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Original Research

Assessment of the Severity of Acid Saturations on Soils Collected from Cultivated Lands of East Wollega Zone, Ethiopia

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Abstract

The study was conducted during 2014 on acidic soils collected from agricultural lands of selected Districts of East Wollega Zone and its aim was to determine the status, extents and rating of the level acid saturation percentages of the soils of agricultural lands of the study area. Field observation and soil surveys on acidic soils of agricultural lands of the study areas were carried out and then delineated and dug on different landscape positions. Representative composite soil samples were collected from agricultural fields of the soil surfaces (0-20 cm) depth and analyzed at Nekemte and Holleta Soil Research Center Laboratory for soil pH, Aluminum saturation, exchangeable hydrogen, exchangeable acids and bases as well as soil available and total phosphorus. Laboratory analysis was determined based up on their corresponding standard procedures. Data generated were subjected to analysis of variance using SAS software version, 9. The results of the study revealed that the soils in the entire agricultural fields of the studied districts of East Wollega Zone are ranged the soil pH(H_2O) from 4.63 to 6.01 which rated as very strongly acidic at Wayu Tuka to moderately acidic at Gida Ayana District. Highest (71.85%) and lowest (17.45%) PAS were recorded in the soils collected from Wayu Tuka and Diga Districts, respectively. The inverse relationship of exchangeable acidity and PAS with PBS may be attributed to intensive cultivation which leads to the higher exchangeable acidity content in soils collected from Wayu Tuka District than the remaining agricultural fields. The status of soil acidity in almost all the agricultural field of present study are beyond acidity tolerance limit of acid sensitive crops in the area. Therefore, due attention must be given to minimize the severity of Al toxicity of the soils with high PAS in the area, to reinstate intensively cultivated agricultural fields by improving the soil properties through crop rotation, returning crop residues to the fields and by using different amendment options such as agricultural liming materials.

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INTRODUCTION

Soil acidification is a natural process mainly conditioned by naturally acidic parent rocks and leaching of base forming ions which attributed to high precipitation. Although soil acidity is naturally occurring in some areas, in many others cases, agricultural practices have accelerated the process of soil acidification. Normally, the indication for high soil acidification in the soil solution is associated with the presence of pH levels lower than 5.5 and high exchangeable acidity as well as aluminum saturation (Al). When soil pH drops (pH < 5) active form of Al becomes soluble and results in reduced nutrient uptake. Inadequate crop growth on acid soils is usually a direct result of Al saturation. The negative effects of soil acidity on soil biodiversity and crop growth are related to the deficiency of major nutrients and the toxicity of Al, manganese (Mn) and hydrogen (H) ions in the soil to plant physiological processes. In addition, Differences in land use patterns also play a vital role in governing the spatial variation in soil physicochemical and biological properties under different land use systems, land productivity, and farming practices (Ahmed, 2002; Achalu *et al*., 2012a).

Due to this acidic nature, most of the soils of the highlands of Ethiopia are deficient in inherent available P content. Likewise, in most areas of western Oromia Region, soil acidity and P fixation are the major limiting factors and serious problems to P-use efficiency and has detrimental influences on the growth performances of acid sensitive crop production like barley (Achalu *et al*., 2012b). Because, in acidic soils, plant growth is often limited by Al toxicity and this is characterized by marked reduction in shoot and particularly roots growth by preventing the plants from using available soil P effectively and moreover, nutrients deteriorated land, like the cultivated land may indicate risk to the sustainable crop production and soil fertility (Curtin and Syres, 2001; Achalu *et al*., 2012a). Soil acidity due to aluminum toxicity is a common problem that has major ramifications for plant growth such as barley, wheat and causes significant losses in production, especially in the high rainfall areas of western Oromia.

