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Soils Characteristics in Maize Based Farming System of Western Oromia, Ethiopia

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Abstract: Understanding soil fertility status is a prerequisite to implement appropriate soil management practices for sustainable agricultural production and productivity. In view of this, a study was conducted at Kejo and Ongobo farmers' fields, located at GobuSeyo District of East Wollega Zone of Oromia region in 2011. To investigate soil characteristics, Soil samples were collected from the profiles of the genetic horizons for the analyzing the selected physicochemical properties. The results of the study revealed that the soils had strong coarse sub angular blocky structure at Ap horizon, whereas to angular blocky structures at the B horizon. The soil textural class of both profiles was clayey with the clay fractions being the highest and increased consistently with depth. The bulk density values ranging from 1.25 g cm^{-3} at the Ap horizon to 1.40 g cm^{-3} at the Bt4 horizon. The pH-H$_2$O were strongly acidic ranging from 5.27 at the Ap horizon to 5.83 at Bt2 horizon. The soil organic matter (SOM) contents of the soils ranging from 0.62% at the Bt2 horizon to 3.78% at the surface horizon, whereas total N ranging from 0.03 to 0.19%, available P from 0.62 to 4.0 mg kg^{-1} and CEC from 11.84 to 22.47 cmol$_c$kg^{-1} soil. Available Fe ranging from 7.24 to 33.68 mg kg^{-1}, Mn from 2.37 to 83.91 mg kg^{-1}, Zn from 0.013 to 0.314 mg kg^{-1} and Cu from 0.16 to 2.32 mg kg^{-1} in the soil and showed decreasing trend with profile depth. The result of the study showed that the soils of the study sites had poor chemical fertility and integrated soil fertility management practices can improve the current situation.

Keywords: Soil Characteristics, Soil Chemical Fertility, Soil Horizon

1. Introduction

Agriculture is the predominant economic sector in the majority of the developing countries in the world [1]. People are dependent on soils and, conversely, good soils are dependent on people and the uses they make of the land [2]. Crop yields in the developed world are high and agricultural soils have high fertility status due to intensive use of fertilizers [3]. This implies that using chemical fertilizer plays significant role in increasing food production to meet the demand of the growing world population. On the other hand, sub Saharan Africa is characterized by diverse agricultural systems that are typically low input based subsistence farming systems [4]. These soils have been sustaining agricultural production for centuries; as a result, their native fertility has been extremely low [5]. Soil fertility replenishment has, therefore, been singled out as the necessary, but not sufficient condition for sustainable development in Africa [6].

The low nutrient levels in the soil are caused by crop removal of nutrients from the soil, little or no fertilizer application, and total removal of crop residues from the farmland and burning. Nowadays, due to increasing population pressure and shortage of land, deforestation and cultivation activities are being carried out on steep slopes, which accelerate soil erosion [7, 59]. Moreover, the shortage of land for production of food crops has eliminated the practice of fallowing and crop rotation. According to [8] soil fertility management on small farms in the tropics has become a major issue, as a result of continued land degradation and rapid population growth. Furthermore, shortage of grasslands (grazing areas) has forced the farmers to remove crop residues for animal feed. Since the study area receives high rainfall, leaching may also cause nutrient losses and soil acidity. Continuous cultivation of the soils for many years without replenishing the nutrients mined has negatively affected fertility and availability of nutrients. [9] also stated that cultivated weathered soils commonly suffer from multiple nutrient deficiencies, and nutrient balances are generally

negative. The loss of soil fertility from continual nutrient mining by crop removal without adequate replenishment, combined with imbalanced plant nutrition practices, has posed a serious threat to agricultural production [10].

Soil fertility and plant nutrition are two closely related subjects that emphasize the forms and availability of nutrients in soils, their movement to and their uptake by roots, and the utilization of nutrients within plants [11]. Without maintaining soil fertility, achieving sustainable agricultural production is difficult to feed increasing population. The secret of ensuring food security for the ever increasing world population is strongly linked to the productivity of soils [12].

Application of fertilizer in relation to initial soil fertility status and crop requirement leads to economic and judicious use of fertilizers. Periodic assessment of important soil properties and their responses to changes in land management is necessary in order to improve and maintain the fertility and productivity of soils [13]. Experiments conducted by different researchers to decide rate of fertilizer under different research stations and their surrounding on-farm resulted in different rates of recommendations in terms of both P and N [14]. Trials carried out in many localities across Ethiopia for about nine years also recommend different rates of P and N in accordance to crop and soil types [15]. However, the current maize grain yield has declined regardless of using improved maize varieties and NP fertilizers even in high maize growing potential areas of western Oromia.

