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Research Article

CHARACTERIZATION AND CLASSIFICATION OF SOILS OF TELTELLE DISTRICT, SOUTHERN ETHIOPIA

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ABSTRACT Soil characterization and classification is vital to know the potential and limitations of the soil resources for agricultural production, and for devising relevant soil management strategies. The study was conducted to characterize and classify soils of Taltale District. Three representative soil pedons were opened on land uses bases and described on genetic horizon basis in the field for their morphological characteristics and analyzed in the laboratory for selected physic -chemical soil properties. Result revealed that all the soil pedons was deep and opened till 200 cm with high clay particles in the depths of the profiles. The result of soil pedons opened in crop land (pedon 1) showed low organic carbon, total nitrogen, available phosphorus and high exchangeable bases (Ca, Mg, K and Na) and cation exchange capacity. Based on morphological, physical and chemical properties soils of the study area were classified as Mollic Vertisols for all pedons. Therefore, sound land use planning is required for the soils of study area. Soil under cultivation needs amendment with organic and inorganic fertilizer sources to improve their chemical properties.

Keywords: *soil classification, soil characterization, soil horizon, soil pedon, Talale District*

INTRODUCTION

Agricultural production clearly depends upon the soil resources as the inherent characteristics of the soil greatly affect agricultural productivity all over the world. Understanding the characteristics of soils is prerequisite for designing appropriate management strategies thereby solving many challenges of agricultural sectors [1]. Knowledge on status of soil properties is vital in enhancing production and productivity of the agricultural sectors on sustainable basis [2].

Soil characterization and classification will provide baseline information on the physicochemical and mineralogical properties of the soil for precision agriculture, land use planning, and management [3]. It is useful to facilitate technology transfer and information exchange among soil scientists, decision makers, planners, researchers, and agricultural extension advisors [4]. It also determines the types of vegetation and land use type best suited to a particular location [5]. It is reported that soil profile is important both from the stand point of soil formation and soil development and crop husbandry since it reveals the surface and the subsurface characteristics and qualities [6].

In Ethiopia, soil characterization and classification of the country were made at small scale, which not applicable for large area or at watershed level or even at farm land [7]. Most of the studies undertaken so far were localized mostly to areas close to major transportation and networks. The reliable soils data, which are the base for the design of appropriate land use systems and soil management practices, are not adequately available. Therefore, soil of the country needs a major investigation since national and regional small-scale studies were inadequate in providing basic soil data.

In current study area soil is not yet characterized and classified for sound land uses and management practices where agriculture had been widely practiced. As result, a major soil problem is not studied and documented, the farmers continue to use their land without having the information weather the land is suited for their ongoing use or not. Moreover, the existing land use system and management interventions are not supported with information that shows the potentials and constraints of soil resources. In order to use the limited land resources more efficiently, site-specific management recommendations based on site-specific information are very much required. Therefore, there is a need to characterize and classify soils to identify their constraints and potentials for the study area.

MATERIALS AND METHODS

Description of study area

The study was conducted in Teltelle District, which is located rural area of Borena Zone in Oromia Regional state, Southern Ethiopia (fig.1). Geographically it is located at $4^0$01’33” N_$5^0$14’12” N latitude and $36^0$40’04” E_$37^0$37’13” E longitude.

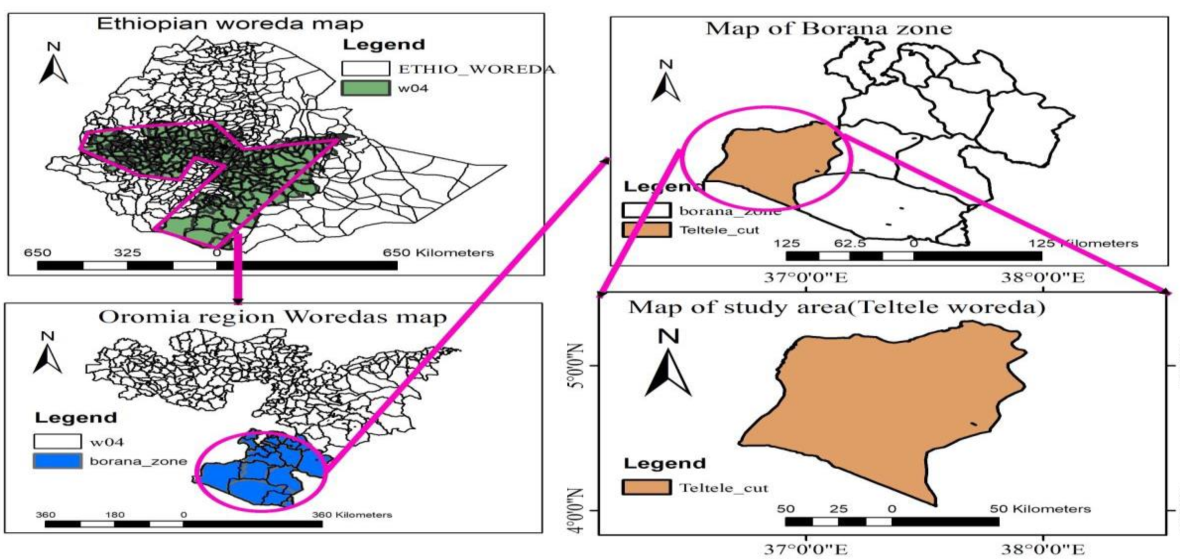

Fig. 1. *Study area map*

It receives bimodal rainfall, short rainy season (September to November) and main rainy season (March to May) (fig. 2). The average annual rainfall ranges from 800 to 900mm. It is characterized with low and erratic rainfall. The average annual temperature is 29.09℃ (fig 2).

