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Characterization and Classifications of Saline/Sodic Soils of Ambo Area of Irrigated Farm Land in Golina Watershed in Raya Valley, Amhara Region, Ethiopia

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***Abstract*— All soils are known to contain a certain amount of soluble salts and exchangeable sodium, magnesium, potassium, and calcium. However, excessive enrichment of any one of them can interfere with many soil processes, including plant growth, and the effects depend on the degree of enrichment and the type of plant. Therefore, the objective of this study was to characterize the salt-affected soils of the Ambo area for irrigated farmlands in the Golina Watershed in Raya Kobo Woreda, Amhara region. One profile was excavated from an irrigated field to carry out this activity. One profile was excavated from the irrigated field to conduct this activity. Ten soil samples were taken from the soil profile at 2 m depth at 20 cm depth intervals. The samples were analyzed for several soil physical properties, including soil pH, soluble cations and anions, soluble salts (electrical conductivity, EC), exchangeable cations (Ca, Mg, Na, K), total nitrogen, organic carbon, soluble phosphorus, percent exchangeable sodium, sodium absorption, and soil physical properties (soil color, texture, bulk density, and soil porosity). Chemical properties were also analyzed. The analysis showed that the irrigated farmland soils had a pH of 7.6 to 8.8, electrical conductivity of 1.3 to 14 dsm-1, organic carbon of 0.3 to 1.2%, total nitrogen of 0.11 to 0.35%, soluble phosphorus of 24 to 41.4 mg kg-1, and cation exchange capacity of 50.3 to 65.5 cmol(+) kg-1. The distribution of exchangeable calcium was not consistent across the soil profiles of the irrigated farmlands. In general, the top layer of soil at both sites (because of its agricultural use) was considered for EC, ESP, and pH values. The irrigated farmland soils were classified as saline soils.**

Keywords*— *Characterization, Classification, Irrigated soil profile, Soil properties

I. INTRODUCTION

Salinity is a major environmental cause of soil degradation in many parts of the world, leading to reduced biomass [1]. This issue is widespread in arid and semi-arid regions where rainfall is insufficient to remove soluble salts. . Most developing countries are situated in these areas. The problem of salt-affected soils is a global phenomenon, impacting developed and developing countries alike. Nearly 20% of the world's cultivated land and almost half of the world's irrigated land suffer from salt damage [2]. Salt-affected soils are found in over 100 countries worldwide and vary in their extent, nature, and characteristics. While arid and semi-arid regions receive the most attention, salt-affected soils are present in all climatic zones. Sodium salts are prevalent in many saline soils worldwide, with other cationic salts like Ca and Mg found in specific locations [3]. Soil quality varies at different spatial scales and is influenced by land use and soil management practices, which can impact the direction and extent of soil change [4]. Therefore, appropriate land use and soil management are crucial for improving soil properties, reducing soil degradation, and achieving sustainability [5]. Differences in fertilization, cropping systems, and farming practices are the primary factors influencing soil quality at the field scale [6] Excessive salt accumulation in the soil surface layer is primarily caused by salinization due to the high salinity of irrigation water, the release of immobilized salts in the soil, atmospheric salt deposition, weathering of soil minerals, and the use of inorganic fertilizers [7]. Salinity is the initial stage of alkalinity in soils [8].

Salinization can even pose a threat to the national economy, particularly in countries like Argentina, Egypt, India, Iraq, Pakistan, Syria, and Iran [9]. Salt-affected soils are also becoming a major issue in Ethiopia [10]. In arid and semi-arid regions, salinity poses a serious and chronic problem for agriculture [11] as it hampers soil fertility, consequently reducing soil productivity [12]. When soil contains an excess of water-soluble salts, it is referred to as saline soil [13; 14]. On the other hand, salt-accumulating soils contain large amounts of both water-soluble salts and exchangeable sodium [15]. The accumulation of excess salts in the root zone of soils in arid and semi-arid climates leads to partial or complete loss of soil productivity, a global phenomenon. Salt-affected soil problems have also been identified in the study area, with their magnitude and intensity rapidly increasing due to accumulation caused by permanent surface runoff, waterlogging, and sustained water usage for irrigation in the region. A white crystalline layer covers the surface soils for extended periods in the watershed, reducing agricultural yields. Therefore, the objective of this study was to characterize and classify the soils of the Ambo irrigated area of the Golina watershed concerning soil salinity and alkalinity.

