 2). In consent with the finding in this study, several reports (Sultana *et al*., 2009; Achalu *et al*., 2012; Abreha, 2013; Sarker *et al.*, 2014) also indicated an increase in pH due to application of lime. In contrary, incubation slightly decreased the pH of the control by 0.03 unit. This decrease might be attributed to mineralization of, $NH_4$-N into $NO_3$-N, which releases protons during incubation (Wang *et al*., 2011). Soil pH was significantly ($p < 0.01$) increased due to the application rate of lime (Table 2). Soil pH of lime received samples increased by 0.35 to 0.58 units above the control treatment. In line with this, several authors revealed that soil pH of lime treated samples were raised in ranges between 0.5 and 1.5 units above the control treatment with comparable lime rates (Holford *et al*., 1994; Slattery *et al*., 1995; Abreha, 2013). However, the change in soil pH decreased progressively with increasing lime rates. A high pH increment per unit of lime (0.39 pH t$^{-1}$) was observed at 1.1 t ha$^{-1}$ rate, whereas lower pH increment per unit of lime (0.15 pH t$^{-1}$) was observed at 4.4 t ha$^{-1}$ lime due to high buffering effect of clay (Table 2). Similarly, Hoskins (1997) disclosed that acid ions in soil solution are small and neutralized by small amount of lime but the reserve acidity that is adsorbed on exchange sites is large, it replenishes hydrogen ions to the soil solution. Thus, soil pH cannot be raised to the desired level until this reserve acidity is neutralized. Some studies confirmed also low lime rate resulted in high pH increment per unit of lime while high lime rate showed low pH increment per unit lime (Fettell *et al.,* 2007; Achalu *et al.,* 2012).

Lime rates (X) were non-linearly associated with soil pH (Y) ($Y = 4.81 + 0.33X - 0.045X^2$, $r^2 = 0.91$). In contrast with this, study report of Sultana *et al.* (2009) shows lime rates linearly increased soil pH ($Y= 0.49 X + 5.06$, $r^2 = 0.96$). Lime rates were positively related with soil pH ($r^2 = 0.87$). This is also supported by Henning (2008). Similarly, Sultana *et al.* (2009) and Diaz (2013) revealed that application of 2 t ha$^{-1}$ lime significantly increased soil pH and enhanced crop growth on acidic soils. Besides, study report of Mahler (2002) indicated that maximum winter wheat yield was obtained in soil pH range between 5.1 and 5.4 depending on variety. Soil samples that received 2.2 t ha$^{-1}$ lime increased pH from 4.77 to 5.32, which is substantial for bread wheat production.

Moreover, exchangeable acidity significantly ($p < 0.05$) decreased with application of $\geq$ 2.2 t ha$^{-1}$ Dejen lime (Table 2).

Exchangeable acidity of lime received treatments decreased by 0.5 to 0.8 cmol$_{(+)}$ kg$^{-1}$ below the control treatment, whereas acid saturation of these treatments decreased by 9.1% as compared to zero level lime received treatment. Similar findings corroborating with the present results were reported (Slattery *et al.*, 1995; Abreha, 2013). According to Taye *et al.* (2007) cultivation of wheat, sorghum, barley and sweet potato crops is permissible in soils with < 10% acid saturation. This can be attained through application of $\geq$ 2.2 t ha$^{-1}$ Dejen lime. Lime rates were negatively associated with exchangeable acidity ($r^2 = -0.84$), this is supported by the finding of Henning (2008).