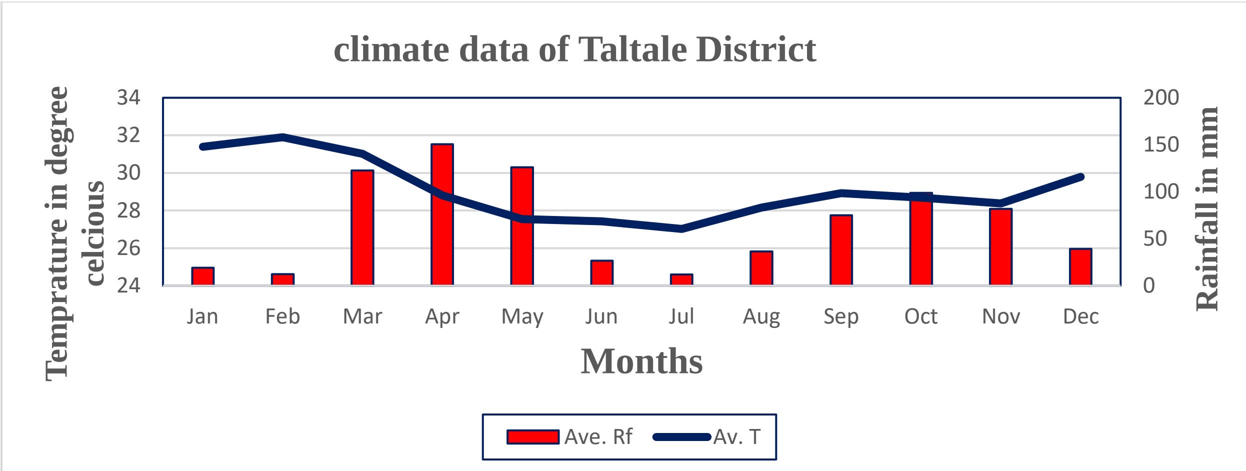

Fig. 2. *Average annual rainfall and temperature of the study area*

The Agro-ecology of the study area is characterized by arid (15%) and semi-arid (85%) climate. The landscape consists mainly of lowland by surrounding isolated hill and characterized by gentle or flat slope; which means most of the study area is gentle and level slope.

The major crops growing in the study area are teff, maize, sorghum and haricot bean. The dominant indigenous trees in study area were *Acacia meliffoeera, Commiphora, Hop bush, Euclea, Snow beryy trees, Rhus, Umbrella thorn, White galled acacia, Falconsclaw acacia, Dobera glabra, Grewia* and others low land trees were available and natural pasture is dominant.

Soil survey and land use selection

A reconnaissance survey was carried out within District to identify the major soils in the area and land use types. The soil of the district within land uses was thoroughly examined and differentiated based on land use, vegetation cover, cultivation history, slope, soil depth, texture, and rockiness. Based on field survey, 80 auger soil samples collected from land uses of the district from 0-20 cm depth and analyzed in the field in order to observe the extent of variation of soil attributes and demarcate the area. Based on the auger samples and surveys three representative pedon opening sites, namely crop land, pasture land and forest land of the area was identified.

Soil profile opening, description and sampling

The pedon was 2 m width x 2 m length x 2m depth for soil morphological examination and soil sample collection. A soil description was done using a standard format developed following the guidelines for field soil description [8]. The color, texture, consistence, structure, plant rooting patterns, and other soil features was examined to determine which horizons are present and at what depth their boundaries occur. Soil color was then determined using the Revised Munsell Soil Color Chart [9]. Soil structure was described in terms of the sequence: grade, size, and type (shape) of aggregates whereas horizon boundaries were described in terms of depths and distinctness. The soil consistence was identified at dry, moist and wet moisture conditions. Core soil samples were collected at different points across each horizon for determination of soil bulk density. Then after the soil was morphologically described, soil samples were collected from every identified horizon. Then the collected samples were bagged, labeled and transported to the laboratory for analysis of selected soil properties.

Soil laboratory analysis

The soil parameters were analyzed in the laboratory using standard procedure as follows; soil particle size distribution was determined by the Boycouos hydrometric method [10, 11]. Soil textural classes were determined following the textural triangle of USDA system as described by Rowell [12]. Soil bulk density was determined by the undisturbed core sampling method. Total porosity (%) was estimated from the values of bulk density (BD) and particle density (PD), with the latter assumed to have the generally used average value of 2.65 g cm^{-3} [13].