Specific objectives:

1) To characterize and classify the soils of irrigated agricultural lands in terms of their physical and chemical properties.
2) To characterize and classify soils in the study area based on criteria for salt-impacted soils.

II. MATERIALS AND METHODS

A. *Description of the Study Area*

The study area is located in the North Wollo Administrative Region, Amhara National Regional State, Ethiopia (Figure 1). It is positioned at 576361 degrees east latitude and 1332919 degrees north longitude. The region's topography consists of flat plains up to 1500 meters elevation, transitioning into mountains rising to over 3000 meters elevation. This consistent topography provides suitable slopes for surface irrigation [16]. The study's location map is in the Ambo area in Raya Kobo, Woreda.

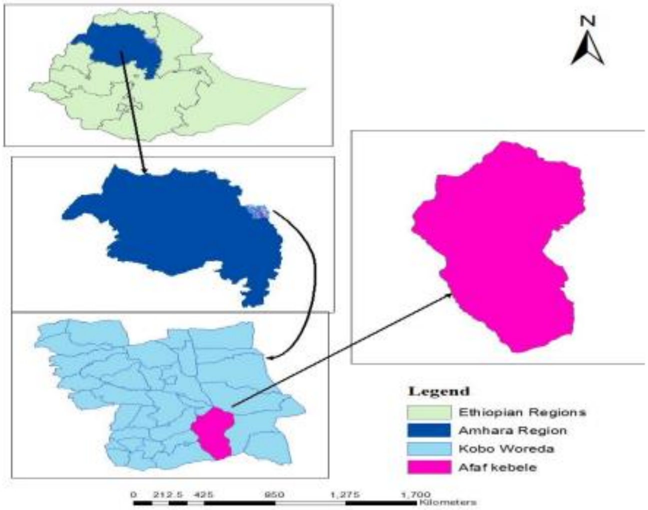

Fig. 1. Location map of the study area

B. *Sampling Procedure*

1) *Selection of sampling site*

A sampling site was chosen from irrigated farmland to represent the study area. Locations for opening the soil profile were identified based on observations of topsoil color, drainage conditions, land use system, slope, and cropping history. Before developing the soil profile, general field observations were made to select representative drilling locations. The main survey method used was the free soil survey method [17], following the random sampling method. A representative soil profile (2 m depth) was surveyed to assess the salinity and alkalinity status and distribution of the soil at one site covering the study area. After site selection, the soil profile at the identified site was excavated. The sampling site was chosen from irrigated agricultural lands within a total area of 100 hectares. One soil profile was excavated after observing the study area within the Raya Kobo Woreda in the Ambo area.

2) *Selection of sampling site*

The soil was dug to a depth of 2 m, with a width and length of 1.5 m each. This 2 m-deep profile was divided into 10 layers. Soil layers varied in thickness, ranging from several feet to a fraction of an inch. Sampling was done at 20 cm depth intervals, and representative soil samples were taken from each layer for analysis of physical and chemical properties. Soil description guidelines from reference [18] were followed for soil sampling and field description. Bulk density was determined in each layer of the soil profile using a core sampler, with 20 soil samples taken at 20 cm intervals from a designated point in one of the soil profiles.

3) *Preparation of soil samples*

Soil samples were collected from each layer of the soil profile, placed in labeled bags, and then spread out on polyethylene sheets to air-dry at room temperature. After drying, the soil samples were ground to pass through 2 mm and 0.5 mm sieves for organic carbon and total nitrogen measurements. Finally, all samples were prepared and ready for soil chemical and physical characterization.