**Table 2. Effects of application dose of Dejen lime on soil pH and exchangeable acidity**

| Lime (t ha$^{-1}$) | Soil pH Mean | Soil pH per unit (t) lime | Exchangeable acidity (cmol$_{(+)}$ kg$^{-1}$) Mean* | Exchangeable acidity per unit (t) lime | ASP (%) Mean | ASP (%) per unit (t) lime |
|---|---|---|---|---|---|---|
| 0 | 4.77$^{c}$ | | 1.75$^{C}$ | | 20.68$^{c}$ | |
| 1.1 | 5.20$^{b}$ | 0.39 | 1.25$^{B}$ | 0.45 | 11.96$^{b}$ | 7.93 |
| 2.2 | 5.32$^{ab}$ | 0.25 | 1.03$^{A}$ | 0.33 | 8.69$^{ab}$ | 5.45 |
| 3.3 | 5.34$^{ab}$ | 0.17 | 0.97$^{A}$ | 0.24 | 8.06$^{a}$ | 3.82 |
| 4.4 | 5.43$^{a}$ | 0.15 | 0.95$^{A}$ | 0.18 | 7.53$^{a}$ | 2.68 |
| CV(%) | 1.05 | | 9.53 | | | |
| LSD ($p < 0.01$) | 0.15 | | 0.21 | | | |

Means with the same letter within a column are insignificantly different at $p < 0.01$, * = mean significantly different at $p < 0.05$, ASP= Acid saturation percentage

Lime rates (X) decreased the exchangeable acidity (Y) in a quadratic manner ($Y = 0.07X^2 - 0.46X + 1.72$, $r^2 = 0.89$). High soil pH induces neutralization of protons and hydrolysis of $Al^{3+}$ to form Al hydroxide. Therefore, soil pH was negatively correlated with exchangeable acidity ($r^2 = -0.93$).

### 3.3. Available and Water Soluble Phosphorus

Mehlich 3 (M3) available P and water soluble P values were significantly ($p < 0.01$) increased in all application rates. Even though incubation slightly decreased available P (by 1.42 mg kg$^{-1}$) due to slight decline in pH, liming enhanced the concentration of P extracted by Mehlich 3 solution (Table 3). This shows that P sorptivity of most acidic soils decreases by liming thereby increasing the availability of P with increase in soil pH regardless of the extracting solution (Holford *et al.*, 1994; Henning, 2008; Mbakaya *et al.*, 2009). Values of soil pH and available P were associated exponentially (Figure 1). The change in available P decreased progressively with increasing rate of lime. Low lime rate elevated soil P at higher rate per unit lime, whereas high lime rate increased soil P at low rate per unit lime. Application of one ton ha$^{-1}$ Dejen liming material elevated available P by 4 mg kg$^{-1}$ on the average (Table 3).

