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Soil Salinity Type Effects on the Relationship between the Electrical Conductivity and Salt Content for 1:5 Soil-to-Water Extract

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Abstract: Soil salinity severely affects soil ecosystem quality and crop production in semi-arid and arid regions. A vast quantity of data on soil salinity has been collected by research organizations of the Commonwealth of Independent States (CIS, formerly USSR) and many other countries over the last 70 years, but using them in the current international network (irrigation and reclamation strategy) is complicated. This is because in the CIS countries salinity was expressed by total soluble salts as a percentage on a dry-weight basis (total soluble salts, TSS, %) and eight salinity types (chemistry) determined by the ratios of the anions and cations (Cl^- , SO_4^{2-} , HCO_3^- , and Na^+ , Ca^{2+} , Mg^{2+}) in diluted soil water extract (soil/water = 1:5) without assessing electrical conductivity (EC). Measuring the EC (1:5) is more convenient, yet EC is not only affected by the concentration but also characteristics of the ions and the salinity chemistry. The objective of this study was to examine the relationship between EC and TSS of soils in a diluted extract (1:5) for eight classic salinity types. We analyzed extracts (1:5) of 1100 samples of a clayey soil (0–20 cm) collected from cultivated semi-arid and arid regions for EC, TSS, soluble cations (Na^+ , Ca^{2+} , Mg^{2+}), and anions (HCO_3^- , Cl^- , SO_4^{2-}). Results revealed that (i) the variation in the proportional relationships ($R^2 \geq 0.91$ –0.98) between EC (0.12–5.6 dS m^{-1}) and TSS (0.05–2.5%) could be related to salinity type, and (ii) the proportionality coefficient of the relationships (2.2–3.16) decreased in the following order of salinity type: $\text{SO}_4 < \text{Cl}(\text{SO}_4)\text{--HCO}_3 < \text{Cl}(\text{HCO}_3)\text{--SO}_4 < \text{SO}_4(\text{HCO}_3)\text{--Cl} < \text{Cl}$. The findings suggest that once the salinity type of the soil is established, EC (1:5) values can be safely used for the evaluation of the soil salinity degree in the irrigated land in the context of sustainable soil and crop management.

Keywords: total dissolved salts; salinity chemistry; irrigation; dryland; salinity stress

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1. Introduction

Cultivated lands, particularly in semi-arid and arid regions or drylands with scarce water resources, spread over more than 100 countries and ~1 billion ha (e.g., Argentina, Australia, China, India, USA) including the Commonwealth of Independent States (CIS, formerly USSR) are seriously affected by soil salinization and sodicity [1]. This environmental problem involves the ground water–soil–water–plant–atmosphere continuum associated with (i) water potential in the growth medium, which causes decreased transpiration and net photosynthetic rates (the osmotic effect, salinity degree), reduced capacity of plants to transform energy to biomass, and accumulation of specific toxic ions (Cl^- , Na^+) to levels exceeding the tolerance limits of plants (salinity stress, specific ion effect); (ii) ionic disequilibrium and imbalance of nutrients in the plant, thus harming seed germination, plant stomatal conductance, density and growth, and biomass partitioning between shoots and roots; and (iii) deterioration of soil structure (soil disaggregation and clay dispersion)

and hydraulic characteristics (solution and air flow) due to high content of exchangeable Na^+ , Mg^{2+} , or K^+ when soil electrolyte concentration is below a “threshold” level [2–5].

Plant tolerance to salinity varies with species and varieties and biotic and abiotic factors, yet the growth of most agricultural plants is negatively affected by salinity, which critically influences soil biological activities. The remediation of salt-affected soils, particularly secondary salinization, is expensive and difficult. Thus, plant response to soil salinity (both concentration and composition of the ions, i.e., osmotic stress and specific ion effects) and irrigation management should take the specific circumstances into account (e.g., leaching fraction, salinity stress, selection of cultivars tolerant to a certain salinity level, deterioration of soil physical quality, role of soil biota), and the interrelationships that exist among soil properties, salt composition, and plant species [2–6].