C. *Soil Analysis*

1) *Analysis of soil physical properties*

We prepared soil samples to analyze particle size distribution, bulk density, particle density, and total porosity. To analyze particle size distribution, we used the Bouyoucos hydrometer method with sodium hexametaphosphate as the dispersant, following the procedure described [19]. Soil particle density was estimated using the pycnometer method reference [20], and bulk density was determined using the core method with undisturbed soil samples. Finally, we calculated the total porosity using the bulk density and particle density values.

$$Total\ porosity(\%) = \left[1 - \frac{pb}{pp}\right] \times 100 \qquad (1)$$

The irrigated farm (color dry) varied from reddish gray (2.5YR5/1) to dark reddish gray (2.5YR3/1 wet) as well. In an irrigated farm, dry soil varied in color from reddish gray (2.5YR5/1) to dark reddish gray (2.5Y4/1) in wet conditions for layers three and five in the profile (Table 3).Soil color was assessed in the field using a Munsell soil color chart [21]. The color of non-irrigated soil profiles was measured for dry and wet conditions.

2) *Analysis of soil soil chemical properties*

The soil's pH and electrical conductivity were measured using digital pH and conductivity meters [22]. Soil organic carbon content was determined using the Walkley-Black method, while total nitrogen was measured using the Macro Kjeldahl digestion and distillation method [23]. Additionally, dietary P was measured using the Olsen method with sodium bicarbonate as an extractant [24]. To measure the exchangeable bases (Ca2+, Mg2+, K+, and Na+), leachates of 1molar ammonium acetate (NH4OAc) solution at pH 7.0 were used. The extract was then analyzed for Ca2+ and Mg2+ using atomic absorption spectrophotometry, and for K+ and Na+ using flame photometry. Cation exchange capacity was determined by leaching the soil samples with a 10% NaCl solution and measuring the amount of ammonium ions in the permeate using the Kjeldahl method. The exchangeable sodium percentage was calculated as the ratio of exchangeable sodium to the cation exchange capacity of the soil. Base saturation and exchangeable sodium percentage were calculated using specific equations.

$$ESP = \frac{Exchangeble\ sodium, Cmole/Kg}{Cation\ \ Exchangeble\ Capacity, Cmole/Kg} \times 100 \qquad (2)$$

$$PBS\% = \frac{Exchangeble\ Bases(Ca, Mg, K, Na}{CEC} \times 100 \qquad (3)$$

Basic water-soluble cations (Ca2+ + Mg2+) were measured by atomic absorption spectrophotometry and Na+ by flame photometry and expressed as 1:1 mmolc of extract (Melese and Gemechu 2010). Carbonate (CO3 2-) and bicarbonate (HCO3-) concentrations were determined from saturated paste extracts by simple acid titration using phenolphthalein as an indicator for CO32- and methylolange for HCO3-. Chloride (Cl-) was determined by titrating aliquots used for CO32- and HCO3- determination with silver nitrate to potassium chromate endpoint, and SO42- was determined from saturated paste extracts by precipitation as barium sulfate (BaSO4) [25].

The sodium adsorption ratio (SAR) value was determined as the proportion of water-soluble sodium to calcium plus magnesium in the soil as:

$$SAR = \frac{Na^{+}}{\sqrt{\frac{Ca^{2+}+Ma^{2+}}{2}}} \qquad (4)$$

Residual sodium carbonate (RSC) content of the soil samples was calculated from concentrations of Ca2+, Mg2+, HCO3-, and CO3- ions as:

$$RSC = [(CO3^{2-} + HCO^{3-}) - (Ca^{2+} + Mg^{2+})] \qquad (5)$$

III. RESULTS AND DISCUSSION

A. Physical Properties of Soils

1) Soil texture classes

The data reveals variations in textural classes among different salt-affected soil types. In the irrigated farm soil profiles (Table I), the textural class ranges from silt loam to loam and sandy loam. The soil texture is predominantly loam, indicating a higher percentage of sand compared to other soil particles. This loamy texture allows for easier salt reaction in the soil mixture and facilitates leaching [26].

