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Electrical conductivity as a salient factor in saline-sodic soils of Tabriz plain

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Abstract Most of characteristic measurements of salt-affected soils are time consuming, expensive and linked with error. For this reason, some researchers have attempted to estimate those from easy-to-obtain characteristics. Electrical conductivity (EC) measurement is a means of easily quantifying salinity in salt-affected soils. Traditionally, EC of saturated soil paste extract (EC_e) has been used to assess soil salinity. This paper presents the relationships between some characteristics of saline-sodic soils and EC_e in the plain of Tabriz. According to the results obtained concentration of sodium ($r^2 = 0.986$) and chloride ($r^2 = 0.991$) are in close double logarithmic relation with EC_e. Additionally, there is a significant correlation ($P<0.001$) between EC_e and the concentration of potassium (r = 0.83), magnesium (r = 0.84), calcium (r = 0.65) and sulfate (r = 0.79) ions. We found equations to estimate TSS and ionic strength from EC_e. It was also found a power function and a double reciprocal model to describe the relationship between SAR and EC_e ($SAR = 1.45\ EC_e^{0.91}$, $r^2 = 0.94$) and between ESP and SAR ($ESP = 1/[0.014+(1.2/SAR)]$, $r^2 = 0.94$), respectively. Therefore, one can estimate ESP from EC_e reliably. We also found a power function equation to estimate EC_e from $EC_{1:1}$ ($EC_e = 3.22EC_{1:1}^{0.85}$, $r^2 = 0.978$). The results showed that there is a significant negative correlation between pH_e and EC_e (r = −0.66). After speciation, it was found relationships between ionic concentration C and corrected ionic strength with EC_e. The average value of K'_G for our soils was 0.00717 $(mmol\ L^{-1})^{-0.5}$ and therefore lower than 0.01475 $(mmol\ L^{-1})^{-0.5}$. This emphasizes the need for measurement of K'_G value for any given area. In a multiple regression procedure, EC_e was negatively and ESP was positively associated with K'_G ($r^2 = 0.61$). After correction of the data for anion exclusion the average value of K'_G was increased to 0.0129 $(mmol\ L^{-1})^{-0.5}$ and the association was only with ESP ($r^2 = 0.41$).

Key words: *electrical conductivity, saline-sodic soils, anion exclusion*

Introduction

Salinity and sodicity are expressed in a number of ways, depending on the method and purpose of the measurements. Electrical conductivity (EC) measurement is a means of easily quantifying salinity in salt-affected soils. Traditionally, EC of saturated soil paste extract (EC_e) has been used to assess soil salinity. Although the preferred parameter to assess soil salinity is EC_e, there are other important parameters, which are useful in several aspects. Some relations between these parameters and EC_e have been reported by several workers [2, 5, 7, 9, 10]. However, the value of the proportionality constant is not unique but a definite function of the nature of the ionic species in solution and their relative proportions. The sodic hazard in soils is directly associated with ESP. However, the criterion most often used to define sodic conditions is the SAR of the soil solution. Studies by the USSL (1954) using the Gapon rule led to the value of 0.01475 $(mmol\ L^{-1})^{-0.5}$ for the modified Gapon selectivity coefficient (K'_G). Despite this, the results of subsequent researches reveled that K'_G isn't a constant value and thus could take on a wide range of values depending on soil properties (electrolyte concentration, mineralogy, clay and organic matter contents, Na saturation, K saturation, Mg/Ca ratio) [1, 6, 8]. Therefore, for a better estimate of exchangeable sodium, the value of K'_G needs to be determined experimentally for each major group of soils. Most of characteristic measurements of salt-affected soils are tedious, time consuming, expensive and linked with error. To overcome some of these difficulties, some researchers prefer to estimate those from easy-to-obtain characteristics. At the present, about the 20,000 hectares of Tabriz plain (with some extent of 53,000 ha) is under cultivation of various crops and the rest is bare because of salinity as well as sodicity. This paper presents relations between some characteristics of saline-sodic soils and EC_e in the plain of Tabriz.

Materials and methods

The aim of this study was to find simple equations to estimate the salinity and sodicity parameters for the salt-affected soils of Tabriz plain. For this purpose, 30 composite soil samples were taken from 0-20 cm depth of the region in two transection lines. Some properties of the soils such as EC, concentration of soluble cations and anions, SP, CEC, pH, the amounts of exchangeable sodium and potassium, OC, the amount of gypsum and CCE were measured [10]. In addition, the percent of clay size particles in the soils was determined using hydrometer method [3]. Furthermore, the amount of anion exclusion in the soils was measured [4]. Additionally, speciation of soil solution was carried out by using of VMINTEQ software.

Results and discussion

Some physical and chemical properties of the soils were given in table 1.