The pH of the soil was measured potentiometrically using a digital pH meter in 1:2.5 soils to water suspension [11]. The EC of soils were measured from a soil water ratio of 1:2.5 by electrical conductivity method [14]. The wet digestion method was used to determine soil carbon content [5]). Total N was determined using the Kjeldahl digestion, distillation and titration method as described by Black [16]. C:N of soil was calculated as ratio carbon to total N. Available soil phosphorus was analyzed according to the standard procedure of Olsen extraction method [17].

CEC and exchangeable bases (Ca, Mg, K and Na) was determined after extracting the soil samples by ammonium acetate (1N NH4OAc) at pH 7.0. Exchangeable Ca and Mg in the extracts was analyzed using atomic absorption spectrophotometer, while Na and K were analyzed by flame photometer [12, 18]. CEC was estimated by distillation of ammonium that was displaced by sodium from NaCl solution [18]. Percent base saturation (PBS) was determined by dividing total exchange bases by the CEC of the soil and multiplied by 100%.

Statistical analysis and classification of soils

Simple correlation analysis was carried out with the help of Statistical Analytical Software (SAS) to reveal the magnitude and directions of relationships between selected soil physicochemical properties. Depending on the result of morphological characteristics and physicochemical properties of soils in the laboratory, the soils of the study area was classified based on FAO, [8] soil classification guideline legend.

RESULTS AND DISCUSSION

Physiographic characteristics of the study sites

The site characteristics of the pedons of the study area were situated to gentle sloping (Table 1) indicating similar physiographic position. The pedons were opened at different land use; perofile 1 (crop land), Profile 2 (grass land) and Pedon 3 (forest land). All the pedons were moderately drained, except Pedon 2, which was weakly drained. Pedon1 was characterized with rill and sheet erosion while pedon 2 was characterized by deposition and pedon 3 was characterized by sheet erosion with deposition (Table 1). Since, pedon 1 was opened in cultivated land; it is exposed to rainfall impact as result erosion was pronounced than pedon 2 and 3. Removal of surface soil from this pedon affected the soil profile development in comparison with soils of other pedons. Soils of all pedons were developed from alluvial basalt parent materials.

Table 1. *Site characteristics of the study area*

pedons	Location		Altitude (m.a.s.l)	Slope (%)	Slope position	Drainage class	Erosion/ deposition	Parent material	Land use
	Latitude (N)	Longitude (E)							
1	04^0 57′ 26.9″	037^0 21′ 20.7″	1394	2	Gentle	MD	Sheet and rill erosion	Alluvial from basalt sediment	Crop land
2	04^0 57′ 23.2″	037^0 21′ 23.1″	1419	1	Gentle	WD	Deposition	Alluvial from basalt sediment	Grass land
3	04^0 57′ 19.2″	037^0 21′ 13″	1417	2	Gentle	MD	Deposition and sheet	Alluvial from basalt sediment	forest land

MD: Moderately Drainage; WD: Weakly Drainage

Soil morphological properties

The pedons exhibited similar in sequence of horizons (4 horizons), except pedon 2, which has 3 horizons (Table 2). All the pedons were opened till to 200m depth since it opened in land uses bases and had variable thickness. The depth of pedon 1 at the surface (Ap-horizon) was relatively shallower (0-25 cm) as compared to others since it was opened at cultivated land where organic matter is low to lose the soil. This indicates organic matter play important role in improving soil depths. Cultivated lands were more affected by erosion, sheet and rill as result it had shallow depth. The thickness of the depths generally increases with depth, probably indicating diminishing of differences in morphological properties with depth of the profile [19].

The surface (Ap) horizon of profile 1 had black color both in dry and moist soil and brownish black in dry soil and black in moist soils for profile 2 and 3 (Table 2). This indicates the soil color at surface horizons varied from black for profile opened at crop land to brownish black for profiles opened at grass and forest lands. This range of color indicates the presence of organic matters in the surface horizons. The color of both surface and subsurface soils of all profiles is dominated by black color while relatively darker in surface layers. Similarly, it is reported that the surface horizons have darker color than the corresponding subsurface horizons as a result of relatively higher soil organic matter contents [20]. The result also indicated that there were few color variations among the all pedons in subsurface horizons. These color variation of the subsurface horizons could be attributed to differences in soil organic matter content, implying soil color is highly influenced by soil organic matter [21].

