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Research Paper

Degree of Acidity Related Soil Chemical Properties and Effect of Lime Rates on Phosphorus Adsorption Characteristics of Wayu Tuka District, Western Oromia, Ethiopia

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Abstract

Soil acidification and Phosphorus (P) deficiency are major challenges to acid sensitive crop production in most of the highlands of Oromia. Study was initiated to evaluate degree of acidity related soil chemical properties and impact of the application of agricultural lime (0, 3, 5, 7 and 9 t ha^{-1}) rates on P-sorption characteristics of acidic soil. Replicated representative soil samples were collected from the soil surfaces (0-20 cm) depth of the four Kebeles and mixed with lime of 100 mesh size was incubated for 90 days at approximately field water holding capacity. A 90 days Greenhouse incubation experiment were employed using standard laboratory procedures to evaluate effect of application of agricultural lime rates on acidity related chemical properties, P-sorption characteristics and percent increment of available P. Analysis of soil chemical properties (pH, exchangeable acidity, Al saturation, available and total P, soil P-sorption characteristics were evaluated before and after incubations. Result of soil pH, revealed that all soils from studied sties fallen in very strongly acidic (4.63-4.89) media. Values of soil exchangeable acidity, percent acid saturation and Al saturation of soils ranged from 1.43-2.49cmol (+) kg^{-1} soil, 5.36-9.37% and 3.57-6.28%, respectively. Available P before liming varied from 7.07-8.02 ppm and qualifying low range. However, due to application of lime, there was decrease of average percent total p- sorption of soils and ranged from 93% in the control to 57% at 9 t ha^{-1} lime rates. Moreover, percent increment of average available P ranges from 7.2% in the control to 43.6% for 9 t ha-1 lime. The positive values of R^2 values of Langmuir regression equation indicated, there was strong positive relationship of increment of P availability with lime rates incubated soils. Therefore, the 90 days soil-agricultural lime incubation study showed the potential capacity of agricultural lime to reduce the P-sorption by increasing available P of acidic soil of the study area. Field experiment to explore the effects of lime on other acidity related soil physical and chemical properties are recommended to strength the present study.

1. Introduction

Phosphorus (P) is a critical essential macronutrient for crop production and considered to be one of the key plant nutrients but its limited availability in soils is often severely restricts crop yields. Acidification of soil is one of the most important soil factors affecting for successful crop production and ultimately yields. Mostly it is the result of a complex set of processes caused by both naturally and anthropogenic activities (Amede et al., 2019; Dubus & Becquer, 2001; Hosseinpur & Ghanee, 2006).

From soil science and agronomic aspects, the study of sorption and desorption reactions between phosphate

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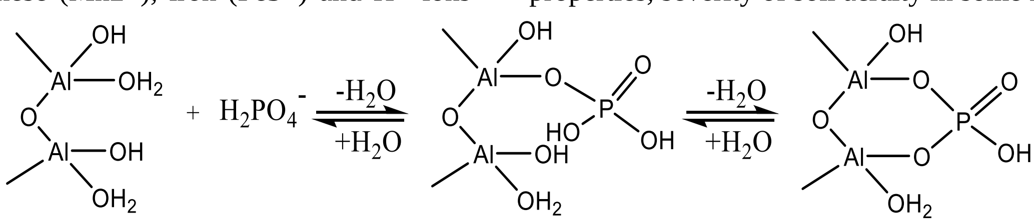
and soils is very important. Phosphorus sorption is mainly studied by sorption isotherms which were historically initiated for evaluating its availability for crop uptake but have become popular for assessing the soil P mobility in environmental applications (Siddique & Robinson, 2003). According to Birru and Heluf (2003) the soil's sorbing capacity in relation to soil properties can be rated using various indexing techniques and the relationship between the various isotherm and sorption parameters. The sorption of P in acid soils occurs mainly on surfaces of Fe and Al oxides and hydroxides as well as through ligand exchange on variable charge surfaces by the exchange of OH- on the surface for the phosphate ion (Scheme 1). There is a covalent bond between the metal ion and the phosphate ion. Phosphate is considered to sorb mainly as an inner-sphere complex which means that the sorption takes place at specific coordination sites on the oxides or hydroxides and no water molecules are present between the surface and the phosphate anion (Agbenin, 2003; Birru & Heluf, 2003).

The P sorption is a continuous sequence of adsorption and precipitation and consists of two processes, one relatively fast, reversible adsorption process and a relatively slow, practically irreversible precipitation process (Van der Zee & van Riemsdijk, 1998). The magnitude of P sorption highly correlated with exchangeable and extractable forms of Fe and Al ions in the soil solutions. Currently, there is increasing awareness that soil nutrient depletion from the agro-ecosystem caused by soil acidification is a very wide spread problem and is an immediate crop production constraint in Ethiopia. Acidification of soil is one of the most important soil factors affecting for successful crop production and ultimately yield. It also limits plant growth not only because of the deficiency of major nutrients like phosphorus (P), calcium (Ca) and magnesium (Mg) but also due to toxicity of aluminum (Al3+), manganese (Mn2+), iron (Fe3+) and H+ ions practice (Bolan et al., 1992). It is important that soil acidity be understood in terms of its fundamental chemistry so that appropriate soil management and remediation schemes are based on sound principles rather than on empirical knowledge that may only be locally relevant.