Understanding soil fertility status and plant nutrients requirement of a given area has vital role in enhancing crop production and productivity on sustainable basis. Hybrid maize grown with high levels of macronutrients is in many cases causing depletion of micronutrients at a rate that the soil can no longer make good [16]. Nevertheless, little information is available on soil characteristics including macro and micro plant nutrients. Increasing yields through the application of nitrogen and phosphorus alone can deplete other nutrients [17]. However, crop productivity can also be limited because of toxicity and/or deficiency of essential plant nutrients. Therefore, understanding the soil fertility status of an area could help to implement demand-driven soil fertility management practices. Hence, the objective of this study was to assess selected soil properties in smallholder maize based farming systems in western Oromia.

2. Materials and Methods

2.1. General Description of the Study Area

The study was conducted at Kejo and Ongobo peasant associations of GobuSeyo District in East Wollega Zone of Oromia National Regional State, western Ethiopia. GobuSeyo is located at 266 kms west of Addis Ababaat 36°53'11" to 37°03'06" east longitude and 9°01'01" to 9°20'33" north latitudes with altitude ranging from 1500 to 2500 masl. Kejo is located at 37°00'55" east longitude and9°07'05"noth latitude at an altitude of 1808masl; whereas Ongobo is located at 36°59'33" east and 9°05'57"north at an altitude of 1758masl (Figure 1).
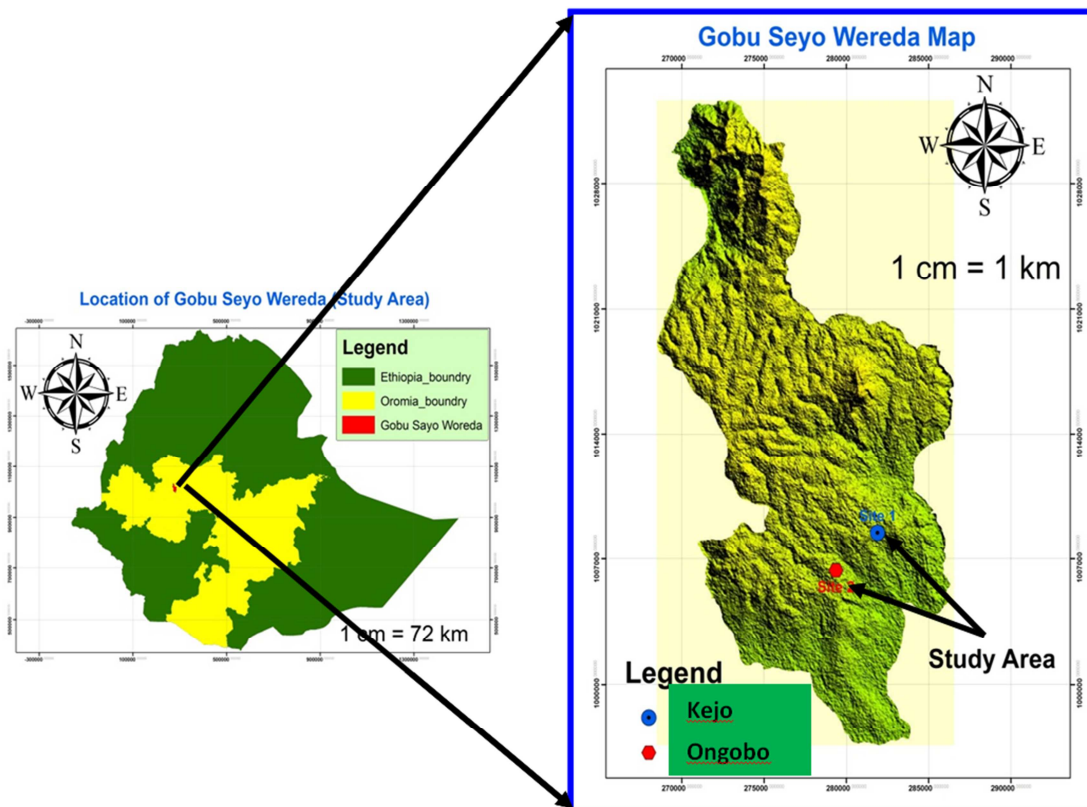

Figure 1. Location map of the study district (GobuSeyo) - East Wollega Zone, OromiaNational Regional State.

The ten years (2002-2011) weather information at nearby study area (Bako Agricultural Research Center) revealed a uni-modal rainfall pattern with average ten years annual rain fall of 1283.4 mmThe rainy season covers April to October and the maximum rainfall is received in the months of June, July and August. The minimum, maximum and average ten years annual air temperatures are 13.5, 28.5 and 21.0°C, respectively, The predominant soil type in southwest and western Ethiopia in general and the study area in particular, is Nitisols according to the [8] soil classification system. Its vernacular name is "*BiyeDima*" meaning red soil. On the average, the soil is deep and relatively highly weathered, well drained, clay in texture and strongly to moderately acidic in reaction. Nitisols are highly weathered soils in the warm and humid areas of the west and southwest Ethiopia [18].