Table 2. *Morphological Properties of soils of Taltale District*

Depth (cm)	Horizon	Color		Structure	Consistency	Horizon Boundary
		Dry	Moist	Grade/Size/Type	Dry/moist/wet	
			Pedon-1			
1-25	Ap	10YR1.7/1	5Y2/1	MO,ME,GR	HA, FR,SP	CS
25-70	A/B	7.5YR2/1	10YR3/1	ST,CO, SB	HA,FI,VST	CS
70-150	B	2.5Y3/1	7.5YR2/1	ST,CO, AB	VHA, VFI, VST	GS
150-200	C	2.5YR3/1	10YR2/2	ST,VCO, SA	VHA, VFI, VST	-
			Pedon-2			
1-50	A	7.5YR3/1	10YR1.7/1	MO, FI, GR	SHA,FR,ST	CS
50-140	B	10YR4/1	5YR3/1	ST,MC,AB	VHA,FI,VST	CS
140-200	C	7.5YR4/1	7.5YR3/2	ST,VC,AB	VHA,VFI,VST	-
			Pedon-3			
1-60	A	7.5YR3/1	7.5YR2/1	WE,FI,GR	SHA,FRS,ST	CS
60-90	AB	7.5YR3/1	2.5YR2/1	MO,ME,GB	SHA,FR,ST	GS
90-135	B	5YR4/1	10YR1.7/1	ST,MC,SAB	HA,FI,VST	GS
135-200	C	5YR2/1	5YR2/2	ST,CO,AB	VH,VFI,ST	-

ST, Strong, WE = Weak, MO = Moderate, ME = FI = Fine, Medium, CO = Coarse, GR = Granular, AB = Angular Blocky, SAB = Sub-angular Blocky, HA = Hard, SHA = Slightly Hard, VHA = Very Hard, FI = Firm, SFI = slightly firm, VFR = Very Firm, FR = friable, SFR = Slightly Friable, VFR = very friable, ST = sticky, VST = very sticky, SST = Slightly Sticky
C = clear, S = smooth, G = gradual

The structures of the soils of study area were varied in the grade, size and type across the pedons of land uses. Soils of all pedons had well-developed granular structures on the surface horizons of soil. The presence of OM in the surface soil might be attributed to the formation of granular type of soil [22]. The structure of the soils in the surface, sub-surface A/B, B and C-horizons of pedon-1 were moderate, medium, granular blocky; strong, coarse, sub-angular blocky; strong, coarse, angular blocky and strong, very coarse, angular blocky structure respectively. The structure pedon 2 was arranged as moderate, coarse, granular blocky in A-horizon changed to strong, coarse, angular blocky structure in sub surface of B-horizon and the lower C-horizon was strong, very coarse, angular blocky structure. Finally, the surface layers of pedon-3 was weak, fine, granular blocky to moderate, medium, granular blocky structure and the bottom sub surface layers had strong, coarse, angular blocky structure in both B and C-horizons. Variation in structure among horizons suggests that there was a vertical variability in development of soil profile. The presence of blocky structure in subsurface horizons' indicates initial soil development [19].

The consistence of pedon 1 at surface horizon was hard (dry), friable (moist) and sticky (wet), whereas slightly hard (dry), friable (moist) and sticky (wet) for pedon 2 (Table 2). Friable consistence at moist moisture content indicates the existence of organic materials, the composition of different size of particles and micro biological activities in the soil. This is in agreement with findings that reported the friable consistence at the surface soils could be attributed to the higher soil OM contents of the layers and soils are workable at appropriate moisture content [23, 24]. The friable consistence of the soils show workability of the soils at appropriate moisture content [25]. In contrast, the sticky, very sticky and very plastic consistencies show the presence of high clay content, and difficulty to till [26].

The boundary of Profile 1 was characterized by clear and smooth boundary in Ap and A/B horizons, which changed to gradual and smooth in lower B horizon (Table 2). This could be due to repeated anthropogenic influence like plowing the land for crop production [27] Profile 2 was characterized by clear and smooth boundary across all horizons. While, Profile 3 was characterized by clear and smooth in surface (A) horizon and gradual and smooth in underlying A/B and B horizons. The clear boundary indicates clear morphological differences between overlying and sub-soil horizons. The gradual boundaries in the lower horizons reflect absence of distinct morphological differences between the subsequent subsoil horizons of such soils.

Physical Properties of soil

The results of the study revealed that the soil textural classes of all pedons were clay indicating similarity in their parent material. The particle size distribution of all pedons of the study area was dominated by clay followed by sand and silt particles. The domination of one particles size than other might be due to the geology of the soil or parent material from which soil was initially formed [28]. The clay contents increased with depths of the profiles while the sand and silt content decreased except silt content at pedon 2. The clay content within the profile increased from the surface layer to underlying sub-soils by 71 to 82% at pedon 1, 70 to 83% at pedon 2 and 56 to 79% at pedon 3 while the sand content decreased by 19 to 14% at pedon 1, 21 to 7% at pedon 2 and 33 to 15% at pedon 3 (Table 3). The high accumulation of clay content at sub-soils was associated with the lateral movement of finer fractions from surface layer to subsurface layer as a result of clay translocation within the pedon. The decrease in sand and silt contents with depths could indicate its destruction through weathering process and transformations to finer materials [19]. The result also indicated that highly significant and strongly negative association (r = -0.92**) of clay with sand content (Table 7).