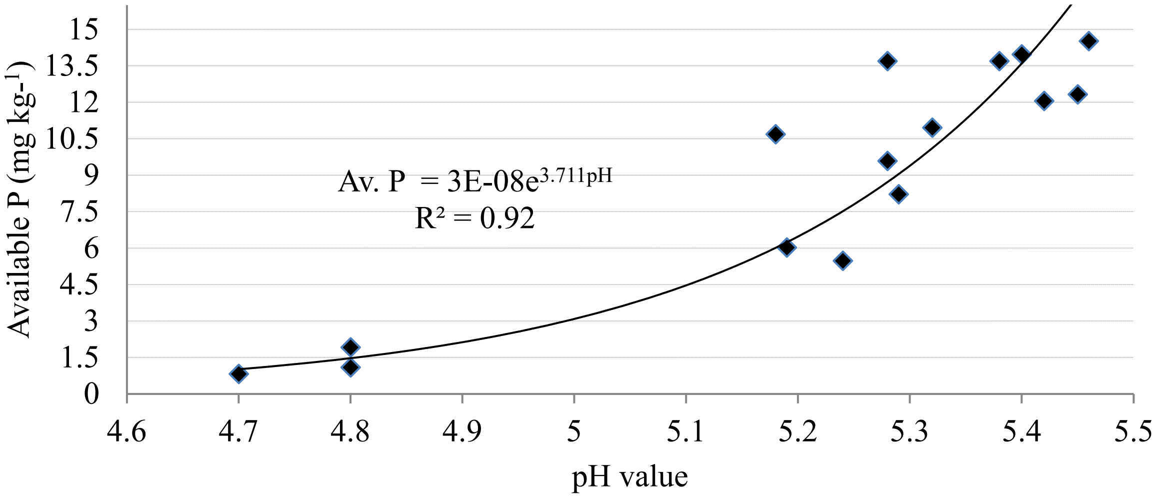

**Figure 1. Effect of soil pH on available P**

Liming increased available and water soluble P by 6.1 - 12.3 and 1.1 - 2.1 mg kg$^{-1}$, respectively. This could be attributed to P desorption from the fixed site and mineralization of organic P compounds (Molina and Fassbender, 1972; Haynes, 1982). The available P content of the soil was 7.1 mg kg$^{-1}$ which is higher than that of water soluble P. The highest liming rate desorbed the maximum amount of M3 soil P (12.3 mg kg$^{-1}$ or 21.6 kg P ha$^{-1}$ in 15 cm depth) but the change rate was lower (2.8 mg P kg$^{-1}$ t$^{-1}$ lime) than 1.1 t ha$^{-1}$ lime. On the other hand, maximum water soluble P was observed at 3.3 t ha$^{-1}$ lime while progressive increase in lime rate (4.4 t ha$^{-1}$) slightly decreased the water soluble P (0.33 mg kg$^{-1}$) (Table 3). In line with this, Curtin and Syers (2001) reported that water extractable P of soils tends to decrease with the application of high lime. Besides, lime incubation study conducted by Sarker *et al.* (2014) indicated that application of 2 t ha$^{-1}$ lime desorbed more phosphorus in soil as compared with the application of 3 t ha$^{-t}$ lime.

Even though the pH of incubated soils was not higher than 5.43, some unavailable P may be extracted by Mehlich 3 (Table 3). It is also likely that Mehlich 3 method, which dissolve the strongly acidic (pH 2.5) compounds (Sharpley *et al.*, 2004), might have overestimates the apparent increment of P availability. The substantial increment of Mehlich 3-P might be due to application of high lime rate since the soil has very low native P. According to Mallarino (2003), 21 to 25 mg kg$^{-1}$ M3 soil P (37 to 44 kg ha$^{-1}$available P) is required for optimum growth of wheat. However, the Mehlich 3 soil P desorbed by application of maximum lime rate was 12.3 mg kg$^{-1}$, which according Mallarino\s suggestion is far below the optimum P level required for successful productivity of wheat. Therefore, liming should be integrated with fertilization for optimum crop yield. Similar empirical studies conducted in different locations of the country indicated that wheat requires 30 kg P ha$^{-1}$ (Damene, 2003; Melesse, 2007).

On the other hand, liming reduces P fixation capacity of soils, enhancing P fertilizer efficiency and increase the apparent recovery of P fertilizer (Donald, 2011). Application of lime nonlinearly increased available soil P and water soluble P. Available P correlated positively with soil pH ($r^2 = 0.90$) and water soluble P ($r^2 = 0.79$) while negatively to Al saturation percentage ($r^2 = -0.93$).

**Table 3. Effects of application dose of Dejen lime on available and water soluble P**

| Lime | Mehlich-P (mg kg$^{-1}$) | | WSP (mg kg$^{-1}$) | |
|---|---|---|---|---|
| t ha$^{-1}$ | Value | P desorbed t$^{-1}$ lime | Value | P desorbed t$^{-1}$ lime |
| 0 | 1.28$^{c}$ | | 0.66$^{C}$ | - |
| 1.1 | 7.4$^{b}$ | 5.56 | 1.79$^{B}$ | 1.04 |
| 2.2 | 10.5$^{ab}$ | 4.19 | 2.29$^{AB}$ | 0.74 |
| 3.3 | 12.24$^{ab}$ | 3.32 | 2.73$^{A}$ | 0.63 |
| 4.4 | 13.61$^{a}$ | 2.80 | 1.97$^{B}$ | 0.30 |
| CV(%) | 20.81 | | 11.05 | |
| LSD ($p < 0.01$) | 5.13 | | 0.57 | |

Means with the same letter in each column are insignificant at $p < 0.01$, M3 = Mehlich 3 method, WSP = Water Soluble Phosphorus

### 3.4. Exchangeable Cations

Exchangeable cations were significantly ($p < 0.01$) affected by the application of lime. Application of 4.4 t ha$^{-1}$ lime significantly ($p < 0.01$) decreased exchangeable Al, while it increased exchangeable Ca and ECEC of soil (Table 4). Lime application rate linearly increased exchangeable Ca content of the soil (Figure 2).