Assessing soil salinity is a critical task for the Kur–Araz basin (600,000 ha) of Azerbaijan, which is located in the shoreline area (situated below sea level up to 30 m with <300–400 mm annual precipitation) and has wide drainage networks. Currently, 60% of the cultivated and irrigated land of the basin has clayey soil in the root zone and is characterized by various degrees and types of salinity (Figure 1) [7–9]. The problem of salinity in the Kur–Araz basin of Azerbaijan, as well as in many semi-arid and arid regions or drylands of the world, is expected to increase with the ongoing climate change and shortage in fresh water. Thus, frequent monitoring of salinity level is important for water resources allocation and sustainable management of salt-affected soils, which may have significant economic ramifications if ill-managed [10].

Figure 1. Soil salinity map of Kur-Araz basin of Azerbaijan (from [9]). Salinity degree is given by total soluble salts (TSS, %). Salinity area (10^3 ha): non-saline: 495.4; slightly saline: 381.8; saline: 414.6; strongly saline: 448.9; extremely saline: 174.4.

Sustainability of the agroecosystem in salt-affected lands could be preserved by studying salinity related soil processes (e.g., the interactions between root–zone environment and plant response to elevated osmotic pressure, soil–plant–salinity interaction) and integrating new soil management and cropping systems resistant to drought and salinity stresses for effective soil function. Along with traditional reclamation (washing and amend-

ing), use of microorganisms (e.g., rhizobacteria) may alleviate salinity stress by altering physiological changes in plants, yet soil microbial activity also depends on soil salinity and composition [5,6]. However, such approaches also require knowledge of previously collected information on soil salinity status (e.g., characteristics, distribution, and trend) for application of advanced approaches and precision agriculture across the various scales (e.g., GIS, remote sensing, digital mapping, geospatial analysis, electromagnetic induction) concerning salinity related management strategy [11,12]. Although the tolerance of plants to salinity strongly depends on the processes of accumulation and leaching of salts in the root zone, the impacts of salinity type (chemistry) associated with the predominant ions and salinity degree in soil solution and irrigation water are still overlooked [2,3,5,6,10,13,14].

Saline soil classification by the USDA is based on the electrical conductivity of the saturated paste extract (ECe); a soil is considered saline if $EC_e > 4 \text{ dS m}^{-1}$, exchangeable sodium percentage (ESP) < 15 , and $pH < 8.5$ [15] (Table 1). Determining ECe for salinity monitoring is related to natural conditions, but using it for the massive number of soil samples during the growing season is time-consuming and laborious. Therefore, researchers proposed to determine EC for various ratios of soil-to-water extracts (e.g., soil/water = 1:1, 1:2, 1:2.5, 1:5) in the laboratory [16–21] (Table 1).

Table 1. US agronomic classification of soil salinity of the studied samples based on salinity of the saturated extract (ECe) [15] and that of the 1:5 soil/water extract (EC 1:5) [13].

Classification	ECe dS m^{-1}	Crop Yield	EC (1:5) dS m^{-1}	Number of Samples EC 1:5
Non-saline	0–2	not affected	0.0–0.25	253
Slightly saline	2–4	sensitive crop affected	0.25–0.5	290
Saline (moderate)	4–8	many crops affected	0.5–1.0	170
Strongly saline	8–16	only tolerant crops	1.0–2.0	101
Extremely saline	>16	a few very tolerant crops	>2.0–3.0	286

Many studies assessed the linear relationships between (i) ECe and EC (1:1, 1:2, 1:5); $EC_e = a \times EC + b$, (ii) EC and total dissolved salts (TDS, mg L^{-1}) concentration: $TDS = a \times EC_e$, and (iii) EC and solution ion components (Na^+ , Ca^{2+} , Mg^{2+} , HCO_3^- , Cl^- , SO_4^{2-}): $EC = a \times \text{Ion (concentration)} + b$, yet the coefficients and intercepts (a and b) of the linear relationships for the similar studies varied between the regions [2,18,22,23]. The difference between the coefficients was associated along with the soil type, texture, presence of carbonate and gypsum, organic matter content, the method used for extract preparation, and the ratio of exchangeable cations and salinity chemistry [21,24–31]. Nevertheless, the relationship between EC of various soil/water extract ratios (1:1, 1:2, 1:2.5, 1:5) and particularly the use of EC (1:5) for quantifying soil salinity (TDS) is considered as an alternative simplified method commonly used in many countries [10,23,32].