Now a day, in Ethiopia 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 (Wakene and Heluf, 2003; Abdenna , 2013; Achalu *et al*., 2013a-c) have been made on soil p availability, dynamics and fertility status as well as on the properties, and reclamation procedures of soil acidity in some parts of Western Oromia highlands. However, the severity of the problem of acid saturations on soils collected from cultivated lands of the suspect Districts of East Wollega Zone were not yet studied and rated in sufficient detail. Most of the Districts of the East Wollega Zone where the present research study conducted also share these problems. Therefore, to fill the gap the present study explored the severity of acid saturation the agricultural lands and its extents as well as rating of the acid saturation percentages of the soil of the selected Districts of East Wollega Zone.

MATERIALS AND METHODS

General Description of the Study Area

The study was conducted in the Districts of East Wollega Zone of Oromia Regional State, western highlands of Ethiopia (Figure 1). According to the FAO (1990) classification legend, the main soil group of most of the East Wollega areas is Nitisols. Similar to most parts of the country, the economic activities of the local community of the study area are primarily mixed farming system that involves crop production and animal husbandry. The major crops grown in the area are coffee (*Coffee arabica* L*.)*, teff *(Eragrostis tef),* barley *(Hordeum vulgare* L*)*, 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 land use system and most natural forest has been cleared for crop production and local fuel. These environmentally unfriendly 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; Achalu *et al*., 2012b).

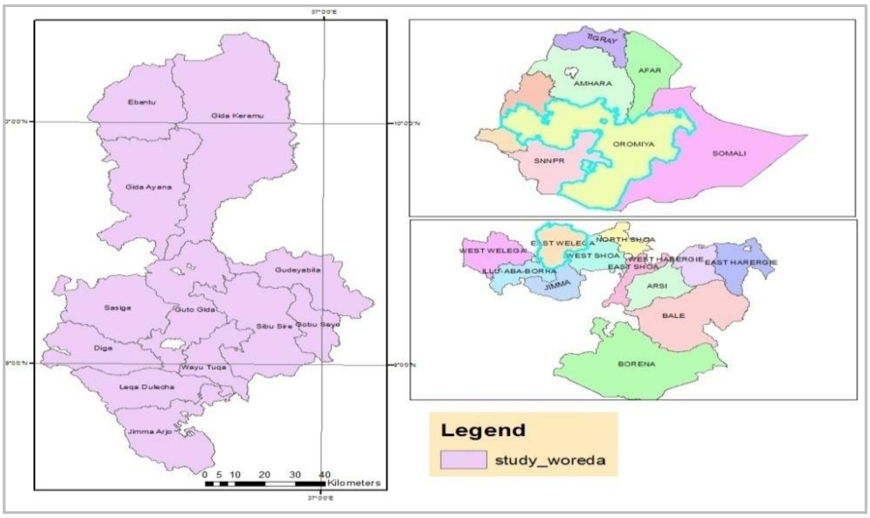

Figure 1: General location map of the study area

Site Selection, Soil Sampling and Preparation

Preliminary survey and field observation was carried out. Based on field observation and soil surveys, acidic soils of agricultural land was delineated and dug on different landscape positions and then samples was collected from the soil surfaces (0-20 cm) depth. Then composite sample (after being well mixed in a bucket) of about 2 kg of the mixed sub-samples (composite sample) was properly bagged, labeled and transported to the laboratory for analysis of acidity related soil chemical properties.

Laboratory Analysis of Soil Samples

The soil pH was measured potentiometrically with a digital pH meter in the supernatant suspension of 1:2.5 soils to water ratio (Baruah and Barthakur, 1997). Soil available P was extracted by the Bray-II method (Bray and Kurtz, 1945) and quantified using spectrophotometer (wave length of 880 ηm) colorimetrically using vanadomolybedate acid as an indicator. The soil electrical conductivity measurement was done using a conductivity meter at 25ºc using its standard procedures.