Table 1. Some physical and chemical properties of the soils

Property	minimum	maximum	average	SD
EC_e (dSm^{-1})	0.55	136	49	36
SAR ($mmol\ L^{-1})^{0.5}$	1.2	484	66	87
ESP	0.93	65.4	25.3	16
TSS ($mmol_c\ L^{-1}$)	7	2271	651	538
pH_e	7.05	8.53	7.7	0.37
CEC ($cmol_c kg^{-1}$)	7	27.5	16	6
Gypsum ($cmol_c kg^{-1}$)	0.003	32	8	10
CCE ($g\ kg^{-1}$)	110	440	200	60
OC ($g\ kg^{-1}$)	3.5	13	7.3	2.6
SP ($g\ kg^{-1}$)	220	780	460	140
Clay ($g\ kg^{-1}$)	100	750	370	185

The results indicated that some criterions of the investigated salt-affected soils (TSS, SAR, ESP, ionic strength and the concentration of sodium and chloride ions) can be estimated from easily obtainable EC_e with reasonable precision. The estimations are performed by the following equations (Figs 1 and 2):

$$\log TSS\ (mmol_c\ L^{-1}) = 1.039 + 1.041 \log EC_e\ (dSm^{-1}) \quad (r^2 = 0.996,\ SEE = 0.036)$$

$$SAR\ (mmol\ L^{-1})^{0.5} = 1.454\ EC_e (dSm^{-1})^{0.913} \quad (r^2 = 0.937,\ SEE = 0.327)$$

$$ESP = \frac{1}{\left[0.0144 + (\frac{1.2041}{SAR})\right]} \quad (r^2 = 0.94,\ SEE = 0.052)$$

$$ESP = \frac{1}{\left[0.0144 + \frac{1.2041}{1.4542 EC_e^{0.9127}}\right]}$$

$$I\ (mmol\ L^{-1}) = 19.84\ EC_e\ (dSm^{-1}) \quad (r^2 = 0.993,\ SEE = 105.2)$$

$$\log Na^+\ (mmol_c\ L^{-1}) = 0.49 + 1.278 \log EC_e\ (dSm^{-1}) \quad (r^2 = 0.986,\ SEE = 0.088)$$

$\log Cl^-$ ($mmol_c\ L^{-1}$) = 0.645 + 1.186 $\log EC_e$ (dSm^{-1}) (r^2= 0.991, SEE = 0.039)

$EC_e = 3.22\ EC_{1:1}^{0.85}$ (r^2 = 0.978 , SEE = 0.198)

The statistical significance of the determination coefficients for the regressions of the other ions [calcium (r^2 = 0.42), magnesium (r^2 = 0.70), potassium (r^2 = 0.69), and sulfate (r^2 = 0.62)] and EC_e is low enough to suggest that for the investigated soils, it is impossible to estimate these from EC_e.

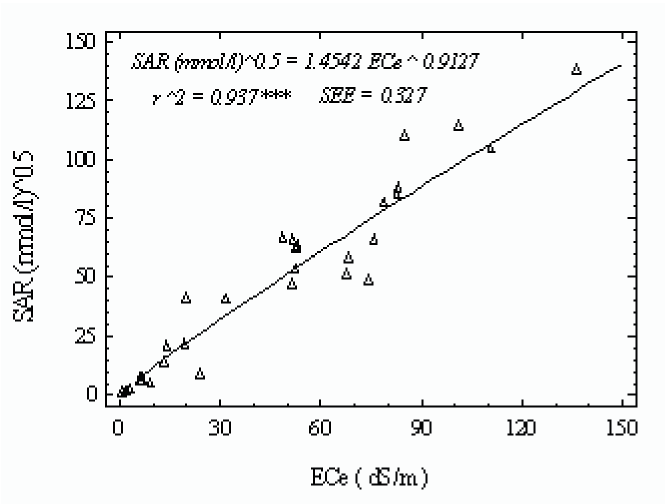

Fig. 1. SAR vs. EC_e

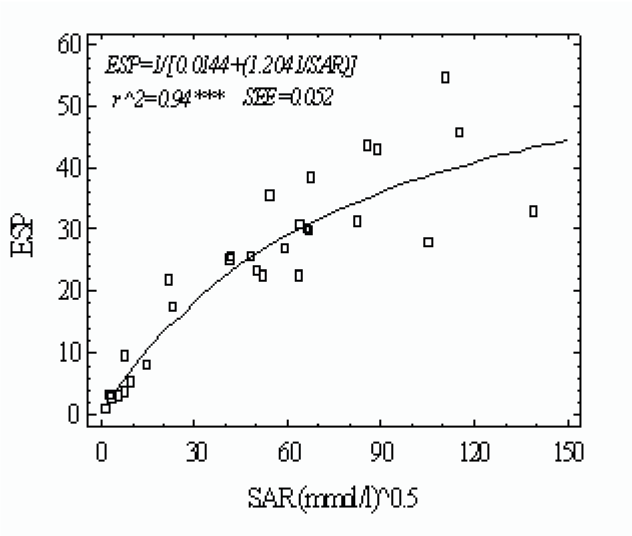

Fig. 2. ESP vs. SAR

The results showed that there is a significant negative correlation between pH_e and EC_{en}(r = –0.66). The decrease in pH with increase in EC may be due to an increased degree of dissociation of the surface functional groups. In addition, this might be the result of an alkaline error in pH measurements.
After speciation of saturation extract, it was found relationships between ionic concentration (C) and corrected ionic strength I_c with EC_e. The relations are as follows:

$\log C$ ($mmol_c\ L^{-1}$) = 1.014+1.0095 $\log EC_e$($dS\ m^{-1}$) (r^2 = 0.997, SEE = 0.028)

I_c ($mmol\ L^{-1}$) = 12.3 EC_e ($dS\ m^{-1}$) (r^2 = 0.998, SEE = 25.72)

According to the results obtained the slope of the linear relation between ionic strength and EC_e in the investigated soils is different from those in the literature. For example, slope values of 23.3 and 16 have been reported by Banin et al. (1972) and Ponamperuma et al. (1966), respectively. In contrast, for the slope of the linear relation between corrected ionic strength and EC_e, there is a good agreement between our results and findings of Griffin and Jurinak (1973). In other words, it seems that the latter relation is unique.
The relation between ESR and SAR for the investigated soils with SAR < 100 $(mmol\ L^{-1})^{0.5}$ was of the form: ESR = 0.011+0.00717 SAR, r = 0.926***(Fig 3). After correction of the data for anion exclusion, this relation was modified as follows: ESR = –0.0955+0.0129 SAR, r = 0.92*** (Fig. 4). As a result, taking into account the anion exclusion increased K'_G values. However, K'_G value was yet found less than the commonly used value of 0.01475 $(mmol\ L^{-1})^{-0.5}$.This might be attributed to the formation of quasicrystals under highly saline soils, which can lead to increase in affinity of clay minerals for calcium and magnesium.

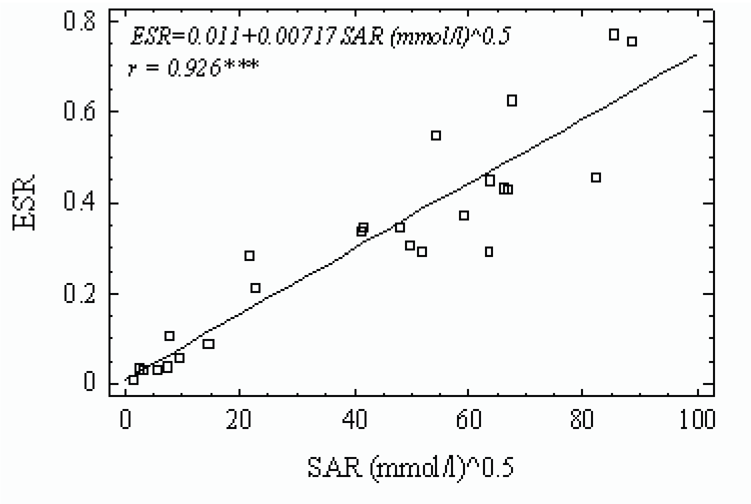

Fig. 3. ESR vs. SAR

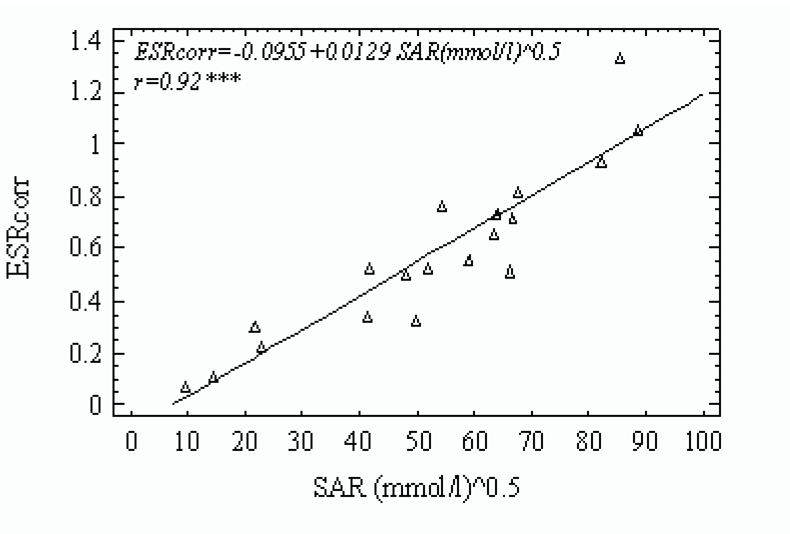

Fig. 4. Corrected ESR (ESR_{corr}) vs. SAR

Our results emphasize the need for measurement of K'_G value for any given area. In a multiple regression procedure, EC_e was negatively and ESP was positively associated with K'_G :

$K'_G\,(mol\ L^{-1})^{-0.5} = 0.2061 - 0.0026\ EC_e + 0.0062\ ESP$ ($r^2 = 0.614$, $P < 0.001$)

After correction of the data for anion exclusion the association was only with ESP:

K'G (mol L-1)-0.5 = 0.2041 + 0.0049 ESP ($r^2 = 0.409$, P< 0.001)

It can be concluded that the failure to correct for anion exclusion in the investigated soils lowers the average value of K'G from 0.0129 to 0.00717 (mmol L-1)-0.5. Furthermore, the results obtained emphasize the dependence of modified Gapon selectivity coefficient (K'G) on the Na+-saturation.

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