The EC of soil is not only determined by the concentration of ions but also by the characteristics of the ions or salinity chemistry [11,15,33]. Consequently, the ionic composition of the soil solution, in addition to the above attributes, should be taken into account for proper interpretation of salinity stress and soil–plant interactions [2,3,5]. In general, the CIS (and many other countries) classification of soil salinity (Table 2) is based on (i) salinity degree expressed as a percentage of salt in the soil on a dry-weight basis (total soluble salts, TSS, %; g salt/100 g dry soil) and (ii) eight salinity types (i.e., salinity chemistry) determined by the concentration ratios of anions (HCO_3^- , Cl^- , SO_4^{2-}) and additionally by cations (Na^+ , Ca^{2+} , Mg^{2+}) in 1:5 soil–water extraction (meq L^{-1}), yet without measuring EC. This type of classification suggests that along with the TSS, the threshold level or toxicity of salts (highly soluble salts in toxic quantities to plants) is associated with the relationship between anionic and cationic ions, i.e., type and degree of salinity [33–35].

Table 2. Commonwealth of Independent States (CIS) classification of salt-affected soils according to the degree and salinity type [10,14,34].

Salinity Type			Salinity, %				
Type	Ion Ratios	pH	Non	Slight	Moderate	Strong	Very Strong
Chloride (Cl)							
Sulfate–Chloride (SO ₄ –Cl)	Cl:SO ₄ > 1	<8.5 neutral	<0.05	0.05–0.12	0.12–0.35	0.35–0.7	>0.7
Chloride–Sulfate (Cl–SO ₄)	Cl:SO ₄ = 0.2–1.0	<8.5 neutral	<0.10	0.10–0.25	0.25–0.50	0.50–1.0	>1.0
Sulfate (SO ₄)	Cl:SO ₄ < 0.2	<8.5 neutral	<0.15	0.15–0.30	0.30–0.60	0.60–1.5	>1.5
Chloride–Soda (Cl–HCO ₃)							
Soda–Chloride (HCO ₃ –Cl)	Cl:SO ₄ > 1, HCO ₃ : Cl > 1 HCO ₃ > Ca+Mg	>8.5 alkaline	<0.10	0.10–0.15	0.15–0.30	0.30–0.5	>0.5
Sulfate–Soda (SO ₄ –HCO ₃)							
Soda–Sulfate (HCO ₃ –SO ₄)	Cl:SO ₄ < 1; HCO ₃ : Cl > 1 HCO ₃ > Ca+Mg	>8.5 alkaline	<0.15	0.15–0.25	0.25–0.40	0.40–0.6	>0.6

A vast quantity of data on soil salinity (TSS and ion composition, soil/water ratio = 1:5) has been collected by research and other relevant organizations in the CIS and other countries, including Azerbaijan, during the past 70 years. However, using these data in current international scientific networks (and irrigation and reclamation strategy) is complicated due to the lack of EC measurements and proper linkage to the quantity of soluble salts (TSS). To the best of our knowledge, this is the first work that attempts to investigate the relationship between EC and TSS in association with salinity type (chemistry). This activity is of great importance for assessing various advanced practical activities and contributing to sustainable agriculture in the salt-affected fields in support of increasing crop yield, obtaining and analyzing digital mapping, determination of leaching fraction, combining waters of diverse quality for irrigation, etc. [36]. We hypothesized that for a 1:5 soil/water extract, the association between the EC and TSS varies among soils differing in their salinity chemistry. Therefore, the objective of this study was to evaluate the relationship between EC (dS m^{−1}) and TSS (%) of soil–water extract (1:5) with consideration of eight salinity types, available in the Kur–Araz basin. It should be noted that the relationships between the EC (1:5) and E_{ce} (or EC (1:1), EC (1:2)), as well as between EC (dS m^{−1}) and TDS (mg L^{−1}) or TSS (% or meq L^{−1}) and between EC and typical ion composition (Na⁺, Ca²⁺, Mg²⁺, HCO₃[−], Cl[−], SO₄^{2−}) are the subject of another ongoing study, which also compares results of new experiments with well-established relationships from the literature for similar climate and soil types and textures [1,18,23,29,32,37].