Table 3. *Soil Physical Properties of the Taltale District*

Depths (cm)	Horizons	Particle size distribution (%)			Textural class	Bulk density (g/cm^3)	Total porosity (%)
		Sand	Clay	Silt			
Pedon-1							
1-25	Ap	19.48	71.24	9.28	Clay	1.24	53.21
25-70	A/B	16.79	73.68	9.56	Clay	1.24	53.21
70-150	B	14.76	76.32	8.92	Clay	1.31	50.56
150-200	C	17.12	82.68	0.2	Clay	1.34	49.43
Pedon-2							
1-50	A	21.12	70.68	8.2	Clay	1.10	58.49
50-140	B	7.12	82.68	10.2	Clay	1.22	53.96
140-200	C	7.48	83.24	9.28	Clay	1.23	53.58
Pedon-3							
1-60	A	33.12	56.68	10.2	Clay	1.06	60
60-90	AB	17.48	73.24	9.28	Clay	1.18	54.47
90-135	B	15.12	79.24	5.64	Clay	1.19	55.09
135-200	C	20.48	73.24	6.24	Clay	1.74	34.33

The bulk density of the soils was in the range of 1.06 to 1.24g/cm3 in surface layers of all pedons (Table 3). In comparing surface soils, the highest bulk density (1.24 g/cm3) was recorded on the surface horizon of pedon 1 (pedon opened at crop land) this might be attributed to compaction resulted from continuous cultivation and poor management practices. It may be also due to low organic matter content and more disturbances of soils under cultivated land than uncultivated soils [28]. Similarly, soil OM contents decreased, the soils would be less aggregated and the bulk density would be increased [29]. The result also revealed negative correlation (r=-0.457) of bulk density with organic carbon (Table 7). The critical value of bulk density for plant growth at which root penetration is likely to be severely restricted is 1.4 g cm^{-3} for clay soils [30]. Accordingly, the bulk density values of the surface horizons in the crop lands were at sever range. Therefore, it needs option to minimize the raising bulk density. Organic matter on the surface of soils makes soils loose, porous and well aggregated, thereby reducing bulk density. The result also indicated the increase in bulk density with depths of all profiles (Table 3). This could attribute to low soil organic matter and the weight of overlying soils in sub-soil horizons. Similarly, the increase of bulk density with increasing soil layers was due to the decrease in OM content with soil depths [31].

The porosity of the soils ranges from 49.43 to 53.21%, 53.58 to 58.49 and 34.33 to 60% in pit opened at crop land, grass land and forest land uses, respectively (Table 3). The total porosity in the surface layers of the soils ranged from 53.21 to 60% and decreased consistently with soil depths in all pedons (Table 3). The decrease in the total porosity with soil depths could be due to the limited penetration of plant roots into subsurface layers and decrease in content of organic matter with soil depth. The ideal total pore space values, which are acceptable for crop production was around 50% [13], as result, the soils of the study area are qualifying to this range except C horizons of pedon 3.

Soil chemical properties

The pH of the surface soil horizons ranged from 7.92 in pedon 3 to 8.17 in pedon 2 (Tabel 4). The pH of the soils of study area was ranged as moderately alkaline for all pedons [32, 33]. This alkaline range pH could be due to the low and erratic rainfall in the study area that unable to leach and removal bases from the soil surface. The result also revealed that pH of the soils increase with depths of the all pedons except pedon 2 (Tabel 4). The increment in pH value of soil might be attributed to high accumulation of exchangeable base at the sub-soils. The pH value of surface soils were lower than the bottom horizons representing the removal of the basic cations from the surface soils vertically by leaching and through by uptake of crops [34]. On the other hand the pH values increased with soil depth might be due to less H^+ ions released from low OM decomposition [35].

Electrical conductivity value of the soils ranged from 1.0 dS m^{-1} in pedon 2 to 1.63 dS m^{-1} in pedon 3 and 2.97 dS m^{-1} in pedon 3 and increased with increasing soil depths of the pedons (Table 4). The increasing of EC with depth indicates more basic cations in sub-soil horizons of the study area. In line with this finding, it is reported that electrical conductivity increases with increasing salt concentration [36]. The soils qualifies for salt free (AB & B horizons of pedon 1; A horizon of pedon 2 and O & A horizons of Pedon 3), Very slightly saline (Ap horizon of pedon 1 and B horizon of pedon 3), slightly saline (B&C horizons of Pedon 2 and C horizon of pedon 3) and Moderately saline (C horizon of pedon 1) [37]. This indicates the concentration soluble salts will affect growth and productivity of salt susceptible agricultural crops. Therefore, it needs carefully attention to avoid the development of salinity in the study area.

The organic carbon content of surface horizons ranged from 2.14% in pedon 1 to 4.37% in peon 3 (Table 4). The OC contents of surface soil horizons were in the range of medium for pedon 1 (pedon opened at crop land) and high for pedon 3 (pedon opened at grassland and forest land soils) [38]. The variation of OM between the profiles reflects the difference in vegetation cover. The higher OC (4.37%) was recorded in surface horizon of the pedon opened at forest land while the lowest (2.14%) was recorded in surface layers of the pedon opened at crop land (pedon Ap-1). The lower OC contents in pedon 1 attributed to complete removal of crop residues for animal feeds and house hold fuels and continuous cultivation with no external organic inputs in study area. It is reported that reported tillage of the land might favor the mineralization of OC and significantly depleted OC content of the soil [22, 39]. The relatively higher content of organic carbon in Profile 2 and 3 could be due to the presence of sufficient grass, plant roots and liter fall for decomposition. The result also indicated the organic matter declines with depth in horizons all profiles attributed to the accumulation organic matter in surface soil. This might also due to no source of organic matter in sub-surface horizons. In line with this finding, the surface horizon showed higher organic matter content than subsurface horizons which could be due to its frequent addition and accumulation of litter and annual grasses [40].