Exchangeable basic (Ca, Mg, K and Na) ions were extracted using 1 M ammonium acetate (NH_4OAc) solution at pH 7. The extracts of Ca and Mg ions were determined using AAS while K and Na were determined by flame photometer. To determine the cation exchange capacity (CEC), the soil samples were first leached with 1 M NH_4OAc, washed with ethanol and the adsorbed ammonium was replaced by Na (Chapman, 1965). The CEC was then measured titrimetrically by distillation of ammonia that was displaced by Na following the micro-Kjeldahl procedure. Total exchangeable acidity was determined by saturating the soil samples with 1M KCl solution and titrated with 0.02M HCl as described by Rowell (1994). From the same extract, exchangeable Al in the soil was titrating and analyzed using with a standard solution of 0.02M HCl and finally percent Al saturation was calculated from the ratio of exchangeable Al to the CEC as a percent. The soil percent base saturation (PBS) was calculated from sum of the basic exchangeable cations (Ca, Mg, K and Na) as the percentage of CEC. From the composite soil samples total P was determined using perchloric acid digestion method as described by (Kuo, 1996). Available P was analyzed using Bray-II method colorimetrically using vanadomolybedate acid as an indicator and its concentration was measured using spectrophotometer at a wave length of 880nm. Soil moisture content was done by gravimetric method and calculated as:

Soil moisture content (%) =

$$100 \times \frac{(\text{Moist soil weight. - Oven dry soil weight.})}{(\text{Oven dry soil weight.})}$$

Statistical Analysis

Data recorded were subjected to analysis of variance using SAS software version 9.1 (SAS Institute, 2004. Different rates of classification of acid and Al saturation classified by different researcher was compared to classify the acid saturation of the different locations of the soils of the study area.

RESULTS AND DISCUSSION

Soil pH (H_2O, $CaCl_2$ and KCl) and Electrical Conductivity

Soil pH is one of the most common and important measurements in standard soil analyses. Many soil chemical and biological reactions are controlled by the pH of the soil solution in equilibrium with the soil particle surfaces. In the present study, results of standard measurement of soil pH using H_2O, $CaCl_2$ and KCl are presented in (Figure 1 and Table 1). Higher (6.01) soil pH-H_2O value was recorded in soils of the agricultural fields of Gida Ayana (GA) Districts while lower value (4.63) was recorded in soils of Wayu Tuka (WT) Districts (Tables 1 and Figure 2). As per the rating indicated by Jones (2003) the soil pH values of the agricultural lands were found to be varying from very strongly acidic for agricultural lands of WT District soil to moderately medium acidic soil reaction for the agricultural land of GA District. The lower value of soil pH under the agricultural land of WT Districts may be due to the depletion of basic cations in crop harvest and due to its highest microbial oxidation that produces organic acids, which provide H ions to the soil solution lowers its soil pH value.

Table 1: Mean values of chemical properties of agricultural lands of experimental soils

Location	pH (H_2O)	EC (mS/cm)	% OM	% N	C:N ratio	Av. P (ppm)	Av. K (mg/kg)	CEC (Meq/100g soil)
SS	5.22	0.151	3.13	0.156	11.641	8.75	1.04	43.15
GB	5.17	0.154	3.14	0.156	11.571	8.12	0.89	42.74
SA	4.93	0.043	6.47	0.320	11.606	7.34	0.35	40.75
DI	5.37	0.023	7.82	0.387	11.622	10.27	3.38	44.39
KI	4.68	0.033	5.036	0.249	11.601	7.68	0.24	38.69
LD	5.17	0.037	4.123	0.206	11.610	8.79	0.06	43.54
GS	5.90	0.221	5.489	0.272	11.584	9.06	3.55	48.79
WT	4.63	0.049	5.213	0.258	11.600	7.57	0.46	38.30
JA	4.89	0.147	8.102	0.401	11.598	8.03	0.83	40.31
GA	6.01	0.240	8.69	0.430	11.602	11.3	3.18	49.71
GG	4.75	1.226	3.968	0.196	11.622	7.45	1.03	39.27
EB	5.26	0.151	3.170	0.156	11.660	8.14	1.05	43.50

DI= Diga; EB= Ebantu; GA= Gida Ayana; GB= gudeya Billa; GG= Guto Gida; GS= Gobu Sayo; JA= Jimma Arjo; KI= Kiremu; LD= Leqa Dullecha; SA=Sasiga; SS=Sibu Sire; WT=Wayu Tuka

