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Modeling of Soil Exchangeable Sodium Percentage Function to Soil Adsorption Ratio on Sandy Clay Loam Soil, Khartoum- Sudan

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Authors' contributions

This work was carried out in collaboration between all authors. Author MMAE designed the study and wrote the first draft of the manuscript. Author SX managed the literature searches. Author AASA managed the experimental process. Author BHO checked the manuscript prior to submission. All authors read and approved the final manuscript.

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ABSTRACT

An experiment was conducted at the Wadi Soba farm, Khartoum- Sudan. The aim of this study is to estimate the Exchangeable Sodium Percentage (ESP) function to Sodium Adsorption Ratio. In this study, linear regression model (ESP_{-SAR} model) for predicting soil ESP from SAR was suggested. For this purpose, 30 soil samples were collected from the field of experiment, soil ESP was estimated from soil SAR in order to compare the predicted results with measured SAR using laboratory tests on saline and non- saline soil samples. The results show that on saline soil

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samples, the Standard Error of Mean (SEM) of predicted ESP obtained by ESP_{-SAR} model was (0.9389) and the P-value was (0.0572). On non- saline soil samples, the Standard Error of Mean (SEM) of predicted ESP acquired by ESP_{-SAR} model was (0.2920) and the P-value was (0.2628). The statistical results indicated that the linear regression model (ESP_{-SAR} model), ESP= 0.84 × SAR + 2.17 with R^2 = 0.7347 has a good performance in predicting soil ESP from SAR meanwhile the ESP_{-SAR} model reflected more accuracy on non- saline soil samples and it can be recommended for both saline soil and non-saline soil samples.

Keywords: Electrical conductivity; exchangeable sodium percentage; cation exchange capacity; sodium adsorption ratio.

1. INTRODUCTION

Soil chemical, physical and biological properties affect many processes in the soil that make it suitable for agriculture practices and other purposes. Some physical properties such as texture, structure, and porosity influence the movement and retention of water, air and solutes in the soil, which subsequently affect plant growth [1].

Soil salinity and sodicity are important chemical properties and have a negative impact on crops production, particularly in arid and semi-arid areas [2,3,4]. [5] stated that soil salinity refers to the total concentration of soluble salts in the soil and soil sodicity represents the amount of exchangeable sodium relative to other exchangeable cations. Soil salinity and sodicity are recognized by soil Sodium Adsorption Ratio (SAR) and Exchangeable Sodium Percentage (ESP), as defined in Eq. (1) and (2) [6]:

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

Where:

SAR= Sodium Adsorption Ratio.

Na^+, Mg^{++} and Ca^{++} = Soluble cations in soil solution (meq/L)

$$(\text{Exchangeable Na}^{+}/\text{CEC}) \times 100 \quad (2)$$

Where:

ESP = Exchangeable Sodium Percent, %.
Na+ = Measured exchangeable Na^+, meq/100 g.
CEC = Cation Exchange Capacity, meq/100 g.

Accurate and rapid predictions and relatively simple methods are ideally needed for soil analysis [7,8,9]. The measurement of ESP is often using laborious and time-consuming laboratory tests through determination of Cation Exchange Capacity (CEC) and exchangeable Na+, therefore the prediction of ESP from SAR is useful due to their existed relation [10,11]. Furthermore, a number of rapid measurement methods and models on prediction of ESP from SAR have recently been developed by many researchers [12-14] and prediction of other soil properties such as soil organic Carbon, water retention and soil bulk density also have been discussed by many researchers [15-17].

The aim of this study is to estimate the Exchangeable Sodium Percentage (ESP) function to soil Sodium Adsorption Ratio (SAR) by using the $ESP\text{-}_{SAR}$ Model on saline and non-saline soil samples.