2. Materials and Methods

A total of 1100 soil samples (taken from a 0–20 cm depth), representing mostly irrigated soils of different salinity types and levels, were collected from five plan areas (Salyan: 49°03′4.81″ E, 39°35′54.01″ N; Shirvan: 48°05′15.75″ E, 40°13′9.17″ N; Mil: 47°57′01.51″ E, 39°47′23.07″ N; Mugan: 48°40′41.17″ E, 39°49′18.87″ N; Karabakh: 47°11′16.29″ E, 40°23′45.86″ N) in the Kur–Araz basin of Azerbaijan (semi-arid and arid region) during the spring period (Figure 1). Soils were used under different types of crop cultivation and were characterized by gray-meadow and meadow-gray soil types (associated with FAO Calcisols), clayey texture, and low organic matter content. Eight types of salinity chemistry (Table 2) were formed in light of the geology and geomorphological and environmental conditions, cultivation, irrigation, and drainage history in the basin [7,8].

The samples were oven-dried, ground, and then passed through a 2 mm sieve. Then, 250 mL of distilled water was added to 50 g of soil, and the suspension was shaken for 1 min by hand 4 times with 30 min intervals. The suspensions were left afterwards to reach

equilibrium for 4 h, and soon thereafter the extract was obtained by filtering. Analyses of soil salinity included EC soluble cations (Na^+ , Ca^{2+} , Mg^{2+}) and anions (HCO_3^- , Cl^- , SO_4^{2-}) in the prepared 1:5 soil/water extracts [38]. Soil TSS, the mass of salt in the extracted solution, was determined by evaporating and subsequent completion of dryness in an oven (at 70 °C) and weighing. Statistical analyses were performed using the SAS Proc GLM procedure [39], where mean comparisons were performed using the Tukey–Kramer honestly significant difference HSD test at $p < 0.05$. Least squares fitting was applied to identify the relationship between soil TSS and EC for 1:5 soil-to-water extracts.

3. Results

Generally, for the salinity types of the samples presented in Table 2, sulfate (SO_4) salinity types coupled with low-to medium exchangeable sodium percentage ($\text{ESP} = 2\text{--}10$) were found mostly in Shirvan plain with various levels of gypsum, whereas mixed soda (carbonate and bicarbonate) related salinity types ($\text{Cl}/\text{SO}_4\text{--HCO}_3$; $\text{HCO}_3\text{--Cl}/\text{SO}_4$) coupled with low-to-elevated ESP ($2\text{--}40$) occurred mostly in Karabakh and infrequently in Mil plains, and chloride–sulfate (Cl--SO_4) and sulfate–chloride ($\text{SO}_4\text{--Cl}$) salinity types, coupled with low-to-medium ESP ($2\text{--}15$), which dominated in Mugan and Salyan and Shirvan plains of the Kur–Araz basin (Figure 1) [7,8]. The relationship between EC (1:5) and TSS (total soluble salts, %) for eight salinity types (chemistry) is presented in Figures 2 and 3.

Figure 2. Relationship ($p < 0.001$) between the electrical conductivity (EC 1:5, dS m^{-1}) and total soluble salt content (TSS, % or g salt/100 g soil) for 1:5 soil-to-water extract as affected by neutral ($\text{pH} < 8.5$) salinity type: (a) Chloride (Cl); (b) Sulfate–Chloride ($\text{SO}_4\text{--Cl}$); (c) Chloride–Sulfate (Cl--SO_4); and (d) Sulfate (SO_4).

Figure 3. Relationship ($p < 0.001$) between the electrical conductivity (EC 1:5, dS m^{-1}) and total soluble salt content (TSS, % or g salt/100 g soil) for 1:5 soil-to-water extract as affected by alkaline ($\text{pH} > 8.5$) salinity type: (a) Chloride–Soda (Cl-HCO_3); (b) Soda–Chloride ($\text{HCO}_3\text{-Cl}$); (c) Sulfate–Soda ($\text{SO}_4\text{-HCO}_3$); and (d) Soda–Sulfate ($\text{HCO}_3\text{-SO}_4$).

The EC of neutral ($\text{pH} < 8.5$) salinity types varied widely between 0.12 and 5.6 dS m^{-1} except for the Cl salinity type (Figure 2), yet it varied to a lesser extent, between 0.11 and 1.2 dS m^{-1} , in the alkaline ($\text{pH} > 8.5$) salinity types (Figure 3). The fitted line presents the proportional relation ($\text{EC} = a \times \text{TSS}$) between the two attributes, with a being the proportionality coefficient (Figures 2 and 3). Because intersects of relationships were negligible, we opted to use the proportional type relation as it is easy to explore. Due to soil salinization–desalinization environmental processes, there were not enough available samples (e.g., locations) or just a limited number of samples exhibiting strongly saline ($\text{EC (1:5)} = 1\text{--}2 \text{ dS m}^{-1}$) and extremely saline ($\text{EC (1:5)} > 2 \text{ dS m}^{-1}$) levels from (i) neutral soils with easily washed Cl salinity type (Figure 2) and (ii) alkaline soils having $\text{SO}_4(\text{Cl})\text{-HCO}_3$ and $\text{HCO}_3\text{-SO}_4(\text{Cl})$ type of salinity (Figure 3).