Sustained production of crops on acidic soils requires addition of soil amendments. Various investigators have shown that this toxic effect of acid soils constraints to crop production can be overcome through the application of lime and of superphosphate in rather large amounts (Amede et al., 2019; Chimdi et al., 2012). The major research intervention in solving the problems of acid soils is liming, and determining lime requirement (LR) of acid soil is one of the major research concerns(Abebe, 2007). Liming acidic soil may often increases crop P uptake by reducing the amounts of soluble Al rather than any direct effects on P availability (Curtin & Syres, 2001). In the western Oromia Region, land use changes particularly from natural forest to grazing land and crop production under poor management practices and/or no crop rotation caused decline in soil fertility.

Moreover, severe erosion and land degradation from the surface soils are the major contributing factors for the soil acidification. Furthermore, crop diversity and yields are declining due to pronounced influence of soil acidity on plants, because of soil acidity. As a result, most of the crops which are susceptible to soil acidity like barley, bean, and wheat are forced to be out of production in the region (Chimdi et al., 2013; Fite et al., 2007; Paulos, 2001).

Currently, in most part of Western Oromia, the problem of soil acidity caused by Al saturation in the high rainfall area has become a national issue. In line with this, several studies (Chimdi, 2014; Chimdi et al., 2013; Wakene & Heluf, 2003) have been done on soil P status, dynamics and its availability as well as on the properties, severity of soil acidity in some Ethiopian



Scheme 1: Mechanism of soil P adsorption on Al- oxide surface.

highlands. However, evaluation of the degree of acidity related chemical properties and impact of different lime rates on P sorption character of highly acidic soils area of the agricultural lands of Wara Babo Migna, Gara Hudha, Wali Galte, and Gute Badiya kebeles of Wayu Tuka district are not yet studied in sufficient detail. Therefore, to fill the gap, the present study was initiated to evaluate the degree of soil acidity and effect of different lime rates on P-sorption characteristics of highly acidic soil areas of the agricultural lands of the study area. Such study is used for estimating the optimum amount of the agricultural lime required for a given agricultural lands and to counteract soil acidity thereby raising soil pH, soil available P and improving crop production and productivity of the study area.

2. Materials and methods

2.1. Description of the study area

The present study was conducted in four Kebeles of Wayu Tuka Districts of East Wollega Zone, Oromia Regional State, Ethiopia. Gute is the administrative center of the district; it is located at a distance of 12 km from Nekemte Zonal capital town. The district is located 320 km from the capital city, Addis Ababa toward the west of the country and 10 km away from Nekemte. It is bounded by Sibu Sire in the north and east, Leka Dulecha in the south, and Guto Gida in the west. Geographically, the district is located in the Western highlands of Ethiopia lying between 8°56'56"N and 9°7'49"N and 36°32'38"E and 36°49'3"E. According to Wayu Tuka Administrative office the altitude of the district ranges from 1300-3140 m.a.s.l. The study area consists of four Kebeles such as Wara Babo Migna, Gara Hudha, Wali Galte and Gute Badiya. Location map of the study area is shown below in (Figure 1).

The topography of the study district is mountainous and slopping landscape. Nitisols are the major soils that cover the western part of Ethiopia (Chimdi et al., 2012; FAO, 1990). The study site soils were classified as Nitisol covering large production areas, according to the FAO (1990) classification legend and the main soil group of most of the east Wollega zone is Nitisols and the soil is acidic in reaction as cited by Ethiopia.The climate of the district is classified traditionally into three main agro-climatic zones, low land, midland, and highland. The total landmass of the district, about 49.23% (14,249 hectares) is Midland ‘Badadaree’ while 37.665% (10,704.73 hectares) categorized as high land ‘Baddaa’ and 13.16% (10,704.73 hectares) is low land ‘Gammojjii’ as reported by (Deresa, 2013; WTWAO, 2017). The thirteen years (2006-2018) climatic data from Nekemte Meteorological Station was recorded and the area has a unimodal rainfall pattern that extends from April to October with average annual precipitation of 2166.43 mm. Maximum rain is received in June, July, and August, with a mean monthly temperature varying from 11.93-28.21°C.