2.2. Soil Sampling and Sample Preparation

A fresh soil profile pits with 1 m width by 2 m length and 2 m depth were excavated at both locations, Kejo and Ongobo. The soil profiles were described for their morphological properties under field conditions, whereas samples were collected on genetic horizon basis for characterization of selected physicochemical properties. The soil properties studied include soil color, structure, consistence, particle size distribution (texture), bulk density (BD), total porosity, pH, organic matter (OM), total N, C: N ratio. available P both (Olsen's and Bray II) methods, available K, cation exchange capacity (CEC), percent base saturation (PBS), exchangeable bases (Ca, Mg, K and Na), exchangeable acidity (exchangeable Al and H), and available micronutrients (Fe, Mn, Cu and Zn).

Moreover, undisturbed soil samples were taken using core sampler from each identified horizon of the profiles for determining bulk density. The collected soil samples were prepared and analyzed following standard laboratory procedures for the selected parameters at Soil and Plant Analysis Laboratory of, DebreZeit Agricultural Research Center.

2.3. Soil Physical and Chemical Analysis

Soil color was determined by Munsell soil color chart [19]. Soil particle size distribution (texture) was analyzed by the hydrometer method following the procedure described by [20]. Soil textural class names were assigned based on the relative contents of the percent sand, silt, and clay separates using the soil textural triangle as described by [21]. Bulk density (BD) was determined from undisturbed (core) soil samples collected using core samplers, and then dried in an oven and the bulk densities were calculated by dividing the masses of the oven dry soils by their respective total volumes. The average soil particle density (PD) value of 2.65 g cm^{-3} for mineral soils was assumed as the PD of the soil. Total porosity was estimated from the BD and PD values as:

$$\text{Total porosity (\%)} = [1-(BD/PD)]\times 100$$

Soil pH was measured potentiometrically using a digital pH-meter in the supernatant suspension of 1: 2.5 soils to liquid ratio where the liquids were water and 1M KCl solution. Organic carbon was determined using the wet oxidation method [22] where the carbon was oxidized under standard conditions with potassium dichromate in sulfuric acid solution. Finally, the organic matter (OM) content of the soil was calculated by multiplying the percent OC by 1.724. The total N content was determined using the Kjeldahl method by oxidizing soil samples with sulfuric acid and converting the N compounds into NH_4^+ as ammonium sulfate. The amount of ammonia present, and thus the amount of nitrogen present in the samples, was determined by back titration. The C: N ratio was computed from the content of the total organic carbon and total N.

Available phosphorus was determined by both Olsen and Bray II methods. In the Olsen procedure, $NaHCO_3$ at nearly constant pH of 8.5 was used as extracting solution [23]. In the Bray II method, ammonium fluoride plus hydrochloric acid (0.03M NH_4F +0.10M HCl) was used as extracting solution. The available phosphorus extracted with the different methods was measured by spectrophotometer. Available potassium was measured by flame photometer following extraction of the soil samples by sodium acetate ($CH_3COONa.3H_2O$).

The exchangeable bases (Ca, Mg, K and Na) in the soil were determined from the leachate of 1M ammonium acetate (NH_4OAc) solution at pH 7.0. Exchangeable Ca and Mg were measured by atomic absorption spectrophotometer, whereas K and Na were read using flame photometer [21]. Similarly, CEC was measured after leaching the NH_4OAc extracted soil samples with 10% NaCl solution. The amount of ammonium ion in the percolate was determined by the usual Kjeldahl procedure and reported as CEC. Finally, PBS was computed as the percentage of the sum of exchangeable bases to the CEC [24].Exchangeable acidity was determined by saturating the soil samples with potassium chloride (1M KCl) solution and titrated with hydrochloric acid (0.02 M HCl) as described by [21]. Available micronutrients (Fe, Mn, Zn and Cu) were extracted from the soil samples with DTPA as described by [25]. All micronutrients extracted with different methods were measured by atomic absorption spectrophotometer.

3. Results and Discussion

3.1. Soil Site and Morphological Characteristics

The soil profiles were very deep (> 200cm) and were not restricted by the depth to parent materials and/or ground water levels. The subsoil horizons increased in thickness with the depth of the profiles, suggesting a diminishing of morphological differences in the same pattern. As a consequence, the boundaries of the horizons were described to be clear to gradual and smooth in the topsoil horizons, which changed to a gradual to diffuse and smooth boundaries in the subsoil horizons.