Moreover, the acidic nature with low soil pH obtained from all the representative agricultural lands of all the Districts may be attributed to the fact that, soils were derived from weathering of acidic igneous granites and leaching of basic cations such as K, Ca and Mg from the surface soil (Frossard *et al.,* 2000). In this study, deforestation and continuous cropping mainly contributed to depletion of basic cations and CEC on the most of the agricultural lands of the studied Districts as compared to the remaining agricultural lands. When comparison are made between the soil pH values that were analyzed using the methods of (H_2O, $CaCl_2$ and KCl), for the agricultural lands of all the studied Districts was lower when analyzed using KCl and higher for H_2O (Figure 2).

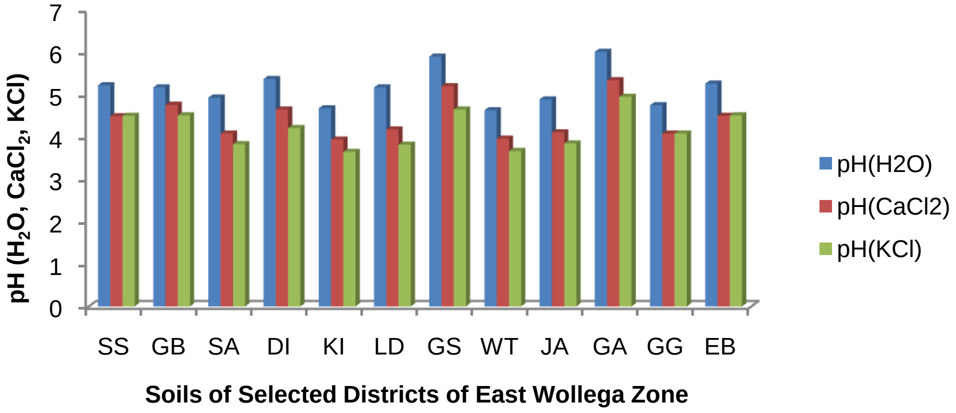

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Figure 2: Soil pH values using (H_2O, $CaCl_2$ and KCl) of the selected districts of East Wollega Zone

Electrical conductivity (EC) is a measure of soil salinity. The ability of soil solutions to conduct electricity (i.e. conductance) depends on the concentration of the ions present and their electrical charge. Electrical conductivity is the conductance of a soil solution filling the space between two metal surfaces 1m apart, each with an area of $1m^2$.The conductivity meter measures the current passing through a solution between two electrodes in a conductive cell. In the present study, all of the soils collected from different districts were recorded small electrical conductivity values of about 0.023 mS/cm at Diga(DI) District and a maximum of 1.226 mS/cm was recorded for the soils collected from Guto Gida (GG) District. All of the soil samples have an electrical conductivity values ranging from 0.023-1.226 mS/cm and lies at lower limit of saline soils. Hence the soil samples are non saline soils. Plants growing in these areas do not have the problem of absorbing water because of the lower osmotic effect of dissolved salt contents.

