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# MODELING OF SOIL SODIUM ADSORPTION RATIO BASED ON SOIL ELECTRICAL CONDUCTIVITY

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**ABSTRACT**

There are many instances in which it is desirable to determine relationships among indices of soil salinity. For example, soil Sodium Adsorption Ratio (SAR) are often determined using laborious and time consuming laboratory tests but it may be more suitable and economical to develop a method which uses a more simple soil salinity index. A linear regression model for predicting soil SAR from soil Electrical Conductivity (EC) was suggested and soil SAR was estimated as a function of soil EC. The statistical results indicated that in order to predict soil SAR based on soil EC, the linear regression model SAR = 1.91 + 0.68 EC with $R^2$ = 0.69 can be recommended.

**Keywords:** model, soil, sodium adsorption ratio, electrical conductivity, 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 (Banaei *et al.* 2005). In addition, the application to soil of poor quality irrigation water may result in an increase in soil salinity. Salinity becomes 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 (Sumner 1993).

Two different criteria are currently recognized in the scientific literature as indices of soil salinity. These are the soil Electrical Conductivity (EC) and the soil Sodium Adsorption Ratio (SAR). The soil Electrical Conductivity is abbreviated as EC with units of dS $m^{-1}$ or mmhos $cm^{-1}$. Both are equivalent units of measurement and give the same numerical value (Page *et al.* 1982). The soil Sodium Adsorption Ratio is abbreviated as SAR and is defined as Eq. (1) (Sumner 1993; Rengasamy and Churchman 1999; Quirk 2001):

$$SAR = Na^{+}/ [(Ca^{2+}+Mg^{2+})/2]^{0.5} \quad (1)$$

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 $kg^{-1}$

As shown in Eq. (1), for determining soil SAR, it is necessary to have exchangeable $Na^+$, $Ca^{2+}$ and $Mg^{2+}$. But, as these parameters are often determined using laborious and time consuming laboratory tests (Seilsepour and Rashidi 2008; Rashidi and Seilsepour 2008), it may be more suitable and economical to develop a method which determines soil SAR indirectly from a more simple soil salinity index such as soil EC.

For almost 50 years many attempts have been made to predict difficult to determine soil properties from some easily available soil properties using empirical models. In soil science, such empirical models are named pedotransfer functions (MacDonald 1998; Krogh *et al.* 2000). So far many of the pedotransfer functions have been developed to predict various soil properties.

MacDonald (1998) developed two models to predict soil Cation Exchange Capacity (CEC) based on Organic Carbon (OC) and Clay (CL) as CEC = 2.0 OC + 0.5 CL and CEC = 3.8 OC + 0.5 CL for Quebec and Alberta soil state in Canada, respectively. Seilsepour and Rashidi (2008) studied Varamin soils in Iran and proposed a model to predict soil CEC based on Organic Carbon (OC) and pH (PH) as CEC = 26.76 + 8.06 OC – 2.45 PH with $R^2$ = 0.77. Rashidi and Seilsepour (2008) also predicted soil CEC from organic carbon as CEC = 7.93 + 8.72 OC with $R^2$ = 0.74.

Moreover, the United States Salinity Laboratory (USSL) proposed one of the earlier models to predict soil Exchangeable Sodium Percentage (ESP) from soil Sodium Adsorption Ratio (SAR) as ESP = – 0.0126 + 0.01475 SAR for United States soils (Richards 1954).

Previously researches report a relationship between soil Sodium Adsorption Ratio (SAR) and soil Electrical Capacity (EC) (Richards 1954; Levy and Hillel 1968; Emerson and Bakker 1973). Thus, soil EC can be used to approximate or estimate soil SAR. For this reason, many attempts have been made to predict soil SAR from soil EC. Al-Busaidi and Cookson (2003) suggested an equation based on EC as SAR = 0.464 EC + 7.077 with $R^2$ = 0.83 for saline soil in Oman.

Since, the above predictive models have been derived from different saline-zone soils, the general models between soil properties may be assumed to be similar to those. However, these models have been shown not to be constant, but to vary substantially with both solution ionic strength and the dominant clay mineral present in the soil (Shainberg *et al.* 1980; Nadler and Magaritz 1981; Marsi and Evangelou 1991; Evangelou and Marsi 2003). Therefore, the relationships between soil properties are not constant and should be determined directly for the soil of interest.

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Despite the considerable amount of research done, which shows the relationship between soil SAR and soil EC, very limited work has been conducted to model soil SAR based on soil EC. Therefore, the specific objective of this study was to determine a soil SAR-EC model for calcareous soils of Varamin region 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 SAR-EC model, some soil physical and chemical properties i.e. sand, silt and clay content (% by weight) and pH, EC, $Na^+$, $Ca^{2+}$+$Mg^{2+}$ and SAR of the soil samples were measured using laboratory tests as described by the Soil Survey Staff (1996). Physical and chemical properties of the fifty-one soil samples used to determine the soil SAR-EC model are shown in Table-1.