At the Kejo study site, the soil color (dry and moist) of the

surface horizon was dark reddish brown (2.5YR3/3 and 2.5YR2.5/2), respectively. The moist soil color of subsurface horizons ranging from dark reddish brown(2.5YR3/2) to dusky red (10YR3/3 to 10YR3/4) at the Bt2. The reddish brown color of the soils can be attributed to the presence of iron oxides [26].The soil structure ranging from strong coarse sub angular blocky at the surface horizon, to strong medium angular blocky at the (15-50cm) and moderate medium angular blocky below 50 cm. The dry consistence of the surface horizon at Kejo was slightly hard, whereas the moist and wet consistencies were friable, sticky and plastic throughout the depth of the profile. The root distribution changed from many fine and few medium in the upper horizon to common fine and few fine at the Bt2 horizon.

At the Ongobo site, the color of the surface horizon was dark reddish brown (5YR 3/3 dry, 5YR 3/2 moist)The subsoil horizons had the same hue (5YR) with a slight variation in value and chroma (3/1 to 2.5/2 moist) in their upper two horizons at 18-50 and 50-120 cm. These changed to dusky red (2.5YR 2.5/2 to 2.5YR 3/3) below 120 cm. The soil structure showed variations with depth that could be attributed to variation in OM content and particle size distribution. The structure of surface horizon was strong coarse sub angular blocky, and changed to strong medium sub angular blocky at the (18-50cm) and then strong medium angular blocky at the (50-120 cm) and to moderate medium angular blocky below 120cm. Strong angular and sub-angular blocky structures might possibly reflect the low contents of OM and the existence of high clay [27]. The soil consistence characteristics were slightly hard (dry), friable (moist), and slightly sticky and slightly plastic (wet) at the surface horizon, whereas the moist and wet consistencies of the subsoil horizons were friable, and sticky and plastic, respectively. The existence of similarity within the horizon of this profile could be related to the more clay contents in the horizons, probably suggesting the presence of intense weathering rates. This is a typical characteristic of most tropical soils [28]. The root distribution changed from common fine at the surface horizon to few fine at the bottom horizons. The lower under lying three horizons of both profiles had few/common faint/distinct and very few faint clay cutans. These characteristics exhibited the existence of the diagnostic properties of Nitisols [8]. The soil was also characterized by many fine interstitial pores and common biological activities in the profile which contributed for mixing of organic matter with mineral soil.

3.2. Soil Physical Properties

In the present study, the soil textural class of both the profiles was clay and did not vary with profile depth (Table 1). The clay fraction dominated the particle size distributions both in the surface and sub surface horizons that showed increasing trends with profiles depth. However, the sand fractions decreased consistently with depth in the profile at Kejo, whereas almost the same value throughout the horizons at Ongobo. The silt fraction showed slight variation throughout the depth of the profile at Ongobo, whereas almost the same value throughout the horizons at Kejo. The reason for more clay content in the bottom horizon than the surface horizon might be attributed to leaching of the clay particles from the surface horizon and subsequent accumulation in the bottom horizons. Similarly, the loss of clay fraction from the surface soil through water erosion may also be important. Finer soil fractions are more subjected to losses by erosion or runoff [29]. Intensive cultivation contributed to the variation of particle size distribution at the surface horizons as a result of vertical and horizontal clay migrations [13].

The bulk density values of the horizons increased consistently with depth ranging from 1.25 g cm^{-3} at the surface horizon of Kejo to 1.40 g cm^{-3} at Bt4 of Ongobo (Table 1). The values were within the normal range of bulk density for mineral soils which is 1.3-1.4 g cm^{-3} as indicated by [24]. The low bulk density value at the surface horizon could be due to the more OM which resulted in high total porosity. On the other hand, high bulk density values in the lowest horizon could be due to compaction caused by the weight of the overlying soil material and reduced root penetration [2]. The bulk density values of the soils in the study areas were not too compact to limit root penetration and restrict movement of water and air. This indicates the existence of loose soil conditions in the upper 15 cm of the soil depth in both sites and, hence, good structure [24].