Soil Organic Carbon, Total Nitrogen and Carbon to Nitrogen (C: N) Ratio

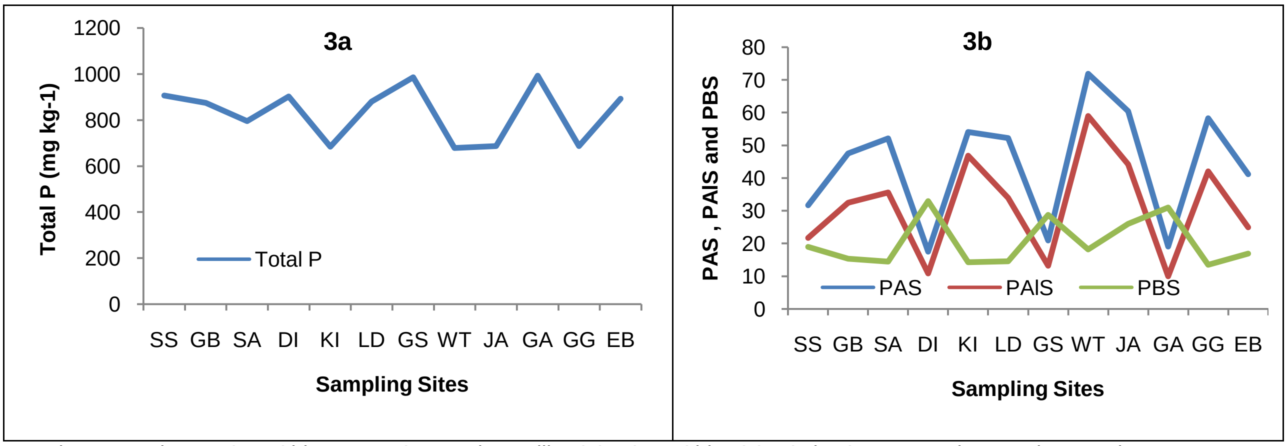
Soil organic carbon (SOC) must be among the most commonly analyzed soil constituents, starting with the earliest soil investigations. Measuring soil organic carbon to quantify soil C ‘‘sinks’’ requires more stringent sampling and analyses than measuring soil organic carbon to evaluate productivity. Total soil N includes all forms of inorganic and organic soil N. Inorganic N includes soluble forms such as NO_2^- and NO_3^-, exchangeable NH_4^+, and clay-fixed non exchangeable NH_4^+. Organic N content includes numerous identifiable and non identifiable forms (Stevenson, 1986) and can be determined by the difference between total soil N and inorganic soil N content. When comparisons are made between the different locations of the agricultural lands, the experimental data of present study recoded higher percent organic matter (OM) content for the GA soils and lower for Sibu Sire (SS) soils. The higher percent OM content in soils of GA Distric t and lower in (SS) land, respectively, attribute to plant litter fall which abundantly returned to soil surface enhancing the fraction of percent SOM in soils of GA District and the presence of high concentration of iron oxide and aluminum saturation lowers percent OM in SS District. Relative to the agricultural land of GA District, percent OM contents in soils of SS land depleted by 64%, (Table 1). The depletion of soil OM was higher in soils of SS and Sasiga (SA) Districts. This is attributed with the fact that, cultivation increases soil aeration which enhances decompositions of SOM and most of the percent SOM produced in soils of SS and SA Districts have been removed with harvest causing for its reduction in values of OM content. As per the rating of nutrients suggested by Tekalign (1991), the soil OM of the different District of the current study site can be categorized as high in the soils of GA, Jimma Arjo (JA), Wayu Tuka, (WT) Gobu Sayo (GS), Diga (DI) and SA Districts and it was rated as medium in the remaining Districts. Studies by Lal, (1996); Mandiringana *et al.* (2005); Michel *et al*. (2010) indicated the decrease of soil OC content due to shifting of natural forest to grass, fallow and to agricultural land. However, there was no significant variation in the value of percent total N, across the soils of all the districts of the present study areas (Table 1) but as suggested by Tekalign (1991), the total N in soils of Sibu Sire (SS), Gudeya Billa (GB), Guto Gida (GG), and Ebantu (EB) Districts were rated as Moderate value of the percent total N and the remaining can be rated as high status of percent total N. Differences in soil organic carbon and total N between the agricultural lands of the Districts of the present study area could arise from the reduction in OM inputs due to removal of biomass during cultivation. Exposure of the top soil to rainfall brings about erosion, rapid decomposition of soil OM and intense leaching of basic nutrients rendering the soil infertile and the agricultural production unsustainable. Moreover, the reduction in the total N contents of the soils of the present study sites due to cultivation is affected among others by the reduction of soil OM content. Relatively, the agricultural land across all the Districts of the present study area recorded narrow and almost similar C/ N ratio (Table 1). However, slight numerical variation in C/N was observed among all the Districts of the study area. The narrow C/N ratio at the surface soil may be due to higher microbial activity and more CO_2 evolution and its loss to the atmosphere in the surface (0-20 cm) soil layer.

