

Pedotransfer Functions for Estimating ESP & SAR for Arid Soils in the Eastern Region of Libya

Ahmed Y. Habel¹

ABSTRACT

Most of the applied methods to determine the Exchangeable Sodium Percentage (ESP) and Sodium Adsorption Ratio (SAR) are time consuming and sometimes expensive, especially in calcareous soils, due to the dissolving of CaCO_3 and MgCO_3 during the chemical analysis and then erroneously driving to an increase of Cation Exchange Capacity (CEC) value. To work around these problems, many researchers have developed Pedotransfer Functions (PTF_s) as an attempt to estimate these parameters from easy-to-obtain some soil characteristics such as Electrical Conductivity (EC). In this work, linear regression models using the EC as a predictor for estimating the ESP and SAR were developed with high recommended determination coefficients. In order to validate these models, they were applied to estimate ESP and SAR from EC for 26 soil samples collected from Al-Jabal Al-Akhdar in the eastern region of Libya. The paired samples t-test analysis of these compared samples showed no significant difference between the laboratory measurements and those estimated by the regression models.

Key words: Exchangeable Sodium Percentage, Sodium Adsorption Ratio, Electrical Conductivity, PTF_s , Libya

INTRODUCTION

Libya can be said to be an arid country, because the average annual rainfall is less than 100 mm, covering about 93% of the country (Ismail, 2007). Generally under these conditions, evaporation and evapotranspiration are not compensated by the precipitation and the irrigation water, so the chance to flush out the accumulated salts from the root zone is little (Bresler *et al.*, 1982). As a result, the saline soils are developed throughout the country. In addition, the application of irrigation water with poor quality may result in an increase of soil salinity hazards (Szabolcs, 1998).

The excessive accumulation of salts in the root zone have some negative effects on plant growth; such as reduction of water availability through the action of osmotic pressure, hinder the growth by toxic effects, and it may also result in unbalanced nutrients uptake by plants (Donahue *et al.*, 1990; Brady and Weil, 2002). On the other hand, the adsorbed sodium under alkaline conditions often affects the plant growth by the specific toxicity and nutrient deficiencies. Also, it usually manifests its destructive effect on soil structure,

producing poor physical conditions such as: increased surface crusting and then a low infiltration rate leading to excessive surface runoff and erosion (Gopalibardhan *et al.*, 2007).

In general, the recognized criterion to identify salt affected soils is based on the measurement of salts content by the Electrical Conductivity (EC), of the saturated soil extract with border > 4 (dS.m^{-1}) (SSSA 1997). The sodium hazard of soil is usually expressed as Sodium Adsorption Ratio (SAR) with reported threshold of 13 ($\text{Cmol}^{\text{+1}}.\text{Kg}^{-1}$), and the Exchangeable Sodium Percentage (ESP) with reported threshold of 15% (Richards, 1954). These are defined in the following equations (1) and (2):

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

Where:

Na^+ , Ca^{2+} and Mg^{2+} : measured soluble sodium, calcium and magnesium, respectively (mmol.L^{-1}).

$$\text{ESP} = (\text{Na}^+ / \text{CEC}) * 100 \quad (2)$$

Where:

Na^+ : measured exchangeable sodium ($\text{Cmol}^{\text{+1}}.\text{Kg}^{-1}$);
CEC: cation exchange capacity ($\text{Cmol}^{\text{+1}}.\text{Kg}^{-1}$).

As shown in equations (1) and (2), for determining the soil SAR and ESP, it is necessary to determine the exchangeable cations such as Na^+ , Ca^{2+} , Mg^{2+} and K^+ . This therefore leads to a lot of time, coupled with the chance of mistakes during the laboratory work. The other problem is that, extraction of exchangeable Ca^{2+} and Mg^{2+} during chemical analysis might dissolve some of CaCO_3 and MgCO_3 , existing in soil and erroneously driving to an increase of CEC values, especially in Calcareous Soils (Oustan *et al.*, 2007).