Table 1. *Particle size distribution, textural class, bulk density and total porosity of the soil profiles of the study areas.*

Depth(cm)	Horizon	Particle size distribution (%)			Textural class	Bulk density(g cm^{-3})	Total porosity(%)
		sand	silt	clay			
Soil profile at Kejo							
0-15	Ap	23.28	24.28	52.44	Clay	1.25	52.83
15-50	Ab	13.28	26.28	60.44	Clay	1.30	50.94
50-85	Bt1	11.28	28.28	62.44	Clay	1.35	49.06
85-200$^+$	Bt2	11.28	24.28	64.44	Clay	1.38	47.92
Soil profile at Ongobo							
0-18	Ap	23.28	27.28	49.44	Clay	1.29	51.32
18-50	Bt1	25.28	19.28	55.44	Clay	1.30	50.94
50-120	Bt2	21.28	21.28	57.44	Clay	1.35	49.06
120-180	Bt3	29.28	10.28	60.44	Clay	1.38	47.92
180-200$^+$	Bt4	23.28	14.28	62.44	Clay	1.40	47.17

Total porosity values showed almost similar pattern of variability to that of bulk density but in an opposite trend. It ranging from 47.17 to 52.83% (Table 1). The lowest (47.17%) and highest (52.83%) total porosity were observed in the Bt4 horizon at Ongobo and surface horizon at Kejo, respectively. The highest total porosity at the surface horizon corresponded to the highest OM content, whereas the lowest total porosity corresponded to the highest bulk density value of the lowest horizon. Decrease in OM and increase in clay contents with depth in many profiles are associated with a shift from macro pores to micro pores [2, 61]. According to the same author, normal porosity ranges of 47-51% and 51-55% for clay loam and clay textures, respectively. The total porosity observed on both sites of surface horizon could enable the soils of the study area to provide good aeration for crop production and microorganisms.

3.3. Soil Chemical Properties

The pH (H_2O) of the soil profile at Kejo ranging from 5.31 in the surface horizon to 5.83 in the extreme bottom horizon (Table 2). Similarly, it rangs from 5.41 in the surface horizon to 5.70 in the Bt4 horizon at Ongobo. Accordingly, the soils were strongly to moderately acidic in reaction throughout the profile depths based on the pH (H_2O) values [30]. The pH increased consistently with depth in both profiles. This increase in pH may be due to the observed increase in basic

cations with depth and hence, percent base saturation. The increase in basic cations contents with depth, in turn, may suggest the existence of downward movement of these constituents within the profile. The surface soils possess lower pH values than the subsoil horizons in all soil profiles indicating the removal of the basic cations from the surface soils vertically by leaching, laterally by runoff and through uptake by cultivated crops. Soil pH values measured in a suspension of 1:2.5 soil to water ratio (pH in H_2O) were greater than the pH values measured in the same ratio of soil to KCl solution (pH in KCl) in both profiles. The decrease in soil pH when measured in KCl solution indicates that appreciable quantity of exchangeable hydrogen (H) has been released into the soil solution through exchange reaction with K in the KCl solution [31].

The OM content of the soil profile at Kejo ranging from 3.71% at the surface horizon to 0.62% at the Bt2 horizon, whereas from 3.78 to 1.66% at Ongobo (Table 2). It decreased consistently with depth. The OM content of the soil was low to moderate [32]. Most cultivated land soils of Ethiopia are poor in their organic matter content due to the low amount of organic materials applied to the soil and complete removal of the biomass from the field [33]. As a result, the major source of organic matter in cultivated soils below ground plant biomass has little contribution to increasing OM [34, 60].

Table 2. Soil pH, organic matter, total N and C: N ratio of the soil profiles of the study areas.

Depth(cm)	Horizon	pH		OM(%)	TN (%)	C:N ratio
		H₂O	KCl			
		Soil profile at Kejo				
0-15	Ap	5.31	4.40	3.71	0.19	11.32
15-50	Ab	5.60	4.61	1.74	0.09	11.22
50-85	Bt1	5.72	5.08	1.38	0.07	11.43
85-200⁺	Bt2	5.83	5.30	0.62	0.03	12.00
		Soil profile at Ongobo				
0-18	Ap	5.41	4.35	3.78	0.19	11.53
18-50	Bt1	5.31	4.21	2.79	0.14	11.57
50-120	Bt2	5.40	4.26	2.09	0.10	12.00
120-180	Bt3	5.52	4.27	1.72	0.09	11.11
180-200⁺	Bt4	5.70	4.50	1.66	0.08	12.00

OM = Organic matter; TN=Total nitrogen; C: N= Carbon to nitrogen ratio

The total nitrogen (N) contents of soil profile at Kejo ranging from 0.19% at the surface horizon to 0.03% at the Bt2 horizon while that of Ongobo ranging from 0.19 to 0.08% (Table 2). In general, the total N content of the investigated soils was low to moderate [35]. The trends of total N contents were similar to that of OM in both surface and subsurface horizons regardless of study sites. Accordingly, the total N decreased consistently with depth suggesting the strong correlation between the two soil parameters. In general, as OM is the main supplier of soil N in low input farming systems, a continuous decline in the soil OM content of the soils is likely to affect the soil productivity and sustainability. The C: N ratios of the soils in the study areas were within the range of 10:1 to 12:1 commonly cited as the average for mineral soils [33] (Table 2). 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 soil horizon than in the subsurface soil horizon.