Available and Total Phosphorus of the Soils

Since the plant obtains phosphorus (P) from the soil solution through its roots or root symbionts, available P is composed of solution P plus P that enters the solution during the period used to define availability. Phosphorus may enter the solution by desorption or dissolution of inorganic P associated with the soil’s solid phase, or by the mineralization of organic P. Result of the present finding indicated that, the available P content in the top soils of the agricultural lands varied from 7.34-11.30 ppm using Bray-II method. The value was lower in the agricultural land of SA District and relatively higher in GA Districts (Table 1 and Figure 3). Generally, variations in available P content in soils are related with the intensity of soil weathering or soil disturbance, the degree of P-fixation with Fe and Ca and continuous application of mineral P fertilizer sources as indicated by Paulos (1996).

As per the rating suggested by Jones (2003), the available P of soils of all the agricultural lands of the studied Districts were qualifying from very low to low range, however, numerically better in the soils of the agricultural lands of GA and DI Districts and lower in soils of Sasiga (SA) Districts (Bray-II method). The relatively higher value of the available Pat GA and DI Districts may be because of the forest vegetation which absorb larger amount of available P with their larger biomass. However, the lower available P in soils of SA District may be due to lower SOM status and dominance of the HPO_4^{1-} anion in strongly acidic soils than $H_2PO_4^{-2}$ anion (Mishra *et al.*, 2004). Result of this study is consistent with Achalu *et al*. (2012a) finding who observed that variations in available P contents in soils are related with the intensity of soil disturbance, the degree of P- fixation with Fe and Ca ions.

Similarly, Tekalign and Haque (1987) and Dawit *et al*. (2002) reported SOM as the main source of available P and the availability of P in most soils of Ethiopia decline by the impacts of fixation, abundant crop harvest and erosion. The distribution of total P content followed a similar pattern to available P distributions and ranged from 678 to 993 mg kg^{-1}. As per the ratings of Landon (1991), medium total P content was observed in all agricultural lands of the studied Districts, though numerically higher in the Agricultural lands of GA District (Figure 3).



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Figures 3 (a and b): Total phosphorus, Percent Acid (PAS), Aluminum (PAlS) and percent Base Saturation (PBS)of Experimental Soils

Soil Percent Base Saturation and Cation Exchange Capacity

When comparison are made among the Percent Base Saturation **(**PBS) of the experimental soils of the studied Districts, the PBS of soils of the different districts of the present study area vary from one District to another, and it was lowest value 4.18% in soils of SA district to the highest value 37.86% in soils of GA District. However, as per the ratings recommended by Hazelton and Murphy (2007), the value of PBS of the top soil (0-20 cm) depth of the agricultural lands of SA, SS, GB, LD, GG and EB Districts can be classified as very low status of PBS and it were classified as low and moderate for the remaining agricultural lands. In general, processes that affect the extent of basic cations also affect percent base saturation.

The cation exchange capacity (CEC) of soils ranged from 38.30 Meq/100g of soil in the soils of the agricultural land of JA District to 49.71 Meq /100g of soil in the soils of the agricultural land of GA District. As per the ratings recommended by Hazelton and Murphy (2007), the CEC value of the top soil (0-20 cm depth) of all of the agricultural lands of the present study qualifies for very high where as soils of KI, WT and EB Districts classified as high status of CEC value (Table 1). The relatively very higher and high CEC values recorded, across the soils mentioned above may be attributed to the fact that soils which recorded very high CEC accumulate high percent OC and has greater capacity to hold cations thereby resulted greater potential fertility in the soil.