Low level of salinity was related to soils under long-term cultivation with drainage setup, irrigation with substantial amount of fresh water, or with pre-vegetation winter leaching by flooding. High levels of salinity usually were related to (i) salinity spots in irrigated fields with deficit of irrigation, (ii) ineffective irrigation and drainage setup, and (iii) unused salt-affected areas located near cultivated fields, with superior evaporation over rainfall [7,8,40,41]. Long periods of irrigation practices and leaching processes under annual crops may change soil salinity degree, pH and ion composition, and exchangeable cations, and consequently salinity type. Intensity and direction of the processes depend on soil properties, irrigation and groundwater quality, irrigation depth, depth of

groundwater [40,41], and content of carbonates (2–20%) and gypsum (0.2–3%) typically present in the soils of the Kur–Araz basin [7,8].

Though soil EC 1:5 was proportional to its salt content (i.e., TSS, %) in all the salinity types, there were differences in the proportionality coefficient ($a = 2.22\text{--}3.16$) (Figures 2 and 3, Table 3). The coefficient a increased in the following order: $\text{SO}_4 < \text{Cl}(\text{SO}_4)\text{--HCO}_3 < \text{Cl}(\text{HCO}_3)\text{--SO}_4 < \text{SO}_4(\text{HCO}_3)\text{--Cl} < \text{Cl}$. The proportionality coefficient for conversion from TSS (%) to EC (1:5) (dS m^{-1}) varied between 0.313 to 0.447 and decreased in the following order: $\text{SO}_4 > \text{Cl}(\text{SO}_4)\text{--HCO}_3 > \text{Cl}(\text{HCO}_3)\text{--SO}_4 > \text{SO}_4(\text{HCO}_3)\text{--Cl} > \text{Cl}$ (Table 3). In both related cases, difference in the proportionality coefficient could be related to salinity characteristics [35].

Table 3. Proportionality coefficients (a) of linear relationship between electrical conductivity (EC 1:5, dS m^{-1}) and total soluble salts (TSS, %). Within a column, numbers followed by the same letter do not differ significantly at $p < 0.05$.

Salinity Type	Number of Samples	pH	Salinity Range		EC = a TSS		TSS = a EC	
			TSS %	EC 1:5 dS m^{-1}	a	R^2 $p < 0.001$	a	R^2 $p < 0.001$
Cl	32	<8.5	0.044–0.414	0.120–1.20	3.156 a	0.95	0.313 e	0.94
SO ₄ –Cl	96	<8.5	0.050–1.504	0.135–4.20	3.072 ab	0.97	0.323 e	0.97
Cl–SO ₄	390	<8.5	0.046–2.448	0.140–5.60	2.680 c	0.98	0.369 d	0.98
SO ₄	246	<8.5	0.054–2.369	0.115–5.20	2.217 e	0.96	0.447 a	0.96
Cl–HCO ₃	56	>8.5	0.044–0.343	0.120–0.87	2.457 d	0.93	0.402 b	0.93
HCO ₃ –Cl	32	>8.5	0.085–0.394	0.230–1.20	2.959 b	0.96	0.336 e	0.95
SO ₄ –HCO ₃	144	>8.5	0.046–0.341	0.140–0.95	2.483 d	0.92	0.396 c	0.91
HCO ₃ –SO ₄	104	>8.5	0.063–0.347	0.170–1.05	2.645 c	0.91	0.371 d	0.91
All	1100		0.044–2.448	0.115–5.60	2.401 d	0.96	0.408 b	0.96