Table 4. *Organic matter, Organic Carbon, Total Nitrogen, Carbon to Nitrogen ratio and Available P of the soils of Taltale District*

Depth (cm)	Horizon	pH	EC	OM (%)	OC (%)	TN (%)	C:N	Av.P (ppm)
				Pedon-1				
1-25	Ap	8.11	2.97	3.69	2.14	0.17	12.59	7.15
25-70	A/B	8.13	0.85	3.17	1.84	0.16	11.50	6.73
70-150	B	8.42	0.13	1.12	0.65	0.09	7.22	4.14
150-200	C	8.48	9.19	1.48	0.86	0.06	14.33	3.85
				Pedon-2				
1-50	A	8.17	1	4.52	2.62	0.22	13.89	10.32
50-140	B	7.92	4.75	4.31	2.5	0.18	11.91	7.16
140-200	C	7.96	7.95	3.72	2.16	0.15	14.4	7.20
				Pedon-3				
1-60	A	7.92	1.63	7.53	4.37	0.25	17.48	15.76
60-90	AB	8.19	1.54	5.59	3.24	0.13	24.92	10.12
90-135	B	8.36	3.99	5.45	3.16	0.1	31.6	8.60
135-200	C	8.43	5.25	3.71	2.15	0.09	23.89	6.77

OC=organic carbon, OM= organic matter, C:N= carbon to nitrogen ratio, TN= total nitrogen and Av.P= available phosphorous

The total N content of the surface soils ranged from 0.17% in pedon 1 (opened at crop land) to 0.25% in pedon-3 (pedon opened at forest land) (Table 4). The total N content of the investigated soils was medium for opened 1 and 2 and high for pedon 3 [38, 41]. The medium range of TN in pedon 1 indicated that nitrogen is found to be near the limiting nutrients, this is mainly due to uptake of nitrogen was not replaced by external nitrogen source fertilizer in study area. Similarly, it is reported intensive and continuous cultivation enforced oxidation of OC and resulted in reduction of TN in pedon opened in the cultivated land [21, 42]. Therefore, as N is dynamic and prone to loses, the soils of study area must be fertilized with external N containing fertilizer for sustainable crop production. The TN content of the surface horizons was higher as compared to the subsurface soil horizons. The distribution of total N throughout the profiles follows similar pattern with OC in all pedons. The result also indicated the positive relationship (=0.617) between TN and OC (Table 7). Similarly, there was the positive and highly significant correlation between TN and OC indicating OM is the main source of N [24].

The carbon to nitrogen ratio of the surface horizons ranged from 12.59 in pedon 1 to 13.89 in pedon 2 to 17.48 in pedon 3 (Table 4). Relatively the highest (23.89) C:N ratio was observed in C layers of pedon 3 while the lowest (11.50) was observed in A/B horizon of pedon 1. When the C:N > 30:1, nitrogen is immobilized by soil microbes while if C:N < 20:1; there is a release of mineral nitrogen into the soil environment [43]. Accordingly, the C:N of the soil of the study were below 20:1 range except sub-soil horizons of pedon 3 which is above this range. This indicates the release of mineral nutrient to plant and soil environment with exceptions [29]. The result also indicted the decline of C:N ratio with increasing soil depth. This attributed to the decline of OM and TN with soil depth as value of C:N ratio was calculated from the value of OC and TN.

The available phosphorus of the study ranged from 3.85 ppm in C-horizon of pedon 1 to 15.76 ppm in surface layer (A-horizon) of pedon 3 (Table 4). The available P content of the surface soil horizons was in the range of medium for pedon 1 while high for pedon 2 and 3 [17]. While, the available phosphorus on surface horizon of pedon opened at crop land was below critical level [38]. This indicates the value of available phosphorus was the limiting factor for crop production in study area. This might be due to low inherent P content of the parent material, and might also be due to high clay content which increases the retention capacity [28]. In line with this, correlation result showed insignificant ($P \leq 0.01$) and negative association (r=-0.784) of available phosphorus with clay content (Table 7). Therefore, the soils of study area must be fertilized with adequate phosphorus contains fertilizer. The result also revealed that available phosphorus of the soils decreased with depths of the profiles in all pedons. This would probably due to decrease in soil OM, which might be source of soil phosphorus and increase in clay content, which increases the retention and fixation. The result also showed highly significant ($P \leq 0.001$) and strong positive association (r = 0.94) available phosphorus with OC (Table 7). In agreement with finding, it is revealed that the available phosphorus content of the soils decreased with profile depths of pedons [24].