Soil Exchangeable Aluminum and its Percent Saturation

In strongly acidic soils, Al^{3+} becomes soluble and increase soil acidity while in alkaline soils, exchangeable basic cations tend to occupy the exchange sites of the soils by replacing exchangeable H and Al ions .The amount of exchangeable acidity is largely a function of soil pH and the exchange capacity. In most soils, the exchangeable acidity will be composed of exchangeable H^+, exchangeable Al as either Al^{3+} or partially neutralized Al-OH compounds such as $AlOH_2$ or $Al(OH)^{+2}$, and weak organic acids (Brady and Weil, 2002). The highest (2.89 Meq/100g soil) and the lowest (1.29 Meq/100g soil) exchangeable aluminum were recorded under the JA and the GA lands, respectively (Figure 4). These results show that deforestation, intensive cultivation and application of inorganic fertilizers leads to the higher exchangeable acidity and aluminum content under the crop field of almost all the studied Districts of the East Wollega Zone. The results of this study were in agreement with those reported by different researchers (Baligar *et al*., 1997; Wakene, 2001; Abdenna, 2013), who reported that inorganic fertilizer application is the root cause of soil acidity.

In soils of almost all the agricultural lands of the present study areas, there was inverse relationship between the exchangeable acidity and base saturation. The inverse relationship of exchangeable acidity and PAS with PBS may be attributed to deforestation and intensive cultivation which leads to the higher exchangeable acidity content in soils. Because the more acid the soil, the greater Al will be dissolved into the soil. Once the soil pH is lowered much below 5.5, aluminosilicate clays and Al-hydroxide minerals begin to dissolve and release Al-hydroxy cations from soil colloids and fractions of exchange sites occupied by Al-H. The soil chemical reaction processes that affect the extent of acidic cations (Al^{3+} and H^+) also affect the PAS. For instance, in the present study, the contribution of Al percentage in making soils of WT acidic was 59.02% while it was 9.96 and 10.89% in the soils of Gida Ayana and Diga Districts, respectively (Figure 4). At low soil pH, oxides of Al and Fe get in to soil solution and through stepwise hydrolysis and releases H^+ ions resulting in to further soil acidification. In the present study, higher exchangeable acidity and percent Al saturation were recorded in the soils of JA and WT Districts, respectively.

Soil Exchangeable Acidity and Percent Acid Saturation

The agricultural land of the soil sample collected from DI District showed lower values of percent acid saturation. The highest (3.96 cmol (+) kg-) exchangeable acidity in soil of JA and the lowest (1.94 cmol (+) kg-) in the soil collected from agricultural land of KI District were recorded (Table 1). Highest (71.85%) and lowest (17.45%) PAS were recorded in the soils collected from WT and DI District, respectively (Figure 3b and 4). The inverse relationship of exchangeable acidity and PAS with PBS may be attributed to intensive cultivation which leads to the higher exchangeable acidity content in soils collected from WT District than the remaining agricultural lands. Because the more acid the soil, the greater Al will be dissolved into the soil. Once the soil pH is lowered much below 5.5, aluminosilicate clays and Al- hydroxide minerals begin to dissolve and release Al-hydroxy cations from soil colloids and fractions of exchange sites occupied by Al-H. The soil chemical reaction processes that affect the extent of acidic cations (Al^{3+} and H^{+}) also affect the percent acid saturation. For instance, in the present study, the contribution of Al percentage in making soils of WT District acidity was 71.85% while it was 17.45% in the soils of DI District. At low soil pH, oxides of Al and Fe get in to solution and through step wise hydrolysis and releases H^{+} ions resulting in to further soil acidification. In this study, higher exchangeable acidity and percent Al saturation were recorded in the soils of JA District followed by soil of GA 2.46% District. Whereas, the average percent acid saturation of the agricultural lands of the soil of present study area was 43.87% (Table 1 and Figure 4).