4. Discussion

Differences in the proportionality coefficient ($a = 2.22\text{--}3.16$) of the linear relationship between EC (1:5) (dS m^{-1}) and TSS (%) ($\text{EC} = a \times \text{TSS}$, Table 3, Figures 2 and 3) were associated with salinity type (chemistry), and ion specific concentration and conductivity, and presence of gypsum or lime, as samples have similar soil texture [35]. The effect of each ion on the EC and TSS relationship is related to its size. Generally, for the same concentration (meq L^{-1}), the conductivity of multi-charged and larger ions is smaller than that of smaller single-charged ions; thus, the larger anions SO_4^{2-} and HCO_3^- have lower conductivity (Figures 2d and 3c,d) than the smaller Cl^- anion (Figures 2a,b and 3b). However, the divalent cations (Ca^{2+} and Mg^{2+}) have higher conductivity than the monovalent cations (Na^+ and K^+) [13]. The relationship between EC (1:5) and TSS (%) is also affected by the dilution factor of the solution, since by increasing the water/soil ratio, the degree of dissolution of the slightly soluble CaSO_4 and CaCO_3 increases and thus affects the concentration of the salts (TSS) and ratio of the soluble ions, as well as the composition of the exchangeable ions. Our results were in agreement with previous studies, reporting that the relationships between E_{ce} and EC (1:5) or EC (1:1, 1:2), as well as EC and TDS (mg L^{-1}) or TSS (meq L^{-1} or %), for the diluted extract were associated with presence of lime and gypsum and various salts, although different extraction protocols and sampling periods (soil moisture condition) have been used [1,6,11,21,23,26,27,32,42].

In support of the abovementioned conclusion, it should be noted that although no fixed relationships existed between E_{ce} (dS m^{-1}) and total dissolved solid (mg L^{-1}), a coefficient of 640 ($\text{EC} < 5 \text{ dS m}^{-1}$) is commonly used (established for Western US soils) to convert E_{ce} to total dissolved solid (mg L^{-1}) [15,22,32]. This relationship, which was developed in a system where Cl^- was the dominant anion, may overestimate or underestimate the concentration of the TDS in the extracts, largely varying in salt species (e.g., for the $\text{Cl}\text{--HCO}_3$, $\text{Cl}\text{--SO}_4$ and SO_4 system) [2,13,22]. For instance, in gypsum-rich soils, the quantity of extracted salts could be reduced by the quantity of water used due to the limited solubility, and the slow rate of dissolution of CaSO_4 ; for the gypsum-rich semi-arid soils of Canada (260 samples, $\text{EC} = 0.1\text{--}16 \text{ dS m}^{-1}$), the coefficient of relationship

between E_{Ce} and TDS was much higher (924 vs. 640) than the commonly used one [22]. In other relevant studies, soil texture and gypsum (4–25 cmol kg^{−1}) significantly modified the relationship between E_{Ce} and EC (1:2) or EC (1:5) in soils from the arid region of Iran (>250 samples, E_{Ce} = 1–33 dS m^{−1}); the coefficient of the linear relation was significantly higher for the samples with gypsum, which has greater impact (than soil texture) on the accuracy of predicting E_{Ce} [27,37]. In arid soils from Turkey (E_{Ce} = 0.4–16 dS m^{−1}), the coefficient of the linear relationship between E_{Ce} and EC (1:1: 1:2.5; 1:5) increased > 3 times with the change in soil/water ratio from 1:1 to 1:5, whereas change in soil texture from sandy to clay soil reduced by ~1.2 times the mean of the coefficients. Similar results were reported by scientists from Greece and the US [18,21,42]. In the examples of the related studies [13,20–23,27,37,42] the coefficients of determination for the relationship between E_{Ce} and TDS, and E_{Ce} and EC (1:1: 1:2; 1:2.5; 1:5), were mostly strong ($R^2 \geq 0.90$).

Our proportionality coefficient (a , with a mean of 0.408) between TSS (%) and EC (1:5) (dS m^{−1}) was as expected and salinity-type-dependent (Table 3). The internationally reported mean value of conversion (TSS = g salt/100 g dry soil, or % = 0.336 EC (1:5, dS m^{−1})) is based on soil salinity dominated by NaCl with the possible presence of some SO₄^{2−} anions [13]. This value (0.336) was significantly lower than our mean value (0.408) but still within the range of coefficients obtained in the current study (0.313–0.447). Thus, in relation to the coefficients obtained in our study (Table 3), the international coefficient was (i) comparable (slightly higher) for chloride itself and chloride dominant salinity type (0.313, 0.323, and 0.336 for Cl, SO₄–Cl, and HCO₃–Cl, respectively); (ii) similar but somewhat lower for the sulfate dominant type of salinity (0.369 and 0.371 for Cl–SO₄ and HCO₃–SO₄, respectively); and (iii) lower for sulfate itself and the soda (carbonate and bicarbonate) dominant type of salinity (0.447, 0.402, and 0.396 for SO₄, Cl–HCO₃, and SO₄–HCO₃, respectively), all typically present in different parts of the Kur–Araz basin [8]. The deviation of the mean, a value of 0.408, from the internationally reported one, may also stem from the weighted number of the samples used for each salinity type in our study. Nevertheless, the number of samples for non-saline, slightly saline, saline + strongly saline, and extremely saline (253–290) (Table 1) in the current study seems large enough [15,22,37] to ensure sufficient confidence in the significant relationship obtained between TSS and EC (1:5) and the resultant proportionality coefficient (a) arising from our study.