Also, in order to verify the soil SAR-EC 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. Again, sand, silt and clay content (% by weight) and pH, EC, $Na^+$, $Ca^{2+}$+$Mg^{2+}$ and SAR of the soil samples were determined using laboratory tests as described by the Soil Survey Staff (1996). Physical and chemical properties of the fifteen soil samples used to verify the soil SAR-EC model are shown in Table-2.

**Table-1.** Mean values, Standard Deviation (S.D.) and Coefficient of Variation (C.V.) of soil physical and chemical properties of 51 soil samples used to determine soil SAR-EC model.

| **Parameter** | **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 |

**Table-2**. Mean values, Standard Deviation (S.D.) and Coefficient of Variation (C.V.) of soil physical and chemical properties of 15 soil samples used to verify soil SAR-EC model.

| **Parameter** | **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 |

### Regression model

A typical linear regression model is shown in Eq. (2):

$$Y = k_0 + k_1X \qquad (2)$$

where

Y = Dependent variable, for example SAR of soil
X = Independent variable, for example EC of soil
$k_0$, $k_1$ = Regression coefficients

In order to predict soil SAR from soil EC, a linear regression model as Eq. (1) was suggested.

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**Statistical analysis**

A paired samples t-test and the mean difference confidence interval approach were used to compare the soil SAR values predicted using the soil SAR-EC model with the soil SAR values measured by laboratory tests. The Bland-Altman approach (1999) was also used to plot the agreement between the soil SAR values measured by laboratory tests with the soil SAR values predicted using the soil SAR-EC model. The statistical analyses were performed using Microsoft Excel (Version 2003).

## RESULTS

The p-value of the independent variable, Coefficient of Determination ($R^2$) and Coefficient of Variation (C.V.) of the soil SAR-EC model is shown in Table-3. Based on the Statistical result, the soil SAR-EC model was judged acceptable. The $R^2$ value and C.V. of the model were 0.69 and 23.8%, respectively. The linear regression soil SAR-EC model is given in Eq. (3).

$$SAR = 1.91 + 0.68\ EC \tag{3}$$

**Table-3.** The p-value of independent variable, Coefficient of Determination ($R^2$) and Coefficient of Variation (C.V.) of the soil SAR-EC model.

| Model | Independent variable | p-value | $R^2$ | C.V. (%) |
|---|---|---|---|---|
| SAR = 1.91 + 0.68 EC | EC | 5.93E -14 | 0.69 | 23.8 |

## DISCUSSIONS

A paired samples t-test and the mean difference confidence interval approach were used to compare the soil SAR values predicted using the soil SAR-EC model with the soil SAR values measured by laboratory tests. The Bland-Altman approach (1999) was also used to plot the agreement between the soil SAR values measured by laboratory tests with the soil SAR values predicted using the soil SAR-EC model.

The soil SAR values predicted by the soil SAR-EC model were compared with the soil SAR values determined by laboratory tests and are shown in Table-4. A plot of the soil SAR values determined by the soil SAR-EC model and laboratory tests with the line of equality (1.0: 1.0) is shown in Figure-1. The mean soil SAR difference between two methods was -0.11 (cmol kg$^{-1}$)$^{0.5}$ (95% confidence interval: -0.80 and 0.60 (cmol kg$^{-1}$)$^{0.5}$; P = 0.747).

The standard deviation of the soil SAR differences was 1.26 (cmol kg$^{-1}$)$^{0.5}$. The paired samples t-test results showed that the soil SAR values predicted with the soil SAR-EC model were not significantly different than the soil SAR measured with laboratory tests (Table-5). The soil SAR differences between these two methods were normally distributed and 95% of the soil SAR differences were expected to lie between $\mu$+1.96$\sigma$ and $\mu$–1.96$\sigma$, known as 95% limits of agreement (Bland and Altman 1999). The 95% limits of agreement for comparison of soil SAR determined with laboratory test and the soil SAR-EC model were calculated at -2.57 and 2.36 (cmol kg$^{-1}$)$^{0.5}$ (Figure-2). Thus, soil SAR predicted by the soil SAR-EC model may be 2.57 (cmol kg$^{-1}$)$^{0.5}$ lower or 2.36 (cmol kg$^{-1}$)$^{0.5}$ higher than soil SAR measured by laboratory test. The average percentage differences for soil SAR prediction using the soil SAR-EC model and laboratory test was 16.5%.