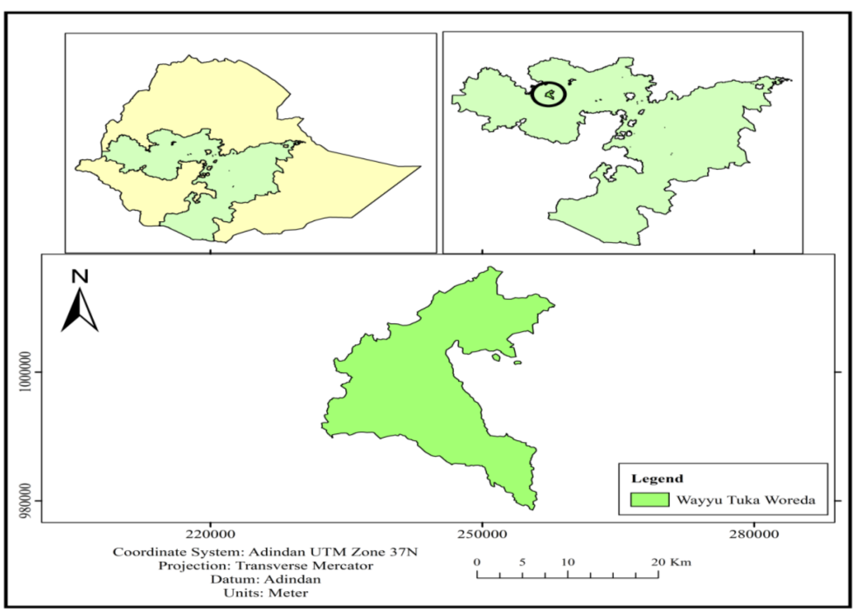


Figure 1: Location map of the study area

2.2. Land uses, major vegetation types and farming system

Cultivated and grazing lands are the major lands used in the area. However, cultivated land is the dominant land use of the area because crop production is widely practiced through traditional subsistence farming on individuals held under rain-fed conditions. The second land use is the grazing land which is individually held by the farmers. The major crops grown in the area are coffee (*Coffee arabica L.*), teff (*Eragrostis tef*), maize (*Zea mays L.*) and potato (*Solanum tubersoum L.*) hot pepper (*Capsicum frutescence*) and are usually produced once in a year under rainfed conditions. Rapid human growth at the study area has resulted in a substantial change in declining soil fertility and most natural forest has been cleared for crop production and local fuel. Intensive farming practices and the high rainfall amounts have exposed the soils of the study areas to severe erosion resulting in nutrient loss, soil acidity and overall land and natural resource degradation. As a result, most of the crops which are susceptible to soil acidity like barley, bean, and wheat are forced to be out of production in the region (Fite et al., 2007). Similar to most parts of the country, the economic activities of the local society of the study area are primarily a mixed farming system that involves animal husbandry and crop production. The farming system is a subsistence involving a mixing crop-livestock production agricultural system.

2.3. Site Selection, soil sampling and preparation

For the present study, Four Kebeles were purposely selected from the Wayu Tuka district as it is among the kebeles in the district where soil acidity problem has been predominantly occurred and reported by (WTWAO, 2017). Based on field observation, soil surveys, and data obtained from the previous studies reported by Chimdi (2014) and Deresa (2013), the following Kebeles (Wara Babo Migna (WBM), Gara Hudha (GH), Wali Galte (WG) and Gute Badiya (GB) were selected as acidic soils Wayu Tuka District. Thus, the selected acidic soils of agricultural lands were delineated and dug on different landscape positions to collect samples from the soil surfaces (0-20 cm) depth of the four Kebeles. Then 2 kg composite soil sample from selected district was properly bagged, labeled and transported to laboratory for analysis of the parameters of selected soil properties (soil moisture contents, soil pH, electrical conductivity, available P, total P, soil P adsorption characteristics supported by batch type experiment and based up on their standard laboratory procedures at the Nekemte soil research and Holetta agricultural research centers.

2.4. Design and soil incubation experiment

Soil incubation experiment was employed to study the effect of different lime rates on P adsorption characteristics of soils in three-way factorial combination of five rates (0, 3, 5, 7 and 9 t ha^{-1}) of 100 mesh sizes of agricultural limes. The incubation experiment was prepared by mixing different proportions of lime rates with 1 kg of a composite of soils from acid soil of study sites was packed into 200ml polythene bag and thoroughly mixed with different rates of (0, 3, 5, 7 and 9 t/ha) of lime with replication. Composite soil samples were incubated for 90 days at approximately field water holding capacity to allow for lime to react with the soils after which they were once again air-dried for laboratory P sorption studies together with the control (no lime). The soil-lime mixture was stirred every seven days to uniformly mix the lime with the soil in a clean plastic bag. Each treatment was wetted and rewetted every three days regularly to maintain the field capacity at Chemistry Department Laboratory of Wollega University. Agricultural lime ($CaCO_3$) was offered from Nekemte soil research center. Its calcium carbonate equivalent was determined by acid neutralization method and found to be 92.6%.

