Soil Quality Status under Dryland Vegetation of Yabello District, Southern Ethiopia

Mohammed Abaoli, Omer Kara

***Abstract*—**The current research has investigated the soil quality status under dryland vegetation of Yabello district, Southern Ethiopia in which we should identify the nature and extent of salinity problem of the area for further research bases. About 48 soil samples were taken from 0-30, 31-60, 61-90 and 91-120 cm soil depths by opening 12 representative soil profile pits at 1.5 m depth. Soil color, texture, bulk density, Soil Organic Carbon (SOC), Cation Exchange Capacity (CEC), Na, K, Mg, Ca, CaCO$_3$, gypsum (CaSO$_4$), pH, Sodium Adsorption Ratio (SAR), Exchangeable Sodium Percentage (ESP) were analyzed. The dominant soil texture was silty-clay-loam. Bulk density varied from 1.1 to 1.31 g/cm^3. High SOC content was observed in 0-30 cm. The soil pH ranged from 7.1 to 8.6. The electrical conductivity shows indirect relationship with soil depth while CaCO$_3$ and CaSO$_4$ concentrations were observed in a direct relationship with depth. About 41% are non-saline, 38.31% saline, 15.23% saline-sodic and 5.46% sodic soils. Na concentration in saline soils was greater than Ca and Mg in all the soil depths. Ca and Mg contents were higher above 60 cm soil depth in non-saline soils. The concentrations of SO_2^{-4} and HCO^{-3} were observed to be higher at the most lower depth than upper. SAR value tends to be higher at lower depths in saline and saline-sodic soils, but decreases at lower depth of the non-saline soils. The distribution of ESP above 60 cm depth was in an increasing order in saline and saline-sodic soils. The result of the research has shown the direction to which extent of salinity we should consider for the Commiphora plant species we want to grow on the area.

***Keywords*—**Commiphora species, dryland vegetation, ecological significance, soil quality, salinity problem.

I. INTRODUCTION

EARTH is a predominantly salty planet, with most of its water containing about 3% NaCl. This concentration of salt has rendered the land very salty. Salt-affected soils occur in all continents and under almost all climatic conditions. Their distribution, however, is relatively more extensive in the arid and semi-arid regions compared to the humid regions [1], [2]. About 47% of the surface of the earth can be classified as dryland [3]-[5]. According to the World Atlas of Desertification, drylands are considered to be areas where average rainfall is less than the potential moisture losses through evaporation and transpiration [6]-[8] while they have a ratio of average annual precipitation (P) to potential evapotranspiration (PET) of less than 0.65 [3], [4], [9].

The main problem of dryland is water. The availability and distributions of moisture in dryland areas will determine the degree of the region to which it could affect the availability of the vegetations as well as the whole ecosystem functions [7], [3], [10]. Where the water deficit prevails throughout the year, drylands are classified as extremely arid or hyper arid; whereas when it occurs for most of the year they are arid and semi-arid regions [6], [2], [11], [12]. Dryland soils are periodically dry, but can receive significant curse of precipitation so that soil humidity is enhanced a bit to allow for biological productivities [10]-[12]. This however requires adequate nutrient resources; and the soil needs to be able to absorb moisture and transfer it to deeper soil layers [13], a through the soil water infiltration rate. Furthermore, the speed at which the moisture is evaporating from the soil depends on available shade or litter cover. Therefore, the biological productivity is only in part determined by the amount of precipitation and depends to a significant part on additional soil and ecosystem parameters [14], [12], [15].

Ethiopia is reported to possess over 11 million hectares of unproductive naturally salt affected wastelands [5], [16]. The considerable area of lands that have been abandoned for cultivation due to the prevalence of salt affected soils at different locations of the country should be tackled and made suitable for the agricultural uses by improving the level soil of management [13], [17]-[19].