Based on the above facts, it will be more convenient and economical to develop such a method which determines soil SAR and ESP, using Pedotransfer Functions (PTF_s) from more readily measured property, such as soil salinity index (EC).

“The Pedotransfer Function (PTF) is used as translating data we have into what we need” (Bouma 1989). Recently, many successful attempts have been done to estimate the difficulty in determining soil property utilizing easy or available measured soil properties by empirical models (Drake and Motto, 1982;

¹Soil & Water Department, Faculty of Agriculture – Omar Al Mukhtar University, El- Bieda - Libya
Received January 23, 2013, Accepted March 28, 2013

Bell and Keulen, 1995). All these models were developed to predict soil cation exchange capacity (CEC), based on the organic carbon, clay fraction and soil pH. Other researchers stated a relationship between the soil Sodium Adsorption Ratio (SAR) and the soil Electrical Conductivity (EC) (Richards 1954; Levy and Hillel, 1968; Emerson and Bakker, 1973; Al-Busaidi and Cookson, 2003).

Most of the above predictive models are specific to a certain region, and may substantially vary from clay minerals types present in the soil and ionic strength (Evangelou and Marsi, 2003). Relatively, there have been considerable amount of work done by many researchers to show the relationships between the soil chemical properties.

The main goal of this research was to determine the optimum soil models for the sake of predicting the ESP and SAR, based on the EC for some Libyan soils.

MATERIALS AND METHODS

Twenty six soil samples were taken randomly from different profiles at Al- Jabal Al-Akhdar region in the eastern part of Libya (Al Izziyat) area, situated at latitude of $32^{\circ}07' N$ and longitude of $22^{\circ}40' E$ (Map 1).

The monthly temperatures mean vary between $11^{\circ}C$ in January and $28^{\circ}C$ in July, with mean annual temperatures of $20^{\circ}C$. While the mean monthly rainfall is very low during the year, and is practically absent during summer season (June-August), with annual rainfall mean about 55 mm.

The land is entirely located on alluvial sediments made up mostly of silt-loamy soils or finer materials, especially in the subsoil and subordinately of sand – loam soils. The substratum is generally made of small and coarse pebbly alluvial, resting on bedrock which being made up of limestone. From a strictly geomorphologic point of view, the study area belongs to a single landscape characterized by an ample depression, closed laterally by limestone hills, which are cut by small wadis that debouch at the borders of the flat surface, contributing to the slow accumulation of the sediments. The absence of natural outlet of the precipitation and surface running waters create, although temporarily and in the more depressed central part, the stagnation of these waters, and consequently enriching the soil in salt both on and below the surface (Ismail, 2007).



Figure 1. location of the studied soil profiles

RESULTS AND DISCUSSIONS

Statistical analysis of physical and chemical properties of 26 soil samples used to determine ESP and SAR Pedotransfer Functions are presented in Tables (1) and (2).

These results indicate that the prevalence of soil samples having basic soil reaction, oscillates between 8.0 to 9.4 with mean about 8.65, as well as high content of calcium carbonate with mean 42.71%, so they may be subtend as silty loam textured- calcareous soils.

A significant depression in the organic matter content is well observed, as it ranges between 0.40 and 2.02% with mean of 0.90%. This may be directly related to the dry and arid climatic conditions, which prevail in this region (low annual precipitation associated with high temperature). According to the mean value of EC, ESP and SAR of soil samples, these soils may be classified as saline-sodic soils. The coefficient of variation (CV) of the EC, ESP, SAR and Na showed more variability than those of other soil properties. This high variation of these properties imparts generality to the findings and allows them to be applied with greater reliability to other soils.

The correlation coefficients between all measured soil variables are given in Table (2). The reverse correlation between calcium carbonate content with silt and clay contents and CEC, is noticeable, while it was significantly proportional with sand content. This indicates that calcium carbonate content in these soils has a coarse texture as a result of the slow weathering processes.