2.5. Laboratory analysis of soil samples

The soil pH using (H_2O) was measured potentiometrically with digital pH meter in the supernatant suspension of 1:2.5 soils to water ratio (Barauah & Barthakulh, 1997). The soil electrical conductivity measurement was done using conductivity meter at 25^0C using its standard procedures. Soil available P was extracted by the Bray-II method (Bray & Kurtz, 1945) and the reading was quantified by using spectrophotometer at wave length of 880 ηm. Soil exchangeable acidity (Al^{+3} and H^+) was determined by saturating the soil sample with 1N KCl solution and titrating with 0.02 N NaOH as described by Rowell (1994). From the same extract, exchangeable Al was measured by titrating the solution samples with a standard solution of 0.02N HCl. Soil moisture content

was done by gravimetric method and calculated as:
$$Soil\ moisture\ content(\%) = 100(Moist\ soil\ weight - Oven\ dry\ wieght) \div Oven\ dry\ wieght \ldots\ldots\ldots\ldots \quad (1)$$

2.6. Phosphorus adsorption study of experimental soils

The incubated soil with and without lime was ground and passed through 2 mm sieve. Then, the air-dried 2 gm of incubated experimental soils with different lime rates and the control (no lime) was tested with a stock solution of 0 and 10 mg P/L P (KH_2PO_4). Each sorption set for P was replicated three times. Phosphorus sorption rate was determined by batch equilibrium methods in which soil samples was agitated with P solutions of known concentrations (Graetz & Nair, 2008). Subsamples of soils were collected from an incubated sample prepared for the study of P-sorption. All soil samples were air-dried at ambient temperature of 25°C crush and sieve through a 2mm sieve. Phosphorus as (KH_2PO_4) was dissolved in a 0.01 M solution of $CaCl_2$ in distilled water. The $CaCl_2$ solution was used as the aqueous solvent phase to improve centrifugation and minimize cation exchange (Fuhrman et al., 2004). According to the method of Fernandes and Coutinho (1994), to study the sorption of P by soils, 2g air-dried samples of each soil was placed in 100ml plastic bottle in order to leave free space for with 25 mLof 0.01M $CaCl_2$ in which the final volume was adjusted to 30mlTwo drops of chloroform were added to suppress microbial growth (Self-Davis et al., 2000). At the end of equilibration period, the soil suspensions were centrifuged at 5000 rpm for 20 minutes. After centrifugation, the soil solution was filtered with a 0.45 µm membrane filter paper and the concentration of P in the clear extract was determined by ascorbic acid method. After the equilibrium, the filtered solution was taken for the measurement of the concentration of initial available P sorbed using a spectrophotometer at a wave length of 880 ηm (John, 2009). Phosphorus that disappeared from the solution was considered as sorbed P which was plotted against P concentration in the solution to obtain a P sorption isotherm. The P sorption data for the soils was fitted into the following forms of Langmuir equation, because linear regression was convenient and best of data-fitting process.

Langmuir equation:
$$\frac{C}{X} = 1/\mathrm{K.Xm} + C/X_m \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$
where, C (mgl^{-1}) was the equilibrium concentration, X ($mg\ kg^{-1}$) was the amount of P adsorbed per unit mass of adsorbent, K ($L\ mg^{-1}$) was a constant related to the energy of sorption, and Xm (mg kg-1) was P sorption maximum. Where,
$$X = C_0V_0 - \frac{C_fV_f}{mass\ of\ soil\ (Kg)} \ldots\ldots\ldots \quad (3)$$
Where, C_o was the initial concentration, C_f is final concentration and V is the volume of solution.

The linear form of equation (2) was obtained by plotting the equilibrium concentration of phosphate (C) against the amount of phosphate adsorbed (X) and the slope of the graph equal to 1/Xm and the intercept of the graph is equal to 1/K.Xm. But, K was easily determined by dividing the slope by intercept.

2.7. Analysis of statistical data

Data generated from analysis and testing linearity between various soil parameters such as soil pH, soil electrical conductivity and soil moisture contents, available P, and sorption patterns were subjected to correlation and regression analysis using SPSS statistical software .