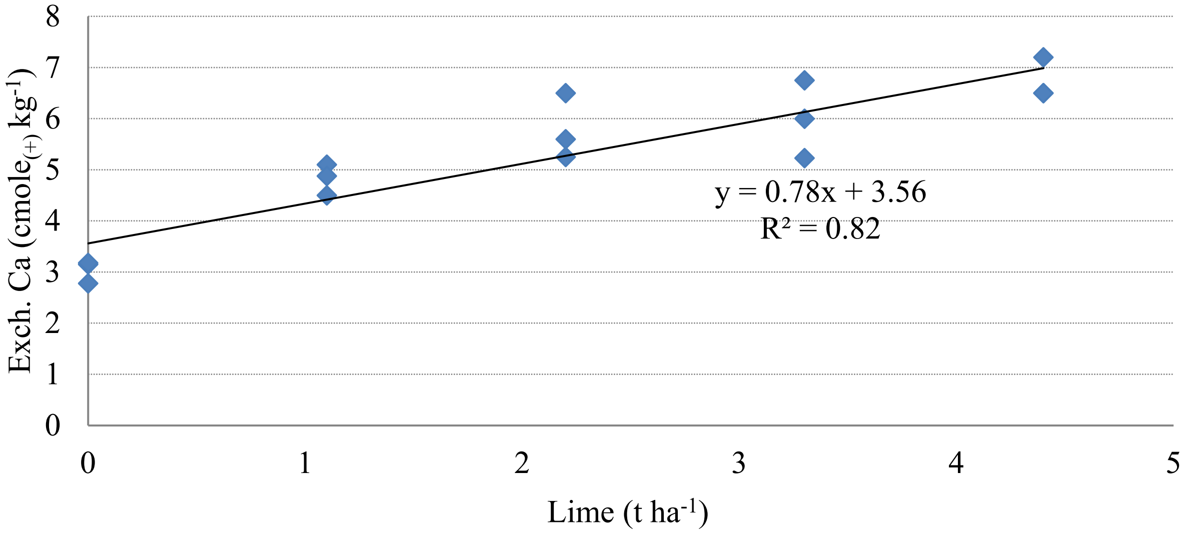

**Figure 2. Lime rate and exchangeable Ca association**

Exchangeable Al values of samples that received lime ranged between 0.32 and 1.2 cmol$_{(+)}$ kg$^{-1}$, whereas the control samples contained between 1.32 and 1.44 cmol$_{(+)}$ kg$^{-1}$. This indicates that application of lime at 1.1 to 4.4 t ha$^{-1}$ decreased the exchangeable Al$^{3+}$ by 8-85%. In line with this, Fageria (2009) and Abreha (2013) reported a significant decrease in Al due to lime application. Aluminum toxicity is the most growth-limiting factor in acid soils (Kinraide, 1995). Low soil pH enhances Al solubility, whereas high pH converts soluble Al into Al hydroxides and decreases Al concentration (Slattery *et al.*, 1995). Soil pH and exchangeable Al are negatively and linearly related (Figure 3).

According to Haynes and Ludecke (1981), Parker *et al.*(1988), Bolan *et al.*(2003), Álvarez *et al.*(2009) and Abreha (2013) reports revealed that liming, through increasing soil pH, decreased the concentration of Al and, intern, enhanced plant root growth and P uptake. According to Parker *et al.* (1988) and Upjohn *et al.* (2005) reports, the critical concentration of Al for wheat is 0.9 mg kg$^{-1}$. In this study, this concentration level maintained through application of $\geq$ 2.2 t ha$^{-1}$ Dejen lime. Exchangeable Al and soil pH were correlated negatively ($r^2$ = -0.87) (Table 5).