2) Soil color

The color of the irrigated farm soil varied from reddish gray (2.5YR5/1) when dry to dark reddish gray (2.5YR3/1) when wet (Table I). Specifically, in the irrigated farm, the dry soil varied in color from reddish gray (2.5YR5/1) to dark reddish gray (2.5YR4/1) under wet conditions for layers three and five in the soil profile (Table I). These variations in soil color seem to be influenced by the chemical and mineralogical composition as well as the texture of the soils, and are affected by the moisture regime [27]. The differences in color between dried and wetted soil could be due to variations in clay depth, organic matter content, parent material, and drainage conditions, which impact the redoximorphic reactions in the soil. Furthermore, the study's findings [28] suggest that soil color might be associated with organic matter and carbonate accumulation.

3) Bulk Density

The bulk density of the irrigated soil varied inconsistently with depth. It started at 1.14 g/cm3 at the surface (0-20cm) and increased to 1.45 g/cm3 at the depth of 180-200 cm (Table I). The lower bulk density at the surface layer could be due to the higher organic matter content, resulting in high total porosity (51%). These bulk density values were within the expected range for most mineral soils [29]. It has been reported that sand-dominated soils have higher bulk density values than silty or clayey soils due to their smaller pore spaces. Below the tillage depth (0 to 20 cm), the reduction in organic matter content, reduced root penetration, and compaction due to the overlying soil material may be responsible for the higher bulk density values. The higher bulk density in salt-accumulating and sodic soils may be due to a higher percentage of exchangeable sodium during wetting, dispersion of flocules, and crust formation during drying. In addition, salt-positive soils had less organic matter and higher bulk density. Regardless of topography, soil bulk density increased with depth, possibly because the overhead weight of surface soils resulted in finer particles in deeper layers [30].

TABLE 1. SELECTED PHYSICAL PROPERTIES OF THE SOIL PROFILE

Irrigated Soil Profile										
Depth	***Particle size distribution (%)***			***Texclass***	***BD Gmcm^{-3}***	***TP (%)***	***Soil color***			
	Clay	***Silt***	***Sand***				***Dry soil***	***Munsell soil color***	***Wet soil***	***Munsell soil color***
1	8	52	40	SiL	1.14	51	RG	2.5YR5/1	DRG	2.5YR3/1
2	18	44	38	L	1.21	54	RG	2.5YR5/1	DRG	2.5YR3/1
3	11	41	48	L	1.28	48	RG	2.5YR5/1	DRG	2.5YR3/1
4	8	31	61	SaL	1.41	45	RG	2.5YR5/1	DRG	2.5YR3/1
5	7	17	76	SaL	1.30	51	RG	2.5YR5/1	DRG	2.5YR3/1
6	9	41	50	L	1.27	51	RG	2.5YR5/1	DRG	2.5YR3/1
7	8	51	41	SiL	1.42	46	RG	2.5YR5/1	DRG	2.5YR3/1

8	10	40	50	L	1.48	47	RG	2.5YR5/1	DRG	2.5YR3/1
9	10	40	50	L	1.38	49	RG	2.5YR5/1	DRG	2.5YR3/1
10	9	39	52	L	1.45	45	RG	2.5YR5/1	DRG	2.5YR3/1

Layer in soil profile depth, textural classs, olor were described as (1-10): 1=0-20 cm; 2=20=40 cm; 3=40-60 cm; 4=60-80 cm; 5=80-100 cm; 6=100-120 cm; 7=120-140 cm; 8=140-160 cm; 9=160-180 cm and 10=180-200 cm.