The available phosphorus (P) extracted with Olsen method at the surface horizons were 3.94mg kg⁻¹ at Kejo and 3.88 mg kg⁻¹at Ongobo (Table 3). The lowest 0.62 mg kg⁻¹ available P was observed in the Bt2 horizon, whereas the highest 3.94 mg kg⁻¹ in the surface horizon at Kejo. On the other hand, the corresponding available P extracted with Bray II method was greater than Olsen method in both profiles. The Olsen method is the most widely used for P extraction under wide range of pH both in Ethiopia and elsewhere in the world [36, 37]. The available soil P was interpreted according to [23] as below 5 mg kg⁻¹ is low; between 5 and 10 mg kg⁻¹ is medium, and greater than 10 mg kg⁻¹ is high. Thus, the present study

showed that the available P contents at the surface horizon were very low. The low contents of available P observed in the soil of the study areas agreed with the results of similar study [38]. The low available P in most Ethiopian soils can be attributed top fixation, crop harvest. soil erosion and low rate of P sources application. The available P extracted with Bray II method at the surface horizons were 13.80 mg kg^{-1} at Kejo and 8.30 mg kg^{-1} at Ongobo. The lowest available P was observed in the Bt4 horizon at Ongobo site, whereas highest in the surface horizon at Kejo site.

The content of P showed a decreasing trend with soil depth both in the Olsen and Bray II extraction methods. This is in agreement with the findings of [39] who reported that topsoil total P is usually greater than that in subsoil due to sorption of the added P, greater biological activity and accumulation of organic material on the surface horizon, [40] also indicated a decrease in P content with depth due to fixation by clay and Ca, which were found to increase with profile depth. Since the study area is located in the humid region receiving a high amount of precipitation, the soils have been subjected to intensive weathering and leaching. The Ethiopian agricultural soils particularly the Nitisols and other acid soils have low available P content due to their inherently low P content and high P fixation capacity [18, 33]. Generally, the available P status in the study areas was very low. Soil P deficiency is a wide spread phenomenon and it is believed to be the second most important soil fertility problem throughout the world next to N and often the first limiting element in acid tropical soils [41, 42].

The lowest available Potassium (K) values ranging from 52.31 at Kejo to 57.30 mg kg^{-1} at Ongobo (Table 3). [43] suggested the available K contents of the study sites were low to medium. The observed available K values of the soils generally showed a decreasing trend with profile depth in exactly the same pattern as observed in soil OM. The most probable reasons for the decreasing trend of available K in the surface soils of the study area could be soil erosion and continuous crop removal without replenishment of the element in question. Many authors were also in agreement with this observation [44, 45]. Therefore, the observed available K content in the study sites could be declining to the low status which need K fertilization. In most of the horizons of the study area, CEC values were low to moderate (Table 3). The lowest and highest CEC values ranging from 11.84 to 16.05cmol$_c$kg^{-1} at Kejo, whereas from 14.30 to 22.47 cmol$_c$kg^{-1} at Ongobo. The observed CEC values of the soils generally showed a decreasing trend with profile depth similar to that of soil OM. This implies that CEC was more influenced by OM than clay content. The results of the present study agreed with similar studies conducted elsewhere [46, 47].

Table 3. Available (P and K), CEC and PBS of the soil profiles of the study areas.

Depth(cm)	Horizon	Av. P (mg kg^{-1}) Olsen'smethod	Av. P (mg kg^{-1}) Bray IImethod	Av. K(mg kg^{-1})	CEC(cmol$_c$kg^{-1})	PBS(%)
		Soil Profile at Kejo				
15-50	Ab	3.94	13.80	197.01	16.05	31.63
50-85	Bt1	2.20	6.60	96.01	15.38	49.29
85-200$^+$	Bt2	2.04	6.30	82.90	13.11	58.81
		Soil profile at Ongobo				
0-18	Ap	3.88	8.30	180.12	22.47	29.28
18-50	Bt1	3.54	6.10	174.11	21.50	34.30
50-120	Bt2	1.60	5.90	85.90	20.18	43.41
120-180	Bt3	1.26	5.70	68.20	16.78	57.93
180-200$^+$	Bt4	1.14	4.80	57.30	14.30	77.27

Av.P = Available phosphorus; Av. K=Availablepotassium, CEC = Cation exchange capacity; PBS = Percent base saturation

The percent base saturation (PBS) of the soils was low on the surface horizon (Table 3). The lowest and highest PBS values ranging from 31.63 to 66.66% at Kejo, whereas from 29.82 to 77.27% at Ongobo. The values of PBS for the surface soils were low indicating less fertile soils of the study area [48]. The relatively high values of PBS for the bottom horizons could be attributed to the leaching of exchangeable bases. Similarly, the content of PBS showed an increasing trend with profile depth. In most of the horizons, the PBS of the soil was found to be below 50%. This could be due to intensive cultivation, erosion, crop harvest as reported by several investigators [49, 50]. Furthermore, the study area is located in the humid region that receives high precipitation where, the basic cations could be leached from the surface of the soils.