**Table-4.** Chemical properties of soil samples used in evaluating soil SAR-EC model.

| Sample No. | EC (dS m$^{-1}$) | **SAR** (cmol kg$^{-1}$)$^{0.5}$ | |
|---|---|---|---|
| | | **Laboratory test** | **SAR-EC model** |
| 1 | 0.60 | 1.90 | 2.30 |
| 2 | 0.40 | 2.10 | 2.20 |
| 3 | 6.80 | 4.90 | 6.60 |
| 4 | 2.00 | 3.60 | 3.30 |
| 5 | 6.00 | 4.50 | 6.00 |
| 6 | 4.00 | 5.00 | 4.60 |
| 7 | 2.30 | 5.00 | 3.50 |
| 8 | 6.20 | 5.10 | 6.20 |
| 9 | 11.0 | 7.70 | 9.50 |
| 10 | 11.0 | 10.0 | 9.40 |
| 11 | 13.0 | 9.80 | 10.8 |
| 12 | 12.0 | 9.30 | 10.1 |
| 13 | 11.5 | 10.9 | 9.80 |
| 14 | 8.00 | 10.0 | 7.40 |
| 15 | 14.0 | 11.8 | 11.5 |

**Table-5.** Paired samples t-test analyses on comparing soil SAR determination methods.

| Determination methods | Average difference $(cmol\ kg^{-1})^{0.5}$ | Standard deviation of difference $(cmol\ kg^{-1})^{0.5}$ | p-value | 95% confidence intervals for the difference in means $(cmol\ kg^{-1})^{0.5}$ |
|---|---|---|---|---|
| Laboratory test and SAR-EC model | -0.11 | 1.26 | 0.747 | -0.80, 0.59 |

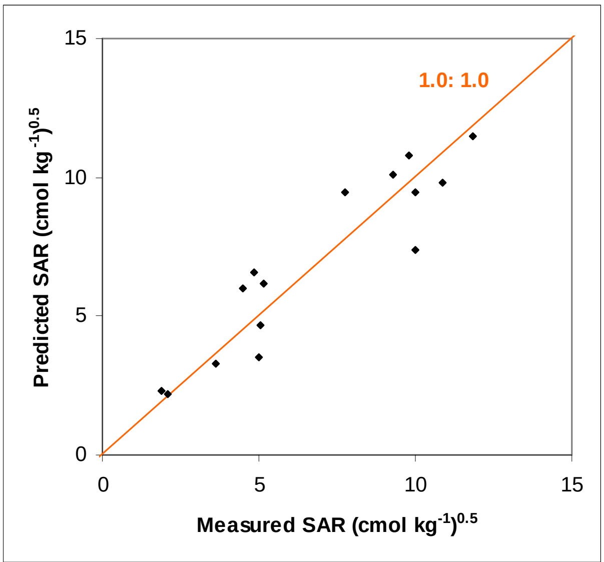


**Figure-1.** Measured SAR and predicted SAR using the soil SAR-EC model with the line of equality (1.0: 1.0).

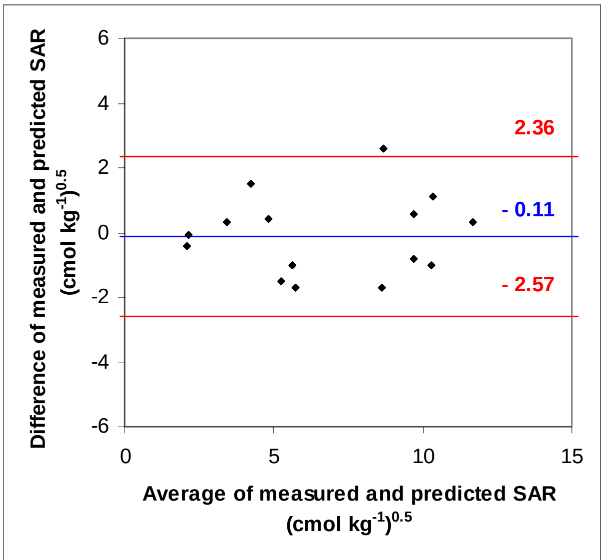


**Figure-2.** Bland-Altman plot for the comparison of measured SAR and predicted SAR using the soil SAR-EC model; the outer lines indicate the 95% limits of agreement (-2.57, 2.36) and the center line shows the average difference (-0.11).

## CONCLUSIONS

Linear regression model based on soil Electrical Conductivity (EC) was used to predict soil Sodium Adsorption Ratio (SAR). The soil SAR values predicted using the model was compared to the soil SAR values measured by laboratory tests. The paired samples t-test results indicated that the difference between the soil SAR values predicted by the model and measured by laboratory tests were not statistically significant ($P>0.05$). Therefore, the soil SAR-EC model can provide a short, simple and profitable method to estimate soil SAR.

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