The Great Rift Valley runs from northeast to southwest of the country and separates the western and southeastern highlands and contains twelve Ethiopian lake basins [3]. The high alkalinity of sodium and bicarbonates are among the dominant soil constituents in the southern parts of the rift valley [3]. High concentrations of dissolved salts in the ground waters from the sedimentary formations are also common; because of reaction of the dissolution often abundant of evaporate minerals [20]. This high salinity may be manifested by high concentrations of sodium, chloride and/or sulphate. In saline and sodic soils, the over accumulated soluble salts particularly the exchangeable sodium can cause water uptake alteration in plants and deteriorate other soil physical properties [15], [6], [8]. The dryland vegetations covering these lands on the other hand have a great commitment to the determination of the ecosystems. The vegetations are mainly acacia species, Commiphora, Frankincense and the likes. Due to their ecological and socio-economic significance for the people living in and around, there should be considerations to the ecosystem health and determining the soil quality status at which it could serve the systems in general. So that, to launch this success, the current research has investigated the soil quality status under dryland vegetation of Yabello district, Southern Ethiopia in which we should to identify the nature and extent of salinity problem of the area for further research bases.

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II. THE STUDY AREA

Yabello district covers an area of 5,550 km^2 among the districts of Borena Zone of Oromia region in Southern Ethiopia. The altitude of Yabello district lies between 1350 and 1800 m.a.s.l [5]. The mean monthly rainfall of Yabello district was 48 mm. This district has a mean annual rainfall of 587.2 mm. The mean monthly minimum and maximum temperatures of Yabello were 15.6 and 18.8 °C, respectively, with a mean annual temperature of 18.3 °C [5]. According to [9], the vegetation of the area can be classified into four types: evergreen and semi-green bush land and tickets; rangeland dominated by A*cacia* and *Commiphora* trees; rangeland dominated by *Acacia* and allied genera; and dwarf shrub grassland or shrub grassland. The dominant herbaceous plants were perennial grasses. The study sites are encroached by woody vegetation, with < 40% of the shrubs established before 1970s [5], and the most extensive woody encroachment occurring after the 1980s because of increased grazing pressure and fire suppressions [4]. According to FAO UNESCO World Soil Map [21], the soil in the study sites is Chromic Cambisol.