3. Results and Discussion

3.1. Soil pH, Electrical Conductivity and Moisture Content of Experimental Soil

In the present study, results of standard measurement of soil pH using H_2O before the application of agricultural lime are presented in Table 1. As revealed from the result of soil pH data, all of the soils samples collected from the four kebeles were fallen in very strongly acidic media. However, relatively higher (4.89) soil pH-H_2O value was recorded in soils of the agricultural fields of Gute Badiya kebele while lower value (4.63) was recorded in soils of Gara Hudha kebele. As per the rating indicated by Jones (2003), the soil pH values of the agricultural lands of all the sites were very strongly acidic. This may be due to the depletion of basic cations (K, Ca and Mg) from the surface soil caused by crop harvest, deforestation and continuous cultivations exposes the soils to sever acidity of the agricultural lands of the studied District. Electrical conductivity (EC) is the conductance of a soil solution filling the space between two metal surfaces. In the present study, all of the soils collected from the four kebeles were recorded small electrical conductivity values of about 0.03 mS/cm at Wara Babo Migna and a maximum of 1.23 mS/cm was recorded in the soils of Wali Galte Kebele. All of the soil samples have an electrical conductivity values ranging from 0.03-1.23 mS/cm and lies at lower limit of saline soils. This implies that, the soil samples of the four kebeles are non-saline soils with no salinity problem. According to (Azeez & Van Averbeke, 2012), lower soil pH implies higher soil acidity which indicates higher concentration of H+ in the soils solution. The high soil acidity at low pH due to higher concentration of H+ can appear in varying amount in the soil solution may affect the level of electrical conductivity as a result aggravated to soil acidification .Thus, higher concentration of H+ in the soil show a higher values of electrical conductivity.

The soil moisture content of the experimental soils was given in Table 1. Information on soil's moisture content is useful for assessing plant water uptake and consumptive use, depth of water infiltration into soil, water storage capacity of soil, rate and quantity of water movement, deep drainage and leaching of chemicals, soil-strength and soil compact-ability (Foth, 1990). However, soil moisture content can be high or low depending on the presence or absence of rain fall. When comparison are made among the moisture contents of the experimental soils of the present studied kebeles, their moisture content vary from one kebele to another, and it was lowest value 11% in soils of Gute Badiya kebele to the relatively high 18.76% in soils of Wara Babo Migna (Table 1). The variation in percent moisture content of the soils of different Kebeles may be due to differences in their sand, silt and clay fractions and its negative effects with soil respiration.

3.2. Status of soil available Phosphorus and total phosphorus before lime application

The soil P may enter the soil solution by dissolution of inorganic P associated with the soil's solid phase. Result of the present finding indicated, available P content before lime application of the four kebeles varied from 7.91-8.82 ppm (Figure 2). The value was lower in all of the four kebeles. The lower available P content in soils of the present studies sites are related the high degree of P- fixation with Fe and Al and continuous application of mineral P fertilizer sources as indicated by Paulos (1996).

The biogeochemistry of P in soils is complicated. Most acidic soils are also extremely P deficient, a problem usually exacerbated by the presence of active Fe and Al oxides. As per the rating suggested by Jones (2003), available P of the studied District was qualifyin low range, however, numerically better in soils of Gute Badiya kebele and lower in soils of Wali Galte kebele. The distribution of total P content followed a similar pattern to available P distributions and range from 679 to 687 mg kg-1. As per the rating of Landon (1991), medium total P content was observed in the entire soil of studied District, though numerically better in in soil of Gute Badiya kebele (Figure 3). Result of this study is consistent with Chimdi et al. (2013) and Wakene and Heluf (2003), findings who observed that variations in available P contents in soils are related with the intensity of soil disturbance, high degree of P- fixation with Fe and Al ions in the soils. Similarly Tekalign and Haque (1987) and Dawit et al. (2002) reported soil organic matter as the main source of available P and the availability of P in most soils of Ethiopia decline by the impacts of P-fixation, abundant crop harvest, continuous cultivations and erosion.

3.3 Exchangeable acidity and Percent acid and Aluminum saturation

Soil exchangeable acidity, percent acid saturation (PAS), and percent Al saturation show some variations among the four kebeles of Wayu Tuka district and ranged from 1.43 to 2.49cmol (+) kg-1 soil, 5.36 to 9.37% and 3.57 to 6.28%, respectively (Figure 3). These soil exchange properties were affected by soil acidity. This may be due to inherited from acidic parent material, application of ammonium fertilizers, wet climate, high

Table 1: Mean values of pH (H_2O), EC (mS/cm) and Moisture content (%) of experimental soils

Location/Districts	pH (H_2O)	EC (mS/cm)	Moisture content (%)
Gara Hudha	4.63	0.05	15.39
Wara Babo Migna	4.68	0.03	18.76
Wali Galte	4.75	1.23	14.15
Gute Badiya	4.89	0.15	11.01

