

Prediction of Soil Exchangeable Sodium Percentage Based on Soil Sodium Adsorption Ratio

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Abstract: Despite the increasing prevalence of salinity world-wide, the measurement of exchangeable cation concentrations in saline soil remains problematic. In this situation, it is desirable to determine relationships among indices of soil salinity. Exchangeable Sodium Percentage (ESP) are often determined using laborious and time consuming laboratory tests, but it may be more appropriate and economical to develop a method which uses a more simple soil salinity index. In this study, a linear regression model for predicting soil ESP from soil Sodium Adsorption Ratio (SAR) was suggested and the soil ESP was estimated as a function of soil SAR. The statistical results of the study indicated that in order to predict soil ESP based on soil SAR the linear regression model $ESP = 1.95 + 1.03 SAR$ with $R^2 = 0.92$ can be recommended.

Key words: Exchangeable sodium percentage • Sodium adsorption ratio • Soil • Prediction

INTRODUCTION

Saline soils are of increasing importance both in Iran and world-wide. In Iran, approximately 44.5 M ha of arable land are affected by dry land salinity [1]. In addition, poor quality of irrigation water may result in an increase in soil salinity. Salinity became a problem when enough salts accumulate in the root zone to negatively affect plant growth. Excess salts in the root zone hinder plant roots from withdrawing water from surrounding soil. This lowers the amount of water available to the plant, regardless of the amount of water actually in the root zone [2].

Two different criteria are currently recognized in the scientific literature as indices of salinity. These are the Sodium Adsorption Ratio (SAR) with a reported threshold of 12 (cmol kg^{-1})^{0.5} and the Exchangeable Sodium Percentage (ESP) with a reported threshold of 15%. These are defined as Eq. (1) and Eq. (2) [2-4]:

$$SAR = Na^+ / \sqrt{(Ca^{2+} + Mg^{2+}) / 2} \quad (1)$$

Where:

SAR = Sodium adsorption ratio, (cmol kg^{-1})^{0.5}

Na^+ , Ca^{2+} , Mg^{2+} = Measured exchangeable Na^+ , Ca^{2+} and Mg^{2+} , respectively, cmol kg^{-1}

$$ESP = (Na^+ / CEC) \times 100 \quad (2)$$

Where:

ESP = Exchangeable sodium percentage, %

Na^+ = Measured exchangeable Na^+ , cmol kg^{-1}

CEC = Cation exchange capacity, cmol kg^{-1}

As shown in Eq. (2), for determining soil ESP, it is necessary to have soil Cation Exchange Capacity (CEC). But, as soil CEC are often determined using laborious and time consuming laboratory tests [5, 6], it may be more appropriate and economical to develop a method which determines soil ESP indirectly from a more simple soil salinity index.

Previously researches report a relationship between soil ESP and SAR [7-9]. Thus, soil SAR can be used to approximate or estimate soil ESP. For this reason, many attempts have been made to predict soil ESP from soil SAR. The United States Salinity Laboratory (USSL) proposed one of the earlier models to predict soil ESP from soil SAR as $ESP = -0.0126 + 0.01475 SAR$ for United States soils [7]. Since, the model developed by the USSL has been derived from 59 arid-zone soils, the general model between soil ESP and SAR has traditionally been assumed to be similar to that. However, this model has been shown not to be constant, but to vary substantially with both solution ionic strength and the dominant

clay mineral present in the soil [10-13]. Therefore, the relationship between soil ESP and SAR is not constant and should be determined directly for the soil of interest.

Despite the considerable amount of research done, which shows the relationship between soil ESP and soil SAR, very limited work has been conducted to model soil ESP based on soil SAR. Moreover, the mentioned predictive model is specific to a region or area and confined to only a few soil types. Therefore, the specific objective of the study presented here was to determine a soil ESP-SAR model for Varamin soils in Iran and to verify the developed model by comparing its results with those of the laboratory tests.

MATERIALS AND METHODS

Experimental procedure: Fifty-one soil samples were taken at random from different fields of experimental site of Varamin, Iran. The site is located at latitude of 35°-19'N and longitude of 51°-39'E and is 1000 m above mean sea level, in arid climate in the center of Iran. The soil of the experimental site was a fine, mixed, thermic, Typic Haplocambids clay-loam soil.

In order to obtain required parameters for determining soil ESP-SAR model, some soil physical and chemical properties i.e. sand, silt and clay content (% by weight) and pH, EC, Na⁺, Ca²⁺+Mg²⁺, SAR and ESP of the soil samples were measured using laboratory tests as described by the Soil Survey Staff [14]. Physical and chemical properties of the fifty-one soil samples used to determine the soil ESP-SAR model are shown in Table 1.