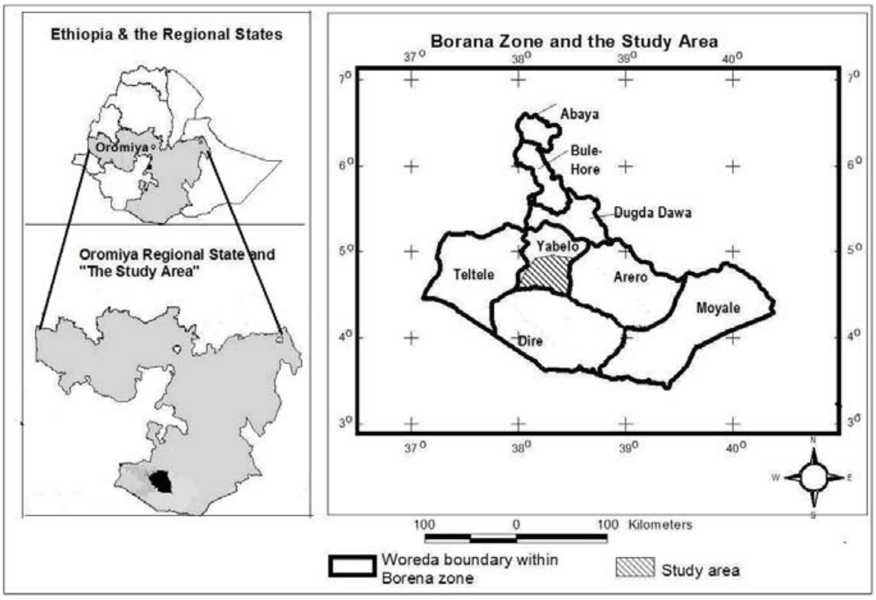

Fig. 1 Map of the study area

III. RESEARCH METHODOLOGIES

The sample soils for the study were obtained from the same bush area of their original ecosystem. Soil samples were taken from 0-30, 31-60, 61-90 and 91-120 cm soil depths, at five points (at the four corners and one at the center) of each plot, laid out for the sparsely vegetated *Commiphora* dominated and some *Acacia* species. About 48 soil samples were taken by opening about twelve representative soil profile pits at 1.5 m depth. Each profile was described in a field sheet [22], [2]. The collected soil samples were mixed to make a composite and representative sample for each plot independently. The collected soil samples of each plot for each soil depths separately were put in a plastic bag; coded and transported to soil laboratory for analysis. In the laboratory, soil samples were air-dried using an ambient air circulating cabinet. Following drying, the soil samples have been crushed using a mortar and then sieved by 2 mm wire mesh. In each soil sample, 200 g soils were taken for analysis using standard soil scoop for each plot and depths. For bulk density analysis, soils were directly augured from the plots for each soil profiles separately.

Soil texture was determined by hydrometer and bulk density was determined by core method. Soil organic matter was determined by procedure of Walkley and Black [23]. Accordingly, sodium (Na) and K were determined by flame photometry; magnesium (Mg) and calcium (Ca) were determined by titration method; the CEC and exchangeable cations were determined from neutral 1N ammonium acetate extracts; calcium carbonate ($CaCO_3$) and gypsum ($CaSO_4$) were determined by acid neutralization method using HCl, and by precipitation respectively. The pH of the soil samples was potentiometrically measured in the supernatant suspension of a 1:5 soils: liquid (v/v) mixture. This liquid is made up of a 0.01 mol/l solution of calcium chloride in water pH (H_2O) [24]. Electrical conductivity was measured from a soil saturation extract by conductivity meter. All soil analysis methods (physical and chemical) have been done in the National Water Works Design and Supervision; Soil laboratory, Addis Ababa, Ethiopia.

SAR was calculated according to the following procedural formulas [2].

$$SAR = \frac{\mathrm{Na}^{+}}{\left(\frac{\mathrm{Ca}^{2+}+\mathrm{Mg}^{2+}}{2}\right)^{1/2}} \tag{1}$$

SOC stock per hectare (Mgha^{-1}) was calculated as follows [25]:

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$$SOC(Mgha^{-1}) = SOC(gKg^{-1}) \times d \times BD(g^{-3}) \times 10 \quad (2)$$

where d is sampled soil depth in meter (m), and BD is bulk density (gm^{-3}).

ESP was calculated according to [2]:

$$ESP = \frac{(1.00(-0.0126 + 0.01475(SAR))}{1 + (-0.0126 + 0.01475(SAR))} \quad (3)$$

Data Analysis

All soil analysis results were subjected to analysis of variance (ANOVA). All statistical computations were made by using SAS (2004) version 9.0 computer software [26]. The least significant difference (LSD) at $P \leq 0.05$ was used to determine statistically significant differences within each variable at each plot. The difference of each analyzed soil properties between and within the plots and profile depth has been determined by using multiple t-tests.

IV. RESULTS AND DISCUSSION

Physical Characteristics

The dominant soil colors were reddish brown, brown, gray and yellow. Fine mottles of different color combinations were also common at different horizons. These might be caused by internal soil drainage problem & parent materials. However, the soil color was predominantly affected sequentially with the soil depths. As usual, these trends may be resulted from climate, drainage conditions and alluvial process as the main agents for soil color development [13], [6], [12], [17].