2. MATERIALS AND METHODS

2.1 Soil Sampling

Thirty soil samples (fifteen soil samples represented saline soil samples and fifteen soil samples exemplified non-saline soil) were taken randomly from the field of experiment, Wadi Soba farm (Sharq Elneel) about 50 kilometers from Khartoum- Sudan. All the soil samples were mixed thoroughly and then air-dried. Then, the soil samples were sieved through a 2-mm sieve. The soil Electrical Conductivity (EC), soil pH, texture, calcium, magnesium, calcium carbonate, SAR and ESP were measured using laboratory tests as described by [12]. Some chemical and physical properties of the soil under investigation are shown in Tables 1 and 2. In this paper, a new regression model that obtained from linear regression with R^2 = 0.7347 defined as Eq. (3) was used.

$$\mathrm{ESP} = 0.84 \times \mathrm{SAR} + 2.17 \quad (3)$$

Table 1. The mean, median, minimum, maximum and standard deviation (Sd.) of some chemical and physical properties used to verify the ESP-$_{SAR}$ model on saline soil samples

Parameter	ECe (dS/m)	pH	Sand %	Silt %	Clay %
Mean	11.33	7.51	48.27	21.4	29.67
Median	17.5	7.6	49	14	35
Min.	4.6	6.8	43	8	22
Max.	35.3	8.1	58	35	50
Sd.	7.99	0.46	6.52	6.98	8.02

ECe: Electrical conductivity of soil saturated extract

Table 2. The mean, median, minimum, maximum and standard deviation (Sd.) of some chemical and physical properties used to verify the ESP-$_{SAR}$ model on non- saline soil samples

Statistics	ECe (dS/m	pH	Sand %	Silt %	Clay %
Mean	1.23	8.1	54.8	23.2	29.67
Median	1.5	8.1	55	21	34
Min.	0.17	7.7	50	14	20
Max.	3.65	8.6	65	35	46
Sd.	1.04	0.3	4.51	5.29	8.01

ECe: Electrical conductivity of soil saturated extract

The results of model were directly compared with the laboratory experimental ones using some statistical measurements.

2.2 Statistical Analysis

A paired samples t-test analyses; the mean difference confidence interval, the standard deviation of difference, standard Error of Mean (SEM) and p-value were used to compare the soil ESP values predicted using ESP-$_{SAR}$ model with the soil ESP values measured by laboratory tests.

3. RESULTS AND DISCUSSION

3.1 Results

The soil SAR values used for predicting the soil ESP by ESP-$_{SAR}$ model and the measured ESP by laboratory tests on saline and non-saline soil samples are shown in Tables 3 and 4 respectively. Average difference, standard deviation of difference, standard error of mean (SEM), 95% confidence intervals for the difference in means and the p-value of the ESP $_{SAR}$ model on saline soil samples and non-saline soil samples are calculated to evaluate the efficiency of the ESP-$_{SAR}$ model compared to the measured laboratory test values as a reference. The results of these statistical analyses using paired samples t-test are shown in Tables 5 and 6 respectively.

3.2 Discussion

3.2.1 On saline soil samples

A paired samples t-test analyses and the mean difference confidence interval approach were used to compare the soil ESP values predicted using the ESP-$_{SAR}$ model with the soil ESP values measured by laboratory tests on saline soil samples are shown in Table 5. The mean of soil ESP difference between the ESP-$_{SAR}$ model and measured ESP was 1.947. The 95% confidence interval was -0.06834 to 3.963. A p-value for ESP-$_{SAR}$ model was 0.0572 and the standard deviation of the soil ESP differences was 3.640. The Standard Error of Mean (SEM) of predicted ESP acquired by ESP-$_{SAR}$ model related to the measured ESP was 0.9398. The paired samples t-test results indicated that the soil ESP values predicted by using ESP-$_{SAR}$ model were not significantly different with the soil ESP measured by laboratory tests (Table 5). Generally, using of soil SAR to predict ESP showed a high degree of agreement with the findings of [10,12,13]. It clear from Fig. 1 that the ESP-$_{SAR}$ model demonstrated a high degree of agreement with the experimentally measured values.

3.2.2 On non-saline soil samples

The mean of soil SAR difference between the ESP-$_{SAR}$ model and measured ESP was 0.3407. The 95% confidence interval was -0.2856 to 0.9670 and the p-value was 0.2628. The standard deviation of the soil SAR differences between ESP-$_{SAR}$ model values and laboratory tests ESP values was 1.131. The Standard Error of Mean (SEM) of predicted ESP was 0.2920. For non-saline soil samples, it clear from Fig. 2 that the ESP-$_{SAR}$ model showed a high degree of agreement with the experimentally measured values. The results of paired samples t-test showed that the soil ESP values predicted by ESP-$_{SAR}$ model were not significantly different with the soil ESP measured by laboratory tests (Table 6). Generally, using of soil SAR to predict ESP showed a high degree of agreement with the results of [6,13].