SiL=Silt Loam; L=loam and SaL=Sandy Loam.

DR =Dusky Red; RB=Reddish Black; RG=Redish gray; DRG=Dark Reddish Gray; WR=Weak Red; DRG=Dark Reddish Gray and VDR=Very Dusky Red

4) *Soil Porosity*

The soil profile of irrigated farmland has a total porosity ranging from 45% to 54% (refer to Table I). Layer 2 (20-40 cm depth) has the maximum porosity value of 54%, while layers 4 and 10 have the minimum porosity. The lower total porosity values at the bottom of the irrigated farmland profile (45%) correspond to a lower organic matter content (0.7%) compared to the surface layer (2%), resulting in higher bulk density (refer to Table I). This aligns with the findings of [31], who noted a decrease in total porosity with soil depth due to increased compaction, reduced rooting effects, and decreased organic matter content. The observed total porosity range in the soils in this study falls within the range of 45% to 54% reported by [32] for the soils of Raya Valley, consistent with the findings of [31]. Studies on soil organic carbon (SOC) often focus on the upper 30 cm of the soil, where organic matter is concentrated and carbon processes are more active. However, limiting estimates of the soil organic carbon pool to the upper layers overlooks the significant amount of soil organic carbon stored in the lower layers. Generally, the vertical distribution of soil organic carbon in mineral soils shows a decrease in organic carbon content with depth [33].

B. *Soil Chemical Properties*

1) *Soil pH*

Soil pH of the irrigated farm land soil profile is at a higher level at all depths (7.6 to 8.8) and very high level (8.8) for soils of 160-180 cm layer (Table 4) as per the pH rating range set (34). Based on the rating, the irrigated soil profile ranges from moderately to strongly alkaline in reaction. According to [35], soil salinity guideline report in 1988, sodic soils contain a high exchangeable sodium percentage (>15%) and also have a high pH value (mostly in the range of 8.0 to 10). The high pH leads to low micronutrient contents and decreases such as calcium, magnesium, and phosphorus [36]. Soil particles that are dispersed as a result of high sodium content are much smaller than well-aggregated or clumped soil and cause the destruction of soil structure [37].

2) *Electrical conductivity*

The soil in the irrigated areas has an electrical conductivity (EC) of 14 dS/m at a depth of 10 cm. As we move deeper into the soil profile, the inconsistency in EC decreases. The high EC in the top layer of the soil suggests a strongly saline condition, likely due to shallow groundwater and high surface temperatures causing the transport of dissolved salts to the surface. The lack of proper drainage in the irrigated farm soil is leading to an increase in salinity, making the situation worse. Additionally, the high to very high CEC (cation exchange capacity) values in the study area indicate the presence of more weatherable primary minerals, which can serve as a nutrient reserve for plants. Therefore, these soils have the potential for satisfactory production if other conditions are favorable [38].

3) *Organic carbon*

The organic carbon content of the irrigated soil profile decreased consistently with depth. It ranged from 1.2% at the surface (0-20 cm) to 0.5% at a depth of 60-80 cm, falling within the very low class (Table II). Similarly, the organic carbon content decreased consistently with depth in all layers, from 0.9% to 0.4% at the layer of 80–200 cm, categorized as low to very low (Table II). According to the soil organic carbon content ratings established by [34], the irrigated soil profiles had very low organic carbon content. This could be due to the relatively lower amount of organic carbon in arid areas, reflecting lower vegetation and indicating the absence of healthy soil biological conditions in the study area [39]. Additionally, [40] revealed that most cultivated soils in Ethiopia are poor in organic carbon content due to the low amount of organic materials applied to the soil and the complete removal of biomass from the field. In salt-affected degraded areas, soil organic carbon (SOC) levels are likely to be affected by declining vegetation health, leading to decreasing biomass inputs and lower levels of organic matter accumulation. Moreover, potential SOC losses can be higher from dispersed aggregates due to sodicity [42].