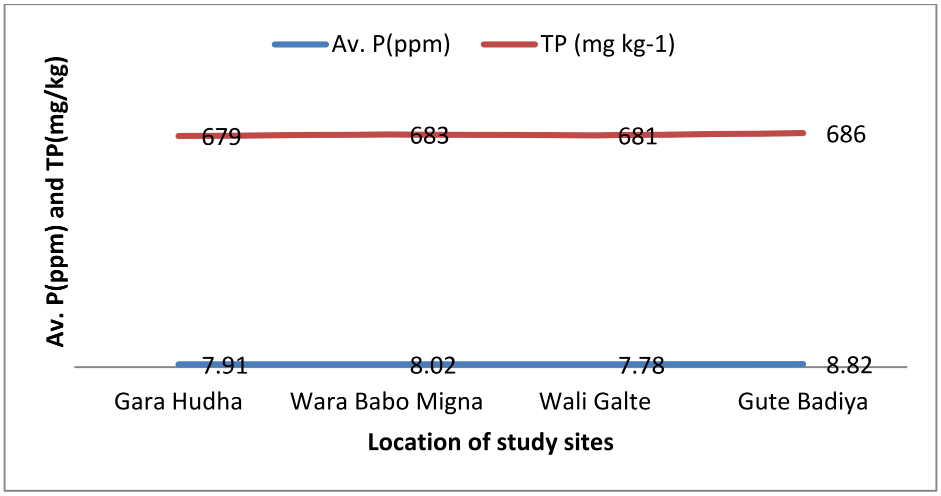
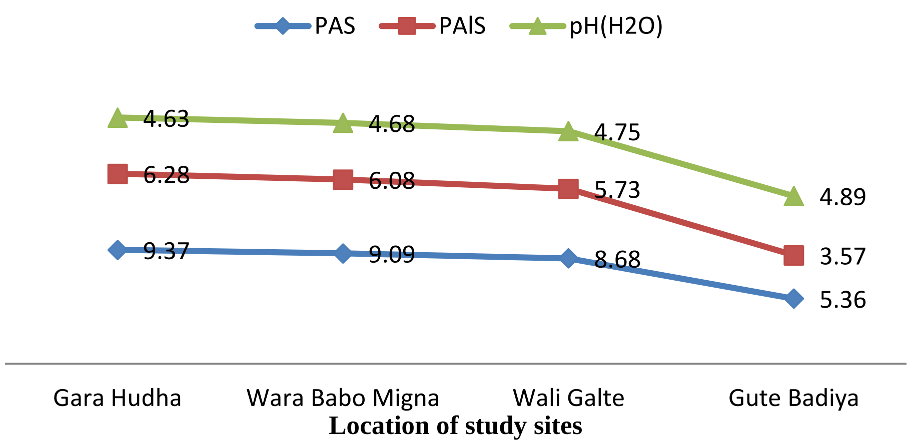


Figure 1: Mean values of available and total phosphorus



PAS= Percent Acid Saturation; PAlS=Percent of Aluminum Saturation

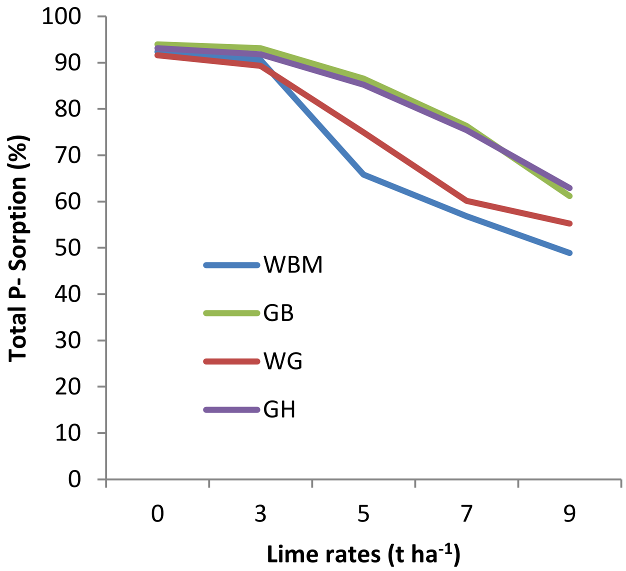
Figure 2: Mean values of acidity related chemical properties of soil of the study area

rainfall and removal of basic elements through the harvest of high yielding crops. The recorded values of exchangeable acidity indicated the ease to manage the acidity problem of soils. Mean values of acidity related soil chemical properties of the study sites were shown below in (Figure 3).

The values of soil exchangeable acidity, percent acid saturation and percent Al saturation levels were higher in soils with low pH in Gara Hudha than the reaming sites. Soil exchangeable acid, percent acid saturation, and percent Al saturation follow the trend of soil pH, as soil pH decreases the values of soil exchangeable acid, percent acid saturation, and percent Al saturation increasing in the soils. This might be due to uses of acid forming fertilizers as source of N and P (urea and diammonium phosphate) for crop production. The value of percent Al saturation ranged from 3.57 to 6.28%. Relatively high value of percent Al saturation was recorded in soil of Gara Hudha kebele. Hence, to reverse the adverse effects of soil acidity and make the soils permissible for crop production, liming and organic materials application was suggested by Fite et al. (2007) and Chimdi et al. (2012). In general, strongly acidic soils could be managed by using lime, whereas moderately acidic soil by growing acid-tolerant crop varieties in the study area.