Table 3. Chemical properties of soil used for predicting soil ESP by ESP-$_{SAR}$ model on saline soil

Sample no.	SAR	Laboratory tested ESP	ESP -$_{SAR}$ model
1	18	20	17.82
2	36	25	32.92
3	80	62	69.9
4	72	63	63.18
5	32	31	29.85
6	63	50	55.62
7	67	54	59.8
8	24	18	22.86
9	45	45	40.5
10	33	32	30.42
11	16	13	16.14
12	27	23	25.38
13	22	19	21.18
14	21	17	20.34
15	15	14	15.3

Table 4. Chemical properties of soil used for predicting soil ESP by ESP-$_{SAR}$ model on non-saline soil samples

Sample no.	SAR	Laboratory tested ESP	ESP -$_{SAR}$ model
1	1	3	3.54
2	0.3	2	2.95
3	1	4	3.54
4	5	7	6.9
5	3	2	5.22
6	2	3	4.38
7	4	5	6.06
8	2	4	4.38
9	6	7	7.74
10	8	11	9.42
11	15	16	16.14
12	6	8	7.74
13	22	19	21.18
14	21	17	20.34
15	15	14	15.3

Table 5. Paired samples t-test analyses on comparing soil ESP determination methods on saline soil samples

Determination method	Average difference (%)	Standard deviation of difference (%)	Standard error of mean (SEM)	p-value	95% confidence intervals for the difference in means
ESP-$_{SAR}$ model & laboratory test	1.947	3.640	0.9398	0.0572	-0.06834 to 3.963

Table 6. Paired samples t-test analyses on comparing soil ESP determination methods on non-saline soil samples

Determination method	Average difference (%)	Standard deviation of difference (%)	Standard error of mean (SEM)	p-value	95% confidence intervals for the difference in means
ESP_{-SAR} model & laboratory test	0.3407	1.131	0.2920	0.2628	-0.2856 to 0.9670

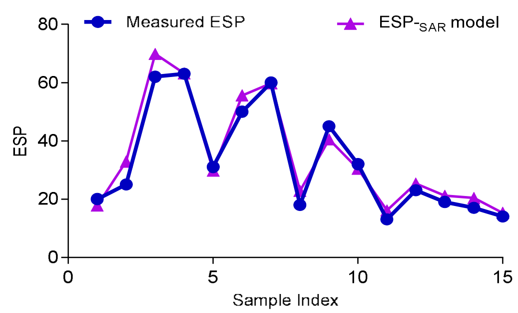

Fig. 1. Measured ESP and predicted ESP using the ESP_{-SAR} model on saline soil samples

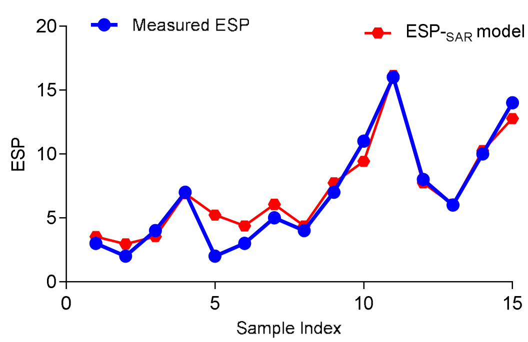

Fig. 2. Measured ESP and predicted ESP using the ESP_{-SAR} model on non- saline soil samples

4. CONCLUSION

In this paper, linear regression model (ESP_{-SAR} model) was used to predict soil ESP from soil SAR in saline and non-saline soil samples. The statistical results on saline soil samples indicated that there was no difference between the ESP values predicted by the ESP_{-SAR} model and the measured values by laboratory tests (P=0.0572, SEM was 0.9398). The paired samples t-test results on non-saline soil samples showed that there was no difference between the ESP values predicted by the ESP_{-SAR} model and the measured values by laboratory tests (P=0.2628, SEM was 0.2920). Generally, the ESP_{-SAR} model showed better values on non- saline soil samples. It can be concluded that the ESP_{-SAR} model ESP= 0.84 × SAR + 2.17 with R^2 = 0.7347 can be recommended for prediction of soil ESP using soil SAR in both saline and non-saline soil samples.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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