The influence of salinity on plant growth is mainly based on E_{Ce}, so it is necessary to convert EC 1:5 to E_{Ce} in order to assess plant response. When there are no available or limited data on soil EC (extract, 1:1, 1:2) and TDS for a given investigated region, then as an initial step or for approximate computation, the obtained relationships from the current study (EC (1:5) = $a \times$ TSS, Table 3) could be used to establish numerous relationships between EC and TDS (or TSS) and between EC and typical salt type from semi-arid and arid regions, for planning of management and irrigation and reclamation strategy [18,20,21,23,27,31,32].

Salinity is a dynamic soil property within the root zone. Evaporation from the soil surface and plant transpiration remove soil water, which concentrates salts in the soil solution. Moreover, dissolved salts within the soil profile are mobile due to convective–dispersive and diffusion processes. Therefore, the main issues in sustainable soil management under irrigation for maintaining crop or plant productivity are somewhat complex as they relate on one hand to preventing excessive salt accumulation in the root zone and on the other to minimizing excess drainage of water (with salts and nutrients) below the root zone, while maintaining soil quality (physical, chemical, and biological) and minimizing off-site effects are required [5,6].

In the studied Kur–Araz basin, it has been observed over recent years that the decrease in total salinity (EC and TSS) is coupled with ion exchange between soil solution and solid phase of soil and shifts in the chemistry of the salts (e.g., from Cl, SO₄–Cl, and HCO₃–Cl to Cl–SO₄, Cl–HCO₃, and SO₄–HCO₃, respectively) during irrigation, rain events, and amelioration processes (e.g., accelerated leaching of salts by intense drainage condition and flooding, adding leaching fraction to irrigation water, or using salt tolerant plants and

microbiota), which result in the leaching of highly soluble salts and hence alter the ratios of cations and anions and affect plant adaptation and growth [2,15]. Consequently, the abovementioned changes are associated with lower soil salinity (below the threshold level for particle flocculation, particularly during rains with very low EC), which may cause clay dispersion and aggregate slaking. These processes can increase soil alkalinity or sodicity after a certain period of time and lead to deterioration of soil physical quality, particularly in clayey soils [4,40,41,43]. In the case of formation of a soda (carbonate or bicarbonate: CO_3^{2-} and HCO_3^-) dominated salinity type, poor soil structure and physical properties hinder the leaching process [43,44], plant growth, and productivity in the soils of the basin, particularly in Karabakh and Mil plains [40,41]. Finally, understanding of the complex relationship between the salinity parameters, including salinity chemistry, involved in ecosystem services (crop production, soil and water conservation, and environmental pollution) and quantifying the associated chemical and mineralogical processes operating in soil water systems are crucial to building sustainable agricultural systems for semi-arid and arid regions [5,12,32,36].

5. Conclusions

Developing an integrated and sustainable management strategy in saline soils requires a systematic study of the processes and factors contributing to salinity parameters for identifying and implementing water-saving and soil-improvement measures based on soil salinity and water-saving irrigation approaches. Our findings suggest that once the salinity type of the soil is established, EC (1:5) values can be used for the evaluation of the soil salinity degree in cultivated and irrigated land in the context of sustainable soil and crop management. While the general EC and TSS (or TDS) relationship may help in achieving salinity management and control under irrigation and amelioration, soil properties and other factors affecting soil salinity dynamics and salinity type should be considered to control salinity level, soil hydraulic properties and structural status under field conditions. Such knowledge can assist in the development of sustainable management practices for irrigated lands and thus maintain crop growth and productivity.

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