**Table 4. Effects of application dose of Dejen lime on exchangeable cations (cmol$_{(+)}$ kg$^{-1}$)**

| Lime | Exch. Ca | | Exch. Mg | | Exch. K | | Exch. Na | | Exch. Al | | ECEC | | AlSP (%) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| t ha$^{-1}$ | Mean | Rate | Mean | Rate | Mean | Rate | Mean | Rate | Mean | Rate | Mean | Rate | Mean | Rate |
| 0 | $3.04^{d}$ | | $2.81^{ns}$ | | $0.73^{ns}$ | | $0.49^{ns}$ | | $1.41^{e}$ | | $8.49^{b}$ | | $16.65^{e}$ | |
| 1.1 | $4.83^{c}$ | 1.63 | $3.15^{ns}$ | 0.31 | $0.82^{ns}$ | 0.08 | $0.47^{ns}$ | -0.02 | $1.15^{d}$ | 0.24 | $10.41^{ab}$ | 1.75 | $11.01^{d}$ | -5.1 |
| 2.2 | $5.78^{b}$ | 1.17 | $4.03^{ns}$ | 0.55 | $0.82^{ns}$ | 0.04 | $0.41^{ns}$ | -0.08 | $0.88^{c}$ | 0.24 | $11.32^{a}$ | 1.29 | $7.46^{c}$ | -4.2 |
| 3.3 | $5.99^{ab}$ | 0.89 | $4.13^{ns}$ | 0.4 | $0.99^{ns}$ | 0.08 | $0.39^{ns}$ | -0.10 | $0.61^{b}$ | 0.24 | $12.11^{a}$ | 1.09 | $5.07^{b}$ | -3.5 |
| 4.4 | $6.73^{a}$ | 0.84 | $4.15^{ns}$ | 0.3 | $0.87^{ns}$ | 0.03 | $0.51^{ns}$ | 0.03 | $0.32^{a}$ | 0.25 | $12.59^{a}$ | 0.93 | $2.55^{a}$ | -3.2 |
| CV% | 6.6 | | 18.0 | | 12.3 | | 27.3 | | 3.339 | | 7.2 | | 8.2 | |
| LSD p<0.01 | 0.95 | | 1.81 | | 0.29 | | 0.34 | | 0.08 | | 2.19 | | 1.91 | |

Means with the same letter in each column are insignificant at $p < 0.01$, Exch. = Exchangeable, ECEC= Effective Cation Exchange Capacity, AlSP = Al Saturation Percentage, CV = Coefficient of Variation, LSD = Least Significance Difference