The exchangeable bases (Ca, Mg, K andNa), and exchangeable acidity (Hand Al) of the Ongobo and Kejo presented in (Table 4). Exchangeable calcium (Ca) and magnesium (Mg) were the predominant cations in the exchange sites of both profiles. Both increased with profiles depth with the same pattern to that of soil pH. The highest values of exchangeable Ca and Mg were observed in the Bt4 horizon at Ongobo, whereas the lowest value in the surface horizon at Kejo, Generally, the content of these cations are rated as low [10]. Crop removal and use of inorganic fertilizers deplete exchangeable Ca and Mg [46, 51].Continuous cultivation causes a significant decline in soil pH and exchangeable Ca and Mg levels that can be pronounced using acidifying fertilizers [52].

The highest contents of exchangeable K (0.38 cmol$_c$ kg^{-1}) and Na (0.15cmol$_c$kg^{-1}) were observed at the surface horizon at Kejo and Bt4 horizon at Ongobo, respectively (Table 4). Exchangeable K values observed in these study areas were at a low level for the production of most crops [32]. In general, the contents of exchangeable K tended to decline towards low to very low status, whereas Na was at very low status. The

observed exchangeable K value generally showed a decreasing trend with profile depth. The result disagrees with the common idea that Ethiopian soils are rich in K. But it agrees with [12, 53] who reported K deficiency in EutricVertisols of Melbe (Tigray) and DystricNitisols of Bako area, respectively. The intensity of weathering and intensive cultivations also affect the distribution of K in the soil systems and enhance its depletion [46].

***Table 4.** Exchangeable bases and exchangeable acidity of the soil profiles of the study areas.*

Depth(cm)	Horizon	Exchangeable bases(cmol$_c$ kg^{-1})				Exch. acidity(cmol$_c$ kg^{-1})	
		Ca	Mg	K	Na	H$^+$	Al^{3+}
		Soil profile at Kejo					
0-15	Ap	3.00	1.66	0.38	0.04	1.70	0.04
15-50	Ab	5.64	1.78	0.12	0.04	1.65	0.02
50-85	Bt1	5.75	1.80	0.11	0.05	0.94	Nil
85-200$^+$	Bt2	5.90	1.83	0.10	0.06	0.69	Nil
		Soil profile at Ongobo					
0-18	Ap	4.68	1.61	0.37	0.04	1.53	0.01
18-50	Bt1	5.45	1.68	0.19	0.05	1.50	Nil
50-120	Bt2	6.54	1.97	0.15	0.10	1.45	Nil
120-180	Bt3	7.45	2.03	0.12	0.12	0.94	Nil
180-200$^+$	Bt4	8.36	2.44	0.10	0.15	0.70	Nil

Ca=Calcium, Mg= Magnesium,K= Potassium, Na=Sodium, H=Hydrogen, Al= Aluminum

One of the possible reasons for the relatively very low to low contents of exchangeable bases on the exchange sites of the surface horizon of the soils could be associated with intensive weathering due to high precipitation where the exchangeable bases were exposed to rapid depletion from the soil exchange complexes by leaching. Research findings on the highland soils of Ethiopia also revealed similar results where the contents of exchangeable bases on the surface horizon showed lower values [1, 18, 38]. These lower values of exchangeable bases were one of the factors attributing to low fertility of the soils in the study areas.

In the surface horizons, the highest exchangeable acidity value of 1.74 cmol$_c$kg^{-1} was observed at Kejo followed by 1.54 cmol$_c$ kg^{-1} at Ongobo (Table 4). It showed a decreasing trend with depth in exactly the same pattern as observed in soil OM. The reason for the existence of higher content of exchangeable acidity on the surface horizon could be due to the release of certain organic acids from the functional groups of OM owing to the higher OM content of the surface horizon than the subsurface horizon [1]. The exchangeable H$^+$ content dominated the exchange complex with regards to the exchangeable acidity but exchangeable Al^{3+} was negligible. [31, 54] also reported similar results from the region. The absence of exchangeable Al^{3+} may be because of the chelating effect of OM and weathering stages of the investigated soils.