The Exchangeable bases of the soils of the study area was dominated by Ca followed by Mg, K and Na (Table 5), which is as suitable for plant growth and development. The exchangeable Ca was varied from 34.06 meq/100g in C horizon of profile 1 to 71.10 meq/100g in C horizon of profile 3 (Table 5). Whereas, exchangeable Mg was varied from 12.44 meq/100g in A/B-horizon of profile 3 to 20.25 meq/100g in C-horizon of profile 3 (Table 5). Exchangeable K was varied from 0.76 cmol/kg(+) in B-horizon of pedon 1 to 2.94 cmol/kg(+) in A/B-horizon of pedon 3. The exchangeable Ca, Mg and K contents of the surface layers of soils are above the critical values [44]. Similarly, the rating the value of exchangeable Ca and Mg was very high in all pedons [45]. This indicates soils of study area were productive agricultural soil [46]. Exchangeable Na was ranged from 0.24 cmol/kg(+) in A/B-horizon of pedon 3 to 1.44 cmol/kg(+) in B-horizon of pedon 1. Accordingly the value of exchangeable Na was ranged from low to high range [45]. This might due to low and erratic rainfall to leach exchangeable below the plant roots. Therefore, this indicates soils of the study area needs attention to minimize the development of sodcity.

The result also showed the irregular pattern of exchangeable bases (Ca, Mg, K and Na) with depths of the profiles of all pedons. This is because of variation in amount of mineral present, soil texture, and degree of weathering, soil management practices, climatic conditions, degree of soil development, the intensity of cultivation and the parent material with soil depths [47]. The variation would also happen due to the differences in crop uptake, animal grazing and recycling of nutrients under different land uses. The Ca: Mg ratio of the soils was varied from 2.37 in subsurface layer of pedon 1 to 5.23 in subsurface layers of pedon 3 (Table 5). Accordingly, the Ca: Mg ratio of the pedons did not reveal deficiency for both cations [45].

The cation exchange capacity of the soils ranged from 72.45 cmol (+) kg^{-1} in surface horizon of pedon 1 to 97.46 cmol (+) kg^{-1} in surface horizon of pedon 3 (Table 4). Relatively highest CEC was recorded in surface horizons of pedon-3 and the lowest was recorded in pedon-1. The CEC of the soils was qualified to very high signifying that the soils have better basic cations nutrient reservoir [30]. Furthermore, the value of CEC was decreased with increasing depth of the profiles in all pedons. This might be due to relatively less leaching of exchangeable cations and strong association with soil organic carbon. The result also showed significant and positive correlation (r = 0.78) of CEC with OC (Table 7). The result was agreed with reports showed that CEC values of the soils generally showed a decreasing trend with profile depth similar to that of soil OM [34]. This implies that CEC was more influenced by OM [28].

The percent of base saturation of the soil varied from 76.44 in A/B horizon of pedon-1 to 97.64% in C-horizon of pedon 3 (Table 5). The PBS was rated from high in pedon-1 to very high pedon 2 and 3 [30]. In comparing surface soils, the lowest (76.44) percent of base saturation was observed in pedon at crop land (pedon 1) while the highest (93.8) was observed pedon opened at forest land (pedon 3). This attributed to the depletion of bases due to continuous cultivation of crop land and relatively better OM contents in forest land. The lowest PBS recorded in the pedon opened at crop land could be also attributed to the low sum of bases in this layer [48]. This indicates the forest soils retain more basic cations than the cultivated land.

Table 5. *Exchangeable bases (Ca, Mg, K and Na), Cation exchange capacity, Ca: Mg ratio and base saturation*

Depth (cm)	Horizon	Exchangeable bases				TEB	CEC cmol/kg	Ca: Mg	PBS
		Ca meq/100g	Mg meq/100g	K cmol/kg	Na cmol/kg				
				Pedon-1					
1-25	Ap	37.54	15.43	1.01	1.40	55.38	72.45	2.43	76.44
25-70	A/B	48.83	15.07	1.34	1.44	66.98	83.23	3.24	80.47
70-150	B	45.04	16.01	0.76	0.96	62.77	69.59	2.81	90.20
150-200	C	34.06	14.39	1.00	0.82	50.27	60.14	2.37	83.59
				Pedon-2					
1-50	A	58.40	16.92	1.92	1.82	79.06	84.28	3.45	93.81
50-140	B	42.32	15.90	1.58	0.38	60.18	74.51	2.97	80.88
140-200	C	39.05	13.05	1.11	1.22	54.43	72.5	2.99	75.07
				Pedon-3					
1-60	A	60.93	22.53	2.94	1.26	87.66	97.46	2.70	89.94
60-90	AB	63.00	21.18	1.01	0.65	85.84	99.16	2.97	86.56
90-135	B	65.12	12.44	1.57	0.24	79.37	89.00	5.23	89.18
135-200	C	71.10	20.25	1.11	1.43	93.89	96.71	3.06	97.08