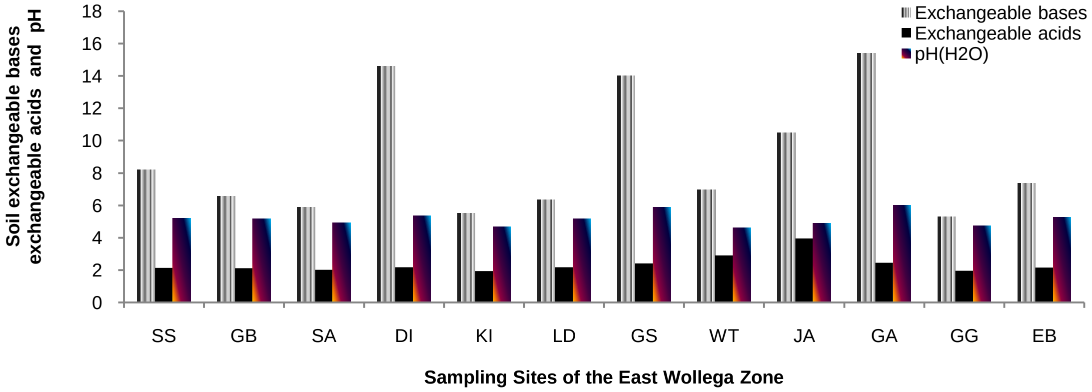

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Figure 4: Contents of soil exchangeable bases and acids of the selected agricultural lands

Moisture Content of Experimental Soils

A quantitative measure of soil's moisture content is important to the understanding soil behavior, plant growth, and soil's numerous other physical processes. 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). Soil moisture content can be high or low depending on the presence or absence of rain fall. Figure 5 presents percent moisture content of the experimental soils considered in the present study. When comparison are made among the moisture contents of the experimental soils of the studied Districts, the moisture content of soils of the different Districts vary from one District to another, and it was lowest value 11% in soils of JA District to the highest value 30% in soils of SS District (Figure 5). The variation in percent moisture content of the soils of different district may be due to differences in their sand, silt and clay fractions.

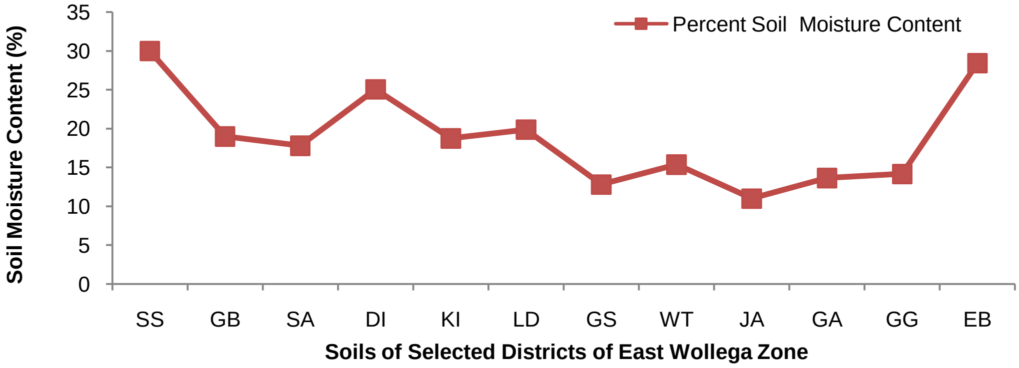

Figure 5: Percent moisture contents of experimental soils

CONCLUSIONS

Soil acidity due to aluminum toxicity is a common problem that has major ramifications for plant growth such as barley, wheat and causes significant losses in production, especially in the high rainfall areas of western Oromia. Most of the Districts of the East Wollega Zones where the present research study conducted also share these problems however; the degree of acidity varies across Districts and the acidity varies from very strongly to strongly acidic while a few soils are moderately to slightly acidic. Although, the soils have high exchangeable Al and PAS, the degree of acidity varies across districts. Accordingly, the contribution of Al percentage in making soils of WT acidic was 59.02% while it was 9.96 and 10.89% in the soils of GA and DI Districts, respectively. In line with this, Highest (71.85%) and lowest (17.45%) PAS were recorded in soils collected from WT and DI Districts, respectively. Therefore, due attention must be given to minimize the severity of aluminum toxicity of the soils with high PAS in the study area, to reinstate intensively cultivated agricultural fields by improving the soil properties through crop rotation, returning crop residues to the fields and by using different amendment options such as agricultural liming materials.

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