The observed available micronutrients of the soils generally showed a decreasing trend with profile depth in exactly the same pattern to that of soil OM (Table 5). The highest value of available Iron (Fe) (33.51 mg kg^{-1})and Manganese (Mn) (81.71mg kg^{-1}) contents were registered at the surface horizon of Ongobo site, whereas the lowest value observed at the Bt2 and Bt4 horizons of Kejo and Ongobo sites respectively. The trend of available Mn content was similar to that of Fe distribution, indicating that these two elements have similar chemical behaviors in tropical soils as described by [55]. The critical or threshold levels of available Fe and Mn for crop production are 2.5 to 4.5 mg kg^{-1} and 1.0 to 50 mg kg^{-1}, respectively [56]. Therefore, the available Mn and Fe contents

of the study soils are in the toxic range for crop production according to nutrient toxicity range established by [25, 57].

***Table 5.** Available micronutrients of the soil profiles of the study areas.*

Depth(cm)	Horizon	Micronutrients (mg kg^{-1})			
		Fe	Mn	Cu	Zn
		Soil profile at Kejo			
0-15	Ap	32.22	77.42	2.17	0.218
15-50	Ab	28.41	31.64	0.74	0.078
50-85	Bt1	17.03	17.25	0.60	0.068
85-200$^+$	Bt2	14.16	2.37	0.16	0.048
		Soil profile at Ongobo			
0-18	Ap	33.51	81.71	2.23	0.314
18-50	Bt1	27.74	54.14	1.91	0.076
50-120	Bt2	14.63	24.12	1.38	0.047
120-180	Bt3	14.43	16.04	0.63	0.025
180-200$^+$	Bt4	7.24	10.60	0.56	0.013

Fe= Iron, Mn= Manganese, Cu= Copper, Zn= Zinc

On the other hand, the highest content of available Zinc (Zn) 0.314mg kg^{-1}was observed at the surface horizon of Ongobo followed by 0.218 mg kg^{-1} at Kejo (Table 5). The content of available Zn decreased consistently with depth from 0.218 mg kg^{-1}at the surface horizon to 0.0480mg kg^{-1}at the Bt2 horizon at Kejo, whereas 0.314 mg kg^{-1} to 0.013mg kg^{-1}at Ongobo. The available Zn was deficient in the soil for crop production [58]. Moreover, the highest content of available copper (Cu) 2.23mg kg^{-1} at Ongobo followed by 2.17 mg kg^{-1} at Kejo was observed at the surface horizon (Table 5) which decreased consistently with depth. The contents of available Cu in the surface horizons were deficient for crop production [58].

In general the data showed that the horizons had varied contents of available micronutrients where Fe and Mn were in the toxicity range, whereas Zn and Cu were deficient. Plant growth and development may be retarded significantly if any of these elements is less than its threshold value in the soil or not adequately balanced with other nutrient elements [36].All micronutrients generally showed a decreasing trend with profile depth in exactly the same pattern as observed in soil OM. Factors affecting the availability of micronutrients are

parent material, soil reaction, soil texture, and soil OM [2]. According to the same authors, intensive cropping, in which a large amount of plant nutrients are removed in the harvest accelerates the depletion of micronutrient reserves in the soil and increase the likelihood of micronutrient deficiencies. Erosion of topsoil carries away a considerable soil OM, in which much of the potentially available micronutrients are held. Increasing yields through intensive cropping, use of high yielding varieties and losses of micronutrients through leaching can cause depletion of micronutrients [17].

4. Conclusions

Soil profile characteristics not only revealed the current status of the soil conditions but also helped understand the long-term ecological and economic benefits of the studied soil resources.Accordingly, all the studied soil physical characteristics showed that the soil had good physical fertility, whereas management practices had negatively influenced the soil chemical properties regardless of the Ap horizon was better than the B horizon because of the high concentration of SOM at the Ap horizon.The results of the study revealed that the soils had strongly acidic ranging from 5.27 and 5.83 at the Ap and Bt2 horizons, respectively. The total N ranging from 0.03 to 0.19%, available P from 0.62 to 4.0 mg kg^{-1} and CEC from 11.84 to 22.47 cmol$_c$kg^{-1}.Available Fe ranging from 7.24 to 33.68 mg kg^{-1}, Mn from 2.37 to 83.91 mg kg^{-1}, Zn from 0.013 to 0.314 mg kg^{-1} and Cu from 0.16 to 2.32 mg kg^{-1} and showed decreasing trend with profile depth. To sustain and/or improve the current soil fertility status of the study sites, precautionary actions such as adopting soil conservation practices and avoiding unbalanced and acid forming fertilizers can help to rebuild the soil degraded conditions. Further researches have to be continued to recommend fertilizer types and rate for the major crops grown in this region.

Acknowledgements

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