TABLE 2. SELECTED CHEMICAL PROPERTIES OF THE SOIL PROFILE

Irrigated soil profile													
Depth	***pH***	***EC (Dsm^{-1})***	***% OC***	***% TN***	***Av P Mgkg^{-1}***	***Ca cmol (+)kg^{-1}***	***Mg cmol (+)kg^{-1}***	***Na cmol (+)kg^{-1}***	***K cmol (+)kg^{-1}***	***CEC cmol (+)kg^{-1}***	***SAR***	***ESP %***	***PBS %***
1	8.2	14	1.2	0.32	41.7	19.1	16.3	7.1	11.8	52.2	1.7	13.6	98.2
2	7.6	5.4	0.9	0.13	36.7	11	15.7	6.1	13.4	47.7	1.7	12.8	83
3	8.3	5.5	0.8	0.19	24.1	14.2	14.9	7.1	3.3	37.5	2.0	18.3	98.4
4	8.5	4.5	0.5	0.18	25.1	17.4	11.7	5.2	9.3	45.5	1.4	11.4	95.8
5	8.3	4.1	0.9	0.18	37.8	18.3	9.3	8.2	4.5	46.3	2.2	17.7	87
6	8.3	3.1	0.8	0.11	39.7	18.6	9.0	7.2	3.6	46	1.9	15.6	83.4
7	7.7	2.5	0.6	0.35	27.1	13.4	8.8	7	3.1	46.6	2.1	15.0	69.3
8	8.5	1.7	0.4	0.13	39	3.3	9.8	7.1	3.2	38.9	2.8	18.2	60.1

9	8.8	1.3	0.3	0.16	26.8	9.4	11.6	7	2.9	34.4	2.2	20.3	89.8
10	8.5	1.4	0.4	0.22	36.7	8.6	10.5	7.5	3.6	36	2.4	20.6	82.9

Layers in soil profile depths were (1-10): 1=0-20 cm; 2=20-40 cm; 3=40-60 cm; 4=60-80 cm; 5=80-100 cm; 6=100-120 cm; 7=120-140 cm; 8=140-160 cm; 9=160-180 cm and 10=180-200 cm

4) Total nitrogen

The total nitrogen content determined in all profiles based on the critical limit description of [42] is generally in the range of low to medium (0.01-0.3%) and tends to decrease with profile depth. In this study, the total nitrogen content of the irrigated farm soil profile ranges from 0.11 to 0.35% (Table II), and its contents are rated as low to very high according to [34]. The results showed inconsistent trends as depth increased in most cases. The total nitrogen also inconsistently decreased and increased with depth. According to [43], intensive and continuous cultivation aggravated organic matter oxidation and subsequently caused losses of nitrogen from the soil system.

5) Available phosphorus

The available phosphorus content in the soil profile consistently decreased from the surface (0-120 cm) to the 60-80 cm depth, with values ranging from 41.7 to 24.1 mg/kg (Table II). This decline in available phosphorus content from the surface to the subsurface layers is likely due to differences in organic matter content and the application of phosphorus-containing fertilizers. Similar trends of decreasing available phosphorus with soil depth have been reported in other studies [38]. In the upper layer (0-20 cm), available phosphorus is typically greater than in the subsoil due to gradual desorption, higher biological activity, and the accumulation of organic matter. This decrease in available phosphorus with depth aligns with findings from other studies, which have also observed higher phosphorus content in surface soils [43; 44]. Additionally, the decrease in available phosphorus with depth can be attributed to its fixation by clay and calcium in the subsurface soil, which increases with depth [47].

6) Cation exchange capacity

Based on the findings of this study, the soil profile of the irrigated farmland showed very high CEC values. These values ranged from 34.4 cmol (+) kg-1 of soil at 180-200 cm to 52.2 cmol (+) kg-1of soil at the surface. According to [45], CEC values are categorized as follows: < 5 is very low, 5-15 is low, 15-25 is medium, 25-40 is high, and > 40 is very high.