3.4. Effect of lime rates on available-P and percent total P-Sorption of soil after incubation

The term sorption was described by McBride (1994) as a continuous process that ranges from adsorption to precipitation reactions. The soil P- sorption isotherms are widely used to describe P sorption desorption characteristics in soils and to predict the risk of P loss to fresh water. Liming rose soil pH available P, while it reduced exchangeable Al and Fe and also P sorption. This is mainly, because of the likely displacement of $Al^{3+,}$ H^+ and Fe^{3+} ions by Ca^{2+} ions. This also led to a decrease of percent P adsorption of soils. Due to the application of the different rates of the agricultural lime,



results of the present study revealed the increment of available P and decease of the percent total P-adsorption characteristics of the soils, and shown in (Figures 4 and 5).

Figure 4: Effect of lime rates on percent total P-Sorption of soils.

Table 2: Regression equations of extent of P sorption as affected by lime application rate.

Sites	Regression equation	R^2
WBM	Y= -5.38x +96.73	0.91
GB	Y= -3.61x +90.88	0.85
WG	Y= -4.53x +96.04	0.92
GH	Y= -3.39x +97.95	0.88
x=lime rates (t ha^{-1}); Y= total P-sorption (%)		
WBM= Wara Babo Migna, GB= Gute Badiya; WG= Wali Galte; GH=Gara Hudha		

The R^2 values of the regression equation of the experimental soils were relatively high and ranges from 0.85-0.92, where the lower and the higher R^2 value were respectively recorded at Gute Badiya and Wali Galte kebeles. The positive values of R^2 obtained from the regression equation under the study sites of each districts indicated that there was strong negative positive relationship of the percent total P sorption with the incubation of soils with different application of the lime rates (Figure 5). Liming of acidic soils could increase soil pH, which enhances the release of phosphate ions fixed by Al3+, H+ and Fe3+ ions into the soil solution and likely displacement of Al 3+, H+ and Fe 3+ ions by Ca 2+ ions it contains. Moreover, the increment of available P content of the soils collected from each Kebele with increasing application lime rate may be attributed to increasing pH due to liming that could release the unavailable P which was previously fixed with Al and Fe at low soil pH condition. Therefore, agricultural liming material added to soil is beneficial to acid soil and enhances the P availability to the soils. Liming and thus raising the pH of acidic soil generally provide more favorable environments for microbial activities and possibly results in net mineralization of soil organic P (Lu et al., 2000).

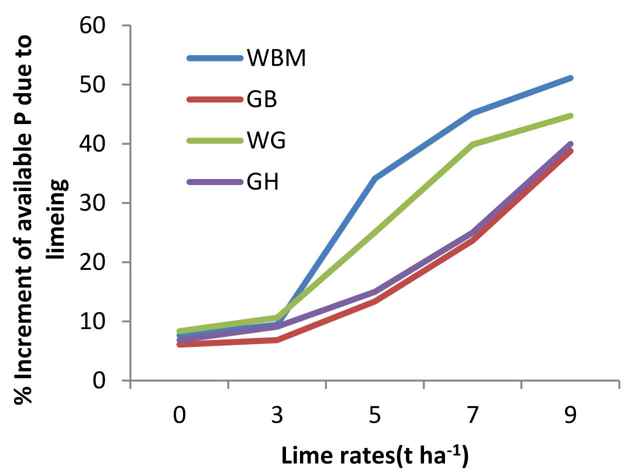


Figure 5: Effects of lime rates on the P-availability of soils

Table 3: Regression equations of the extent of P availability as affected by lime application rate.

Sites	Regression equation	R^2
WBM	Y= 5.47x +3.25	0.95
GB	Y= 3.61x +0.42	0.85
WG	Y= 4.53x +3.96	0.92
GH	Y= 3.62x +1.80	0.87
X = lime rates (t ha^{-1}); Y=increment of p availability		
WBM= Wara Babo Migna, GB= Gute Badiya; WG= Wali Galte; GH=Gara Hudha		

The R^2 values of the Langmuir regression equation of the experimental soils were relatively high and ranged from 0.85-0.95, where the lower and the higher R^2 value were respectively recorded at Gute Badiya and Wara Babo Migna Kebeles. The positive values of R^2 obtained from the regression equation under the study sites of each Kebele indicated that there was strong positive relationship of the increment of P availability with the incubation of soils with different application of the lime rates (Figure 4). The values of R^2 of Langmuir regression equations indicated that, sorption behavior was described by the linearized Langmuir sorption model with regression coefficient (R^2>0.85) observed for all the four studied kebeles. The soils differed relatively in sorption characteristics with different studied kebeles. It indicates that higher values of R^2 more fit the models. The goodness of fit of the model was ascertained by looking at the R^2 values. All the plots were highly correlated with R^2 values ≥ 0.85 indicating apparent high conformity of the adsorption data to the Langmuir model. The average percent of total p-sorption of the agricultural lands of the four kebeles decreased from 93% in the control (no lime) to 57% at lime rate of 9 t ha-1 (Figure 6). On the other hand, percent increment of average available P of the soils of the agricultural lands was from 7.2% in the control (no lime) to 43.6% for the lime rate of 9 t ha^{-1}. Due to the application of different rates of the agricultural lime, when the percent increment of available P of soils of all the studied soils increased with increasing lime rate may be attributed to increasing pH due to liming that could release the unavailable P which was previously fixed with Al and Fe at low soil pH condition. Liming and thus raising the pH of acidic soil across the agricultural lands of the four kebeles generally provide more favorable environments for microbial activities and possibly results in net decrease in total percent P-sorption of the soils.