Soil texture, which refers to the percentage of sand, silt and clay particles, is an important physical property of soils. Plant growth, soil biological mobility, biogeochemical process, pH and site selection for building etc. are all governed by soil texture [12], [27]. The silty clay loam is the dominant soil texture of the investigated samples as compared to other particle sizes; however, the distribution of silt, clay and sand shows varied in all soil matrixes. This might be due to the continuous translocation process of silt, clay and sand. Furthermore, deposits of buried massive clay were frequently found at deep soil layers which was the results of alluvial and erosion processes in the near past. The relationship between electrical conductivity and soil texture showed that the increments of salinity were related directly to the silt content of the soils. Most of the salt-affected soils in the rift valley have higher silt contents [5], [19], [28]. Clay soils tend to have higher CEC, net primary productivity, and litter decomposition rates in the tropics under natural conditions [8].

There were no significant differences ($P < 0.05$) in bulk density across the plots for 0 to 30 cm soil depth. However, the differences in soil bulk densities may be partly due to differences in soil compaction that may alter soil bulk density [29]-[32], [14]. Bulk density of the study area varied from 1.1 to 1.31 g/cm^3. On the other hand, due to soil textural stratification of the profile, it is not uniform with depth trends.

Chemical Characteristics

Soil Organic Matter, CEC and Exchangeable Cations

The SOC varied from 0.46 to 2.08%. High SOC content was observed in the surface soil (0-30 cm). Soil texture exerts a strong influence on many biogeochemical processes in soil ecosystems by affecting the ability of soils to retain C, water, and nutrient ions [33], [8], [15]. On the other hand, the availability of fine roots of different tree species and other giant grasses; and their detritus remain as the main ecological nutrient recycling processes [13]-[15], [25], [22], [34]. Despite the well demonstrated importance of soil texture, many questions remain about the role of texture in belowground C allocation, soil C storage, ion exchange capacity, and ecosystem productivity and decomposition. This is especially true for tropical forests, which exhibit considerable spatial heterogeneity in soil texture at both local and regional scales [15], [35]-[38]. However, organic matter was not much closely related to salinity in the investigated area. The CEC varied also from 12 to 50 me/100 g of soil. Exchangeable Na value was higher than both Mg and K in the upper depth soils.

Soil pH, $CaCO_3$ and $CaSO_4$

Soil PH measurement is useful because it is a predictor of various chemical activities within the soil. The particular pH measured in a soil will be caused by a particular set of chemical conditions. Therefore, it is a useful tool in making management decisions concerning the types of plants suitable for a location, the possible need to modify soil pH, and a rough indicator of plant availability of nutrient in the soil [39], [14], [25]. In the present study, the soil pH shows minimum 7.1 and maximum values of 8.6. Neutral salts of Na, K, Ca and Mg influenced the soil pH in saline and saline-sodic soil. Where, neutral salts of calcium and magnesium cations were dominant, the pH tends to be lower in saline soils as Ca and Mg buffers the soil reaction. As pH increases, $CaCO_3$ increases. This might be due to the higher solubility of $CaCO_3$ and the greater potential of its hydrolysis [32], [34], [36]. However, $CaSO_4$ accumulates ranges from 7 to 8.6 pH values, it may react against pH rises in the soil by forming H_2SO_4.

Salinity

Accordingly, we have used the categories of the soils depending on their ECe less than 4 and ESP less than 15 as non-saline; and ECe more than 4 and ESP less than 15 values as saline while soils with both ECe and ESP more than 4 and 15 respectively has categorized as saline sodic; and ECe less than 4 and ESP more than 15 has been considered as Sodic soils.

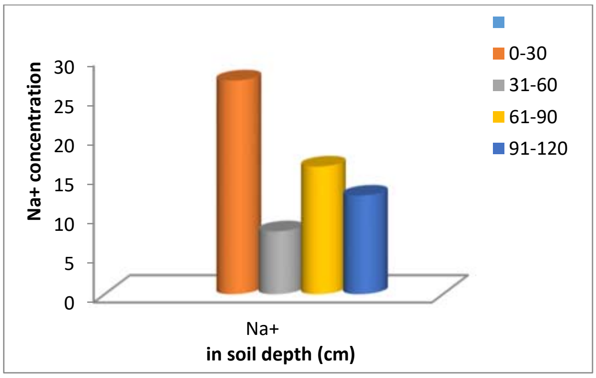
The origin of soil salinity in Yabello could be Capillary rise of saline ground water table from shallow water tables to the soil surface where subsoil leaching is insufficient to remove the salt, and clay or hardpan layers which impeded the downward movement of waters. In the current research, electrical conductivity and other parameters were highly correlated to saline and saline sodic soils (r = 0.99 and r = 0.86) respectively.