7) Exchangeable capacity

The soil profile showed the highest exchangeable Ca value at 19.1 mol (+) kg-1 of soil on the surface, which is considered high according to [34]. The lowest value was recorded at 3.3 cmol (+) kg-1 of soil at the 140-160 cm layer. Exchangeable Ca irregularly increased with depth in some layers, possibly due to leaching of the cation down the soil layer, in agreement with [46]. The high Ca value at the surface layer of the farmlands may be due to the presence of high exchangeable Ca contents on the soil exchange complex. Inconsistency in the decrease of exchangeable calcium was observed in the irrigated soil profiles, with most layers rated as high. According to [18], the concentration of exchangeable Ca observed in the surface depths is categorized as high and medium level in the subsurface depths of the farmland soil profiles. The exchangeable Mg content was very high for all depths, with amounts of Mg greater than 8 cm kg-1 (Table II). Both exchangeable cations did not show any consistent trend with depth. The exchangeable Na in the soil profiles ranged from 5 to 8.2 cmol(+)kg-1, which is very high as per the rating set by [34] (Table II). The exchangeable K content in the irrigated farmland soil profile ranged from 2.9 to 13.4 cm kg-1 (Table II).

8) Soluble cations and anions

The study considered soil-soluble ions such as cations (Ca2+, Mg2+, Na+, and K+) and anions (CO32-, HCO3-). In the irrigated farmland soil profile, Ca2+ was the most dominant cation at the surface with a value of 338 mgkg-1, followed by Mg2+ at 233.58 mgkg-1, Na+ at 17.54 mgkg-1, and K+ at 5.06 mgkg-1(Table 3). Generally, the average contents of cations in the soil followed the order Ca2+ > Mg2+ > Na+ > K+.

In Table III, the content of Ca2+ varies inconsistently with depth in the irrigated soil profile, with the lowest values at the bottom of the profile. The content of Mg2+, Na+, and K+ also shows inconsistent variation with depth (Table III). Specifically, the Na+ and Mg2+ contents also vary with depth. Overall, only K+ decreases with increasing depth of the soil in the study areas. As the levels of HCO32- increase at the second and third layers of the irrigated soil profile, they decrease and then increase again in the soil profile. The content of CO3- can be traced in all layers of the soil in the profile. The trace values of RSC are due to the absence of CO3 in the irrigated farmland soil profile soil samples. However, the irrigation water was suitable for irrigation from the RSC point of view [47]. The dominance of the sum of Ca2+ and Mg2+ over the sum of CO3- and HCO32- is reflected in the trace values of RSC in this specific irrigation water of the study area. Ca2+ and Mg2+ levels are depleted due to less solubility in HCO3-enriched environments, and Na+ becomes the predominant cation in solution. The exchange of Na+ by Ca2+ or Mg2+ on clay surfaces may also contribute to more Na+ in solution [48].

TABLE 3. SOIL SOLUBLE CATIONS AND ANIONS PROPERTIES OF SOIL PROFILE

Irrigated soil profile							
Soluble cations and anions(MeqL^{-1})							
Depth	***Na^{+}***	***K^{+}***	***Ca^{+}***	***Mg^{2+}***	***HCO3^{2-}***	***CO3^{-}***	***RSC***
1	17.54	5.06	338	233.58	152	Trace	-33.9
2	6.33	2.85	62.3	62.75	159	Trace	-5.7
3	9.93	0.51	101.1	87	158	Trace	-9.7
4	8.22	0.53	69.9	65.08	190	Trace	-5.8
5	7.39	3.56	78.3	64.83	173	Trace	-6.5

6	8.59	0.46	82.5	77.08	169	Trace	-7.8
7	6.85	0.29	31.8	70.08	199	Trace	-4.2
8	4.97	0.19	42	31.67	199	Trace	-1.5
9	4.91	0.21	39.3	19.67	171	Trace	-0.8
10	6.3	0.17	45.2	17.67	58	Trace	-2.9

Layers in soil profile depths were (1-10): 1=0-20 cm; 2=20-40 cm; 3=40-60 cm; 4=60-80 cm; 5=80-100 cm; 6=100-120 cm; 7=120-140 cm; 8=140-160 cm; 9=160-180 cm and 10=180-200 cm.