**Table 5. Correlation among soil chemical properties**

| Parameter | pH | Exchangeable Al | Exchange Acidity | Available P | $H_2O$ soluble P | Exchangeable Ca | Exchangeable Mg | Exchangeable K | Exchangeable Na | ECEC | Al Saturation % |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Exchangeable Al | $-0.87^{**}$ | | | | | | | | | | |
| Exchangeable Acidity | $-0.93^{**}$ | $0.85^{**}$ | | | | | | | | | |
| Available P | $0.90^{**}$ | $-0.89^{**}$ | $-0.91^{**}$ | | | | | | | | |
| Water soluble P | $0.83^{**}$ | $-0.68^{**}$ | $-0.86^{**}$ | $0.79^{**}$ | | | | | | | |
| Exchangeable Ca | $0.91^{**}$ | $-0.89^{**}$ | $-0.86^{**}$ | $0.85^{**}$ | $0.79^{**}$ | | | | | | |
| Exchangeable Mg | $0.64^{**}$ | $-0.61^{*}$ | $-0.62^{*}$ | $0.69^{**}$ | $0.61^{*}$ | $0.55^{*}$ | | | | | |
| Exchangeable K | $0.56^{*}$ | $-0.49^{ns}$ | $-0.53^{*}$ | $0.49^{ns}$ | $0.58^{*}$ | $0.29^{ns}$ | $0.33^{ns}$ | | | | |
| Exchangeable Na | $-0.20^{ns}$ | $0.05^{ns}$ | $0.21^{ns}$ | $-0.14^{ns}$ | $-0.31^{ns}$ | $-0.19^{ns}$ | $0.08^{ns}$ | $-0.00^{ns}$ | | | |
| ECEC | $0.90^{**}$ | $-0.84^{**}$ | $-0.85^{**}$ | $0.87^{**}$ | $0.82^{**}$ | $0.90^{**}$ | $0.85^{**}$ | $0.37^{ns}$ | $-0.03^{ns}$ | | |
| Al Saturation % | $-0.95^{**}$ | $0.97^{**}$ | $0.92^{**}$ | $-0.93^{**}$ | $-0.8^{**}$ | $-0.94^{**}$ | $-0.68^{**}$ | $-0.5^{ns}$ | $-0.09^{ns}$ | $-0.92^{**}$ | |
| Acidity Saturation % | $-0.96^{**}$ | $0.84^{**}$ | $0.98^{**}$ | $-0.91^{**}$ | $-0.88^{**}$ | $-0.90^{**}$ | $-0.68^{**}$ | $-0.5^{ns}$ | $0.11^{ns}$ | $-0.91^{**}$ | $0.94^{**}$ |

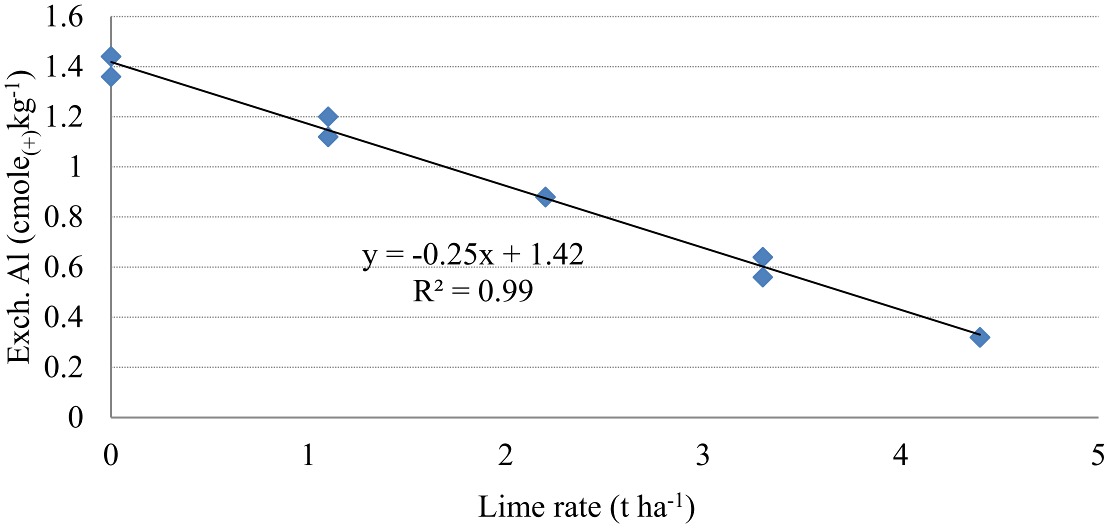

**Figure.3. Lime rate and extractable Al association**

## 4. Conclusions

Dejen liming material application significantly increased soil pH, available P and exchangeable Ca but significantly decrease exchangeable acidity and exchangeable Al of acidic soils of Gozamin District. The overall studied parameters of the soil indicated that application of $\geq$ 2.2 t ha$^{-1}$ Dejen lime substantially improved pH, exchangeable acidity, exchangeable Al, Ca, basic cations, Mehlich 3 and water soluble P properties of acidic soil but supplementary plant nutrient is essential for optimum crop yield in the study area.

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