When comparisons of total P sorption patterns and percent increment of available P made among the four kebeles are made for the lime rate of 9 t ha-1 there were high percent promotions of available P and low soil P fixation in Wara Babo Migna kebele and the reverse was true in soils of Gara Hudha kebele. The reason for these inverse relationships between the increment of percent available P and decrease of percent total P sorption patterns were due to positive and negative effects of exchangeable bases and acids in the soil solutions, respectively. That is, as the rates of agricultural lime applied to the soil increased the concentration of exchangeable bases like Ca^{2+} in the soil solution increases thereby decreasing the percent total P sorption patterns and exchangeable acid (Al and H) ions from the soil exchange complex.

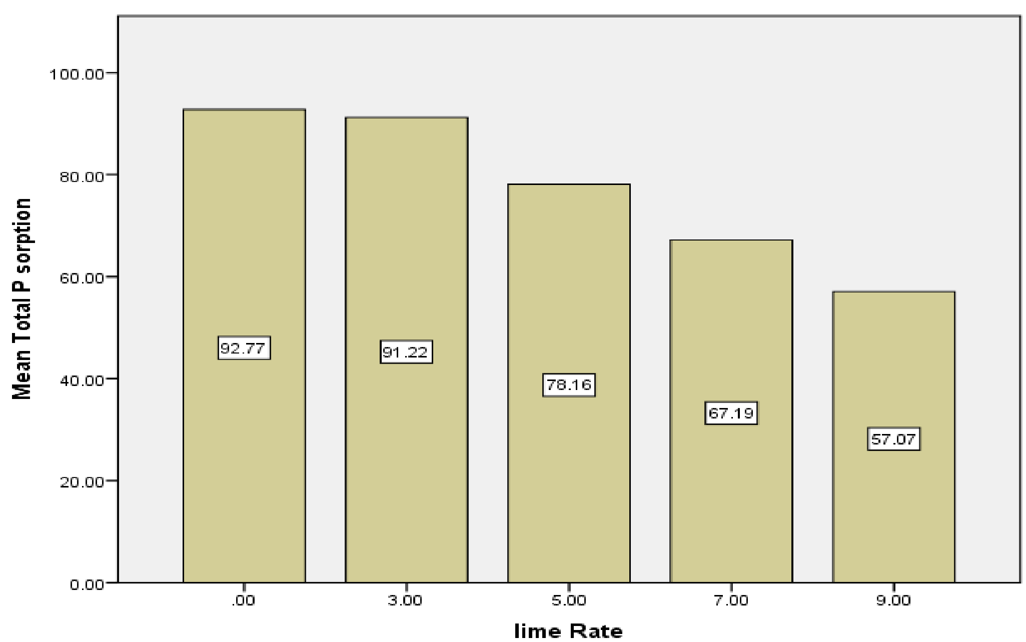


Figure 3: Effects of lime rates on the mean percent total P- Sorption of experimental soils.

4. Conclusion

Soil P is an essential plant nutrient, and its deficiency in soils severely restricts crop yields. Tropical and subtropical soils are predominantly acidic and often extremely deficient in P. Results of this study revealed that, all of the soils samples collected from the four kebeles (Gara Hudha, Wali Galte, Wara Babo Migna and Gute Badiya) were fallen in very strongly acidic (4.63-4.89) media and have an electrical conductivity values ranging from 0.03-1.23 mS/cm. The available P content before lime application of the four Kebeles varied from 7.91-8.82 ppm which was qualifying the low range. However, due to the application of the different rates of the agricultural lime, revealed the increment and decease of the available P and P-sorption patterns of the soils, respectively. Hence, the application of agricultural lime into soil have positive effect to alleviate the inherent acidity of the soils through its ability to neutralize the soil acidity thereby increasing soil pH and the concentration of the basic nutrient such as available P in the soil solutions for plant uptakes. However, further research work may be recommended to validate the findings of the present greenhouse incubation study and for more intensive inclusions of the soil chemical, physical and mineralogical properties and reliable information of the effect of soil properties in predicting soil P sorption patterns at different acidic soils areas is suggested in the field.

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