C. *Soil Chemical Properties*

Based on the data in Table 4, the first five layers of the irrigated soil profile have an electrical conductivity (EC) value greater than 4 and a pH value less than 8.5, except for layer 4. The 3rd and 5th layers have exchangeable sodium percentage (ESP) values greater than 15%. On the other hand, layers 6–10 of the irrigated soil profile showed EC values less than 4, ESP value greater than 15%, and a pH value greater than 8.5, except for layers 6 and 7. In summary, it can be concluded that the top part of the soil is saline for the irrigated farmland. Based on the criteria set by [22], the irrigated soil profile was classified as having an average ECe of 4.4 ds m-1, pHe of 8.3, ESP of 16.4%, and SAR of 2.1 (Table IV).

TABLE 3. THE SALINITY/SODICITY CLASSES OF THE SOIL PROFILE

Irrigated soil profile					
Depth	***pH***	***Ece dsm^{-1}***	***SAR***	***ESP%***	***Salinity Class***
1	8.2	14	1.7	13.6	Saline
2	7.6	5.4	1.7	12.8	Saline
3	8.3	5.5	2.0	18.3	Sodic-sodic
4	8.5	4.5	1.4	11.4	Sodic-sodic
5	8.3	4.1	2.2	17.7	Sodic-sodic
6	8.3	3.1	1.9	15.6	Saline
7	7.7	2.5	2.1	15.0	Sodic-sodic
8	8.5	1.7	2.8	18.2	Sodic
9	8.8	1.3	2.2	20.3	Sodic
10	8.5	1.4	2.4	20.6	Sodic
Mean	8.3	4.4	2.1	16.4	Saline-sodic

Layers in soil profile depths were (1-10): 1=0-20 cm; 2=20-40 cm; 3=40-60 cm; 4=60-80 cm; 5=80-100 cm; 6=100-120 cm; 7=120-140 cm; 8=140-160 cm 9=160-180 cm and 10=180-200 cm.

IV. CONCLUSIONS

The characterization of soils in terms of salinity and sodicity is crucial for assessing and managing soil resources in arid and semi-arid areas. A study was conducted in the Ambo area to characterize and classify the soils in terms of salinity and alkalinity. The bulk density of the layers in the profile varied from 1.14 to 1.48 g/cm³ in farmland soil. The pH of the irrigated soil profiles increased inconsistently with increasing soil depth from 8.2 at the surface of the profile (0-20 cm) to 8.8 at the lower layers of the profile (160-180 cm). The organic carbon content showed a decreasing trend inconsistently with increasing soil depth. The soil exchange complex was predominantly occupied by divalent basic cations (exchangeable Ca followed by Mg). The CEC values of the soils in the study area were determined to be high and very high. The CEC values of the irrigated soil profile decreased inconsistently with depth and were consistently rated as high and very high. The ESP values for the irrigated soil profile showed variations, but in general, were less than 15% for the topsoil of the irrigated farmland. Considering the top layers of the soils for agricultural purposes, taking into account their EC, ESP, and pH values, the soils can be classified as saline soil for the irrigated farmland. This study presents important findings concerning soil physico-chemical characteristics and soil salinity/sodicity status classes in the study area. Based on the analytical results of soil and field observations, the following recommendations can be made: - Frequent monitoring of irrigation waters - Selection of suitable varieties and crops - Removal of excess salts by leaching - Adopting careful means of irrigation and fertilizer application - Addition of organic manures for sustainable and productive land utilization.

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