The electrical conductivity decreases uniformly from top to bottom soil layers in deserted fields. However, the EC in the current field assessment research was low as compared to other studies done on the other dryland soils. This might be due to the positive effect of the scattered vegetation it had on restructuring of the topsoil layer and reducing salt concentration through gradual leaching of salts [14], [2], [7], [40]. This postulate comes to the current findings as high concentrations of $CaCO_3$ and $CaSO_4$ were observed at the lower soil electrical conductivity (dS/m) extract (EC) value. As it has been shown in many researches on exchangeable metals particularly form soil chemical analysis, it has been approved that Calcium Salphate ($CaSO_4$) may directly supply Ca for the replacement of exchangeable Na or Ca_2SO_4 for the formation of Na_2SO_4, which could be easily leached down with water from plant root zone. On the other case, the research has exposed that the EC was highly correlated (r = 0.99) to soil-water suspension extracts of 1:1, 1:2, 1:2.5, and 1:5 of soil analysis.

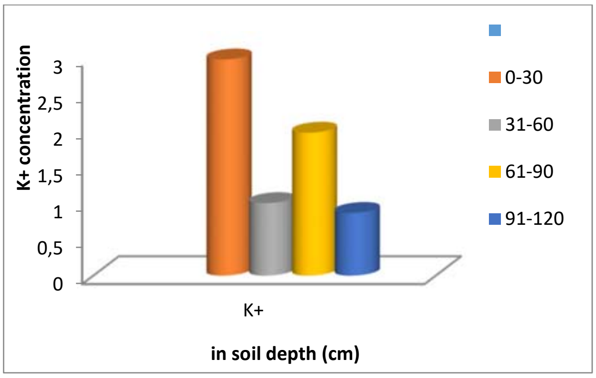
Soluble Cations and Anions

Plant growth could adversely be affected, as of both the poor physical conditions and with the high value of ESP. The current research revealed that, about 41% are non-saline, 38.31% saline, 15.23% saline-sodic and 5.46% sodic soils. Sodium concentration in saline soils was greater than Calcium plus Magnesium in all the soil depths (Figs. 2 (a), (c) and (d)). As the amount of exchangeable Na exceeds 10 to 20%, soil physical properties show high deterioration [6], [19], [7], [41], [42]. Soluble Na content was more excessive in the saline-sodic soils than Ca and magnesium in all soil depths (Figs. 2 (a), (c) and (d)). Calcium and magnesium content was higher above 60 cm soil depth in non-saline soils than the lower depth. However, at 61-90 cm soil depth sodium content tends to increase than the second depths of 31-60 cm. In nature, various sodium salts do not occur absolutely separately, but in most cases either the neutral salts or the ones capable of alkaline hydrolysis exercise a dominant role on the soil-forming processes and therefore in determining soil properties [25], [43]-[45], [19].

Excess Ca was predominant in saline soils; in which excessive amounts of gypsum ($CaSO_4.2H_2O$), calcium chloride ($CaCl_2.6H_2O$) or soluble Ca salt might have been accumulated through capillary rise from the ground soils [46]-[49], [11].