Also, in order to verify the soil ESP-SAR model by comparing its results with those of the laboratory tests, fifteen soil samples were taken at random from different fields of the experimental site. Sand, silt and clay content (% by weight) and pH, EC, Na⁺, Ca²⁺+Mg²⁺, SAR and ESP of the soil samples were measured using laboratory tests as described by the Soil Survey Staff [14]. Physical and chemical properties of the fifteen soil samples used to verify the soil ESP-SAR model are shown in Table 2.

Regression model: A typical linear regression model is shown in Eq. (3):

$$Y = k_0 + k_1X \quad (3)$$

Where:

- Y = Dependent variable, for example ESP of soil
- X = Independent variable, for example SAR of soil
- k₀, k₁ = Regression coefficients

Table 1: The mean values, Standard Deviation (S.D.) and Coefficient of Variation (C.V.) of soil physical and chemical properties of the fifty-one soil samples used to determine soil ESP-SAR model

Parameters	Minimum	Maximum	Mean	S.D.	C.V. (%)
Sand (%)	14.0	44.0	33.1	6.31	19.1
Silt (%)	30.0	56.0	45.3	4.13	9.12
Clay (%)	9.00	50.0	22.0	6.65	30.2
pH	7.00	8.10	7.50	0.27	3.60
EC (dS m ⁻¹)	0.25	14.4	6.91	3.53	51.0
Na ⁺ (cmol kg ⁻¹)	3.00	96.0	42.6	24.6	57.6
Ca ²⁺ +Mg ²⁺ (cmol kg ⁻¹)	5.60	81.0	42.7	19.2	45.1
SAR (cmol kg ⁻¹) ^{0.5}	1.50	11.8	6.64	2.91	43.9
ESP (%)	2.90	13.6	8.79	3.14	35.7

Table 2: The mean values, Standard Deviation (S.D.) and Coefficient of Variation (C.V.) of soil physical and chemical properties of the fifteen soil samples used to verify soil ESP-SAR model

Parameters	Minimum	Maximum	Mean	S.D.	C.V. (%)
Sand (%)	10.0	34.0	24.1	5.87	24.4
Silt (%)	40.0	56.0	48.2	4.40	9.13
Clay (%)	18.0	50.0	28.2	7.90	28.0
pH	7.00	8.00	7.31	0.33	4.51
EC (dS m ⁻¹)	0.40	14.0	7.26	4.67	64.3
Na ⁺ (cmol kg ⁻¹)	3.00	96.0	44.2	30.6	69.3
Ca ²⁺ +Mg ²⁺ (cmol kg ⁻¹)	5.20	84.0	40.1	26.4	65.8
SAR (cmol kg ⁻¹) ^{0.5}	1.90	11.8	6.78	3.30	48.7
ESP (%)	2.50	14.0	9.09	3.60	39.6

In order to predict soil ESP from soil SAR, a linear regression model as above was suggested.

Statistical analysis: A paired samples T-test and the mean difference confidence interval approach were used to compare the soil ESP values predicted using the soil ESP-SAR model with the soil ESP values measured by laboratory tests. The Bland-Altman approach [15] was also used to plot the agreement between the soil ESP values measured by laboratory tests with the soil ESP values predicted using the soil ESP-SAR model. The statistical analyses were performed using Microsoft Excel (Version 2003).

RESULTS

The p-value of the independent variable, Coefficient of Determination (R²) and Coefficient of Variation (C.V.) of the soil ESP-SAR model is shown in Table 3. Based on the statistical result, the soil ESP-SAR model was judged acceptable due to statistical results.

Table 3: The p-value of independent variable, Coefficient of Determination (R²) and Coefficient of Variation (C.V.) of the soil ESP-SAR model

Model	Independent variable	p-value	R ²	C.V.(%)
ESP = k ₀ +k ₁ SAR	SAR	4.93E-28	0.92	12.6

The R² value and C.V. of the model were 0.92 and 12.6%, respectively. The linear regression soil ESP-SAR model is given in Eq. (4).

$$ESP = 1.95 + 1.03 SAR \quad (4)$$

DISSCUSSION

A paired samples T-test and the mean difference confidence interval approach were used to compare the soil ESP values predicted using the soil ESP-SAR model with the soil ESP values measured by laboratory tests. The Bland-Altman approach [15] was also used to plot the agreement between the soil ESP values measured by laboratory tests with the soil ESP values predicted using the soil ESP-SAR model.