TEB = Total Exchangeable base, CEC = Cation Exchange Capacity

Classification of soil

On WRB basis, all pedons had well-structured black surface horizons of more than 25cm thickness having color values ≤ 2 (moist), ≤ 3 (dry) and chroma of ≤ 1 in dry and moist condition. The surface layers of the pedons contained more than 0.6 percent of OC and base saturation of > 50 percent or more throughout the horizons (Table 4 and 5) meeting the criteria for a Mollic diagnostic horizons in according to WRB [8]. On the other hand, all pedons had thick subsurface horizons with greater than 30 percent clay content throughout (dominated by clay textural class), wedge shaped soil aggregates and slickensides produced by shrink and swell cracks that open and close periodically, starting at the surface qualified them for vertic diagnostic horizon [8]. Accordingly, the soils of pedon opened at crop land, grass land and forest land pedons were categorized under Vertisols. Based on the morphological and physicochemical data of the opened pedons, the soils of study area were classified as Mollic Vertisols in accordance with World Reference Base for Soil Resources [8].

On soil taxonomy basis, the morphological features of all profiles had thick (25-50cm) surface horizons, having moist color of 5Y2/1 in pedon 1, 10YR1.7/1 in pedon 2, 7.5YR2/1 in pedon 3 and black/darker. The soils of all pedons have well-developed granular and angular blocky structures throughout their profiles. The organic carbon content of the surface horizons of the pedon ranged from 2.14 to 4.37% with percent base saturation of greater than 50. Thus, the pedons was qualified Mollic epipedons.

The structure of the soils in the subsurface horizons ranged from strong, coarse, sub-angular blocky structure to strong, very coarse, angular blocky structure in pedon 1 whereas, strong, coarse, angular blocky to strong, very coarse, angular blocky structure for pedon 2 and moderate, medium, Granular blocky to strong, coarse, angular blocky structure in bottom layers of pedon 3. The sub-surface soils of all pedons had more than 30% clay contents and exhibit silken sides and cracks that open and close periodically. Thus, the pedon were classified under vertisols. Moisture deficit during some times in normal years and not irrigated during the year, the cracks remained opened for 90 or more cumulative days per year. The pedons were classified under Usterts suborder level due to ustic soil moisture regime, Haplusterts at great group and Typic Haplusterts at subgroup level.

Table 6. *Diagnostic horizon, properties, qualifiers and soil types of Taltale district*

pedons	**Diagnostic Horizons**		**Diagnostic properties**	**Soil Types**		
	Surface	**Subsurface**		**FAO (2014)**	**Taxonomy**	**Local**
1	Mollic	Vertic	Vertic	Mollic vertisols	Typic Haplusterts	Biyo Koticha
2	Mollic	Vertic	Vertic	Mollic vertisols	Typic Haplusterts	Biyo Koticha
3	Mollic	Vertic	Vertic	Mollic vertisols	Typic Haplusterts	Biyo Koticha

Table 7. *Pearson's correlation matrix for selected soil physicochemical properties of the soils of Taltale District*

	Sand	**Clay**	**BD**	**pH**	**OC**	**TN**	**Av.P**	**Ex.Ca**	**Ex.Mg**	**Ex.K**	**Ex.Na**	**CEC**
Sand	1.000											
Clay	-0.92***	1.000										
BD	-0.13	0.263	1.000									
pH	-0.04	0.065	0.118	1.000								
OC	0.48	-0.605	-0.457	0.288	1.000							
TN	0.393*	-0.629	-0.63	0.357	0.617	1.000						
Av.P	0.663	-0.784	-0.537	0.3	0.939***	0.737**	1.000					
EX.Ca	0.466	-0.47	0.171	0.273	0.599*	0.083	0.544	1.000				
Ex.Mg	0.702	-0.702	0.102	0.111	0.442	0.242	0.559	0.049	1.000			
Ex.K	0.626	-0.684	-0.516	0.444	0.771**	0.753**	0.866***	0.371	0.389	1.000		
Ex.Na	0.444	-0.481	0.103	0.063	-0.07	0.439	0.158	0.029	0.213	0.15	1.000	
CEC	0.424	-0.534	-0.002	0.085	0.781**	0.316	0.722**	0.866***	0.544	0.441	0.101	1.000

*, **, *** *Significant at 0.05, 0.01 and 0.001 or than probability levels, respectively.*

CONCLUSION

Soils of the study area were characterized by high clay content, alkaline reaction and high exchangeable bases. The soils of the pedon opened at crop land (Pedon 1) had low total N, OC, available P and high CEC and exchangeable bases (ca, Mg, K and Na) as compared to pedons opened at grassland (pedon 2) and forest land (pedon 3). Based on the morphological, physical and chemical soil properties, soils of the study area were classified as molloic Vertisols. Therefore, soils of study area under cultivation must be fertilized with external N and P containing inorganic fertilizer integrated with farmyard manure, compost, plant residues and agronomic management activities that minimize salinity buildup should be practiced for sustainable production. Finally, soils of study area need further investigation on specific fertilizer recommendation, management strategies for soil conservation in the futures.

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