(a)



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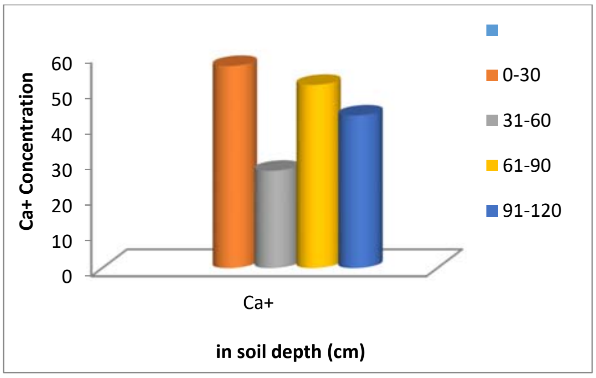

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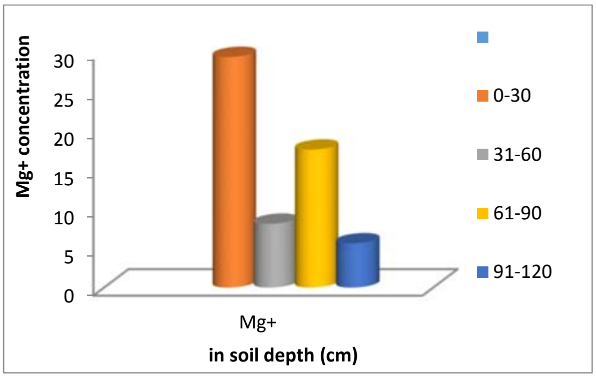

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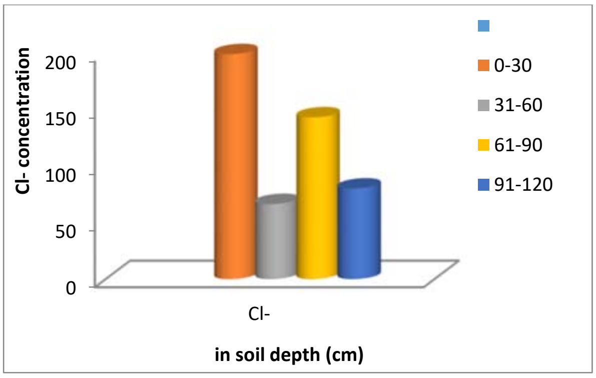

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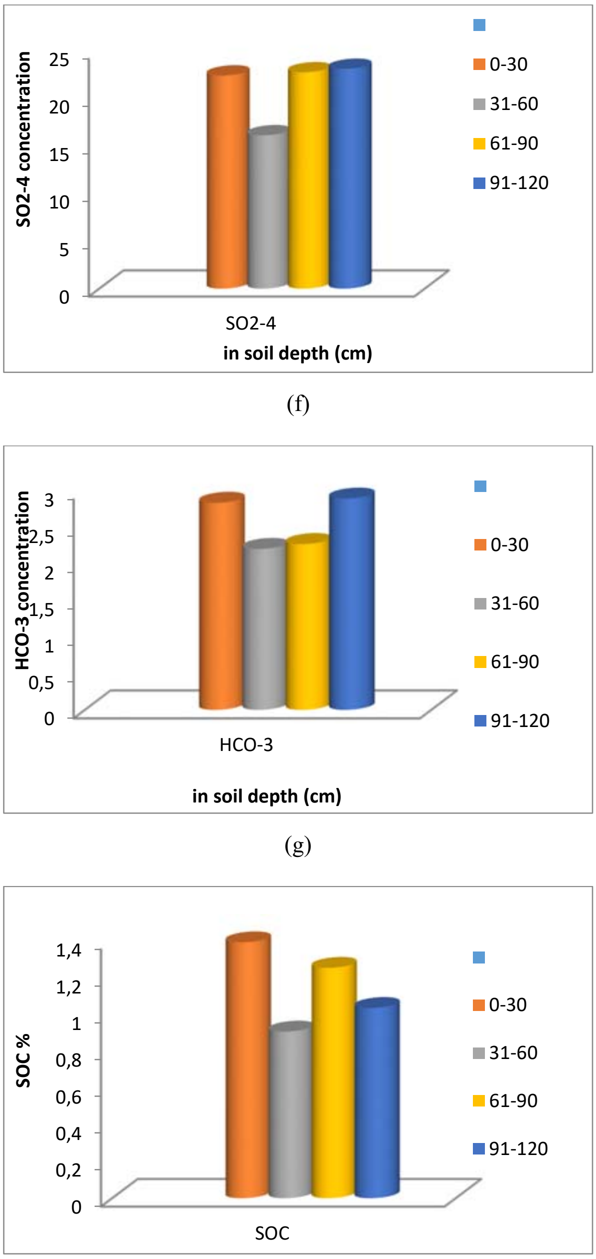