Table 4: Chemical properties of soil samples used in evaluating soil ESP-SAR model

Sample No.	SAR (cmol kg ⁻¹) ^{0.5}	ESP (%)	
		Laboratory test	ESP-SAR model
1	1.90	2.50	3.90
2	2.10	4.00	4.10
3	4.90	6.20	7.00
4	3.60	6.30	5.70
5	4.50	6.80	6.60
6	5.00	7.60	7.10
7	5.00	8.00	7.10
8	5.10	8.40	7.20
9	7.70	9.50	9.90
10	10.0	11.9	12.3
11	9.80	12.3	12.0
12	9.30	12.6	11.5
13	10.9	13.0	13.2
14	10.0	13.2	12.2
15	11.8	14.0	14.1

Table 5: Paired samples T-test analyses on comparing soil ESP determination methods

Determination methods	Average difference (%)	Standard deviation of difference (%)	p-value	95% confidence intervals for the difference in means (%)
ESP-SAR model and laboratory test	0.16	0.75	0.420	-0.25, 0.57

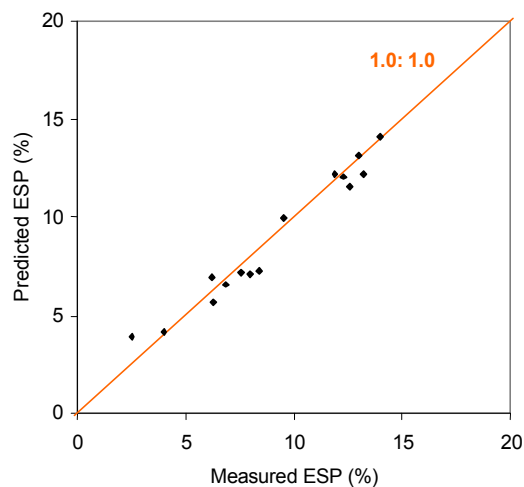


Fig. 1: Measured ESP and predicted ESP using the soil ESP-SAR model with the line of equality (1.0: 1.0)

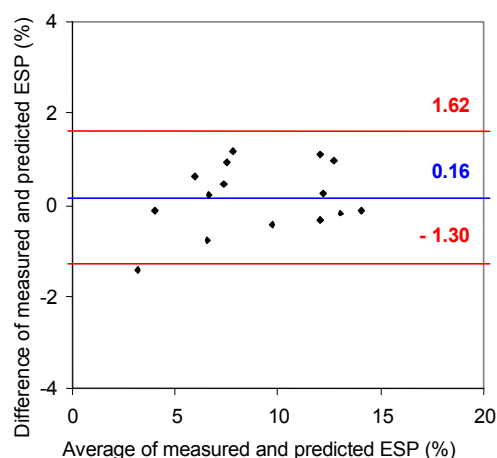


Fig. 2: Bland-Altman plot for the comparison of measured ESP and predicted ESP using the soil ESP-SAR model; the outer lines indicate the 95% limits of agreement (-1.30, 1.62) and the center line shows the average difference (0.16)

The soil ESP values predicted by the soil ESP-SAR model were compared with the soil ESP values determined by laboratory tests and are shown in Table 4. A plot of the soil ESP values determined by the soil ESP-SAR model and laboratory tests with the line of equality (1.0: 1.0) is shown in Fig. 1. The mean soil ESP difference between two methods was 0.16% (95% confidence interval:-0.25 and 0.57%; P = 0.420). The standard deviation of the soil ESP differences was 0.75%. The paired samples T-test results showed that the soil ESP values predicted with the soil ESP-SAR model were not significantly different than the soil ESP measured with laboratory tests (Table 5). The

soil ESP differences between these two methods were normally distributed and 95% of the soil ESP differences were expected to lie between $\mu+1.96\sigma$ and $\mu-1.96\sigma$, known as 95% limits of agreement [15]. The 95% limits of agreement for comparison of soil ESP determined with laboratory test and the soil ESP-SAR model were calculated at-1.30 and 1.62% (Fig. 2). Thus, soil ESP predicted by the soil ESP-SAR model may be 1.30% lower or 1.62% higher than soil ESP measured by laboratory test. The average percentage differences for soil ESP prediction using the soil ESP-SAR model and laboratory test was 9.64%.

CONCLUSIONS

Linear regression model based on soil Sodium Adsorption Ratio (SAR) was used to predict soil Exchangeable Sodium Percentage (ESP). The soil ESP values predicted using the model was compared to the soil ESP values measured by laboratory tests. The paired samples T-test results indicated that the difference between the soil ESP values predicted by the model and measured by laboratory tests were not statistically significant ($P>0.05$). Therefore, the soil ESP-SAR model can provide an easy, economic and brief methodology to estimate soil ESP.

ACKNOWLEDGMENTS

The financial support provided the Agricultural Extension, Education and Research Organization of Iran under research award number 100-15-76048 is gratefully acknowledged.

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