(f)

(g)

(h)

Fig. 2 Soil chemical analysis result indicator

Disproportionate chloride was accumulated in the shallower depth in saline-sodic soils salty typed soils. Accumulation of chloride in these soils might be the lack of enough water to leach the root zone, lack of a good soil permeability due to physical deterioration and capillary movement of chloride into the root zone [11], [50]-[53], [10], [6].

The study indicated that, soluble carbonate was trace in non-saline, saline and saline-sodic soils. Distribution of soluble bicarbonate in saline and saline-sodic soils shows slight decrement as soil depth goes down deep; however, lower for non-saline soils in all soil depths. On the other hand, the concentrations of SO_2^{-4} and HCO^{-3} were observed to be higher at the most lower soil depth than at the upper.

Sulphate was the second anion dominated the soil solution next to chloride. There was no unique distribution in soluble sulphate through the soil profiles as of soil depth varied since Sulphate exists in soils as free or adsorbed sulfate in soil solution and in organic compounds. Studies [54], [18], [55], [40], [1] approve that high sulphur concentrations are encountered in gypsiferous soils and sulphate is always a constituent in irrigation waters in many cases.

SAR and ESP

SAR was the other factor determined in the current soil assessment. The degree to which the replacement of exchangeable Ca and Mg by Na proceeds swiftly with salt accumulation may depend on the properties of Ca and Mg to Na in the soil solution that might come from the contact with the collision of soil particles, and most probably from the total elemental accumulations in the soil solutions that will determine the soil chemical properties. In the current findings, the SAR value shows indirect correlations with soil depths in both saline and saline sodic soils for the selected samples; however, it shows decrease at lower depth of the non-saline soils.

SAR of the soil solution is related to the ESP of the soils that better tell us the soil sodicity problem [56]-[58].

The other point raised here is ESP. The distribution of ESP above 60 cm soil depth was in an increasing order in saline and saline-sodic soils; i.e., the concentration increases as the soil depth increases. ESP value in saline-sodic soils was higher than saline and non-saline soils in all soil matrixes, but does not show significant differences.

The relative concentrations of cation in the soil solution, the valence and size as well as the nature and amounts can affect the exchange rates [39], [40]. On the current findings, the results for SAR and ESP are almost the same, and not seen scientifically significant except some mean differences.

V. CONCLUSION

The dominant soil colors were reddish brown, brown, gray and yellow. Silty clay loam was the dominant soil texture of the investigated area as compared to other soil particle sizes. There were no significant differences ($P < 0.05$) in bulk density across the plots for 0 to 30cm soil depth. High soil organic matter content was observed in the surface soil. Exchangeable Na value was higher than both Mg and K contents of the soil. The soil pH ranged from 7.1 to 8.6. As pH increases, $CaCO_3$ increases. In the current research, electrical conductivity and other parameters were highly correlated to saline and saline sodic soils. Sodium concentration in saline soils was greater than calcium plus magnesium in all the soil depths. Calcium and magnesium content was higher above 60 cm soil depth in non-saline soils than the lower depth. Excessive chloride was accumulated in the shallower depth in both salty typed soils. SAR value tends to be higher at lower depths in saline and saline-sodic soils. It was recommended that if someone undertakes researches of the same objectives under different seasons to identify whether the seasonal weather condition affects the soil chemical and physical properties since there have been enough soil depths and seasonally variable changes of rainfall in the region.

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