The correlation coefficient between pH and EC of investigated soil samples was obviously negative (-0.649). This could be interpreted by the increase degree of dissociation of surface functional groups, replacement of adsorbed H-ions by cations of the saline soil solution (Oustan et al., 2007).

As it was expected, there is a significant negative correlation between the CEC and sand content (-0.817), whereas, it shows positive correlations (0.761, 0.583) for silt and clay contents respectively. This positive correlation may be contributed to the large surface area of these components. (Manrique et al., 1991; Bell and keulen, 1995)

The results indicated that ESP and SAR values increased with increasing of soil salinity, supported with high levels of correlations coefficients of 0.877 and 0.93, respectively. The measured ESP and SAR were plotted against EC, as shown in Figures (2) & (3). This will facilitate the accuracy of height to develop models for prediction ESP and SAR from EC measurements.

The coefficients of determination (R^2) of these regression equations are judged acceptable, so they may suggest models of greater predictive ability to estimate the Exchangeable Sodium Percent (ESP), and Sodium Adsorption Ratio (SAR) from the Soil Salinity (EC), as in Equations 4 and 5.

$$ESP = 3.358 + 0.3909 EC \quad \text{Equation 4.}$$

$$SAR = 2.303 + 0.4023 EC \quad \text{Equation 5.}$$

To verify the usability of these regression equations, they were applied to predict the ESP and SAR for twenty six soil samples, selected with paid attention to the similarity of the environmental conditions to the

Table 1. Descriptive statistics of some soil properties

Variable	Minimum	Maximum	Mean	SD	CV %
Sand %	2.00	85.00	27.77	19.28	69.43
Silt %	12.90	77.10	55.89	15.26	27.30
Clay %	2.10	39.90	16.04	47.40	47.40
pH	8.00	9.40	8.65	0.30	3.46
CaCO ₃ %	23.80	69.80	42.71	11.75	27.51
OM %	0.40	2.02	0.90	0.37	42.01
EC (dS.m ⁻¹)	0.37	54.88	6.26	11.92	190.30
CEC (Cmol ⁺ .kg ⁻¹)	6.34	20.16	13.50	3.15	23.31
ESP %	1.00	24.00	5.81	5.31	91.50
SAR	1.00	26.00	4.82	5.16	106.89
Na ⁺ (Cmol ⁺ .kg ⁻¹)	0.11	3.56	0.75	1.05	110.94
K ⁺ (Cmol ⁺ .kg ⁻¹)	0.37	4.74	2.28	1.07	47.05
[Ca ⁺² +Mg ⁺²] (Cmol ⁺ .kg ⁻¹)	4.94	15.06	10.30	2.55	24.82

Table 2. Correlation coefficients of the measured soil properties

Property	Sand	Silt	Clay	pH	CaCO ₃	OM	EC	CEC	ESP
Silt %	-0.924**								
Sig.(2-tailed)	.000								
Clay %	-0.672**	0.367**							
Sig.(2-tailed)	.000	.003							
pH	0.092	-0.171	0.178						
Sig.(2-tailed)	.475	.183							
CaCO ₃ %	0.878**	-0.777**	-0.691**	0.007					
Sig.(2-tailed)	.000	.000	.000	.955					
OM %	-0.189	0.323*	-0.177	-0.365**	-0.217				
Sig.(2-tailed)	.0142	.011	.169	.004	.089				
EC (dS.m ⁻¹)	-0.085	0.140	-0.156	-0.649**	-0.081	-0.081			
Sig.(2-tailed)	.0510	.0279	.227	.000	.530	.534			
CEC	-0.817**	0.761**	0.583**	0.028	-0.760**	0.149	0.145		
Sig.(2-tailed)	.000	.000	.000	.829	.0000	.249	.261		
ESP %	-0.093	0.093	-0.027	-0.577**	0.051	-0.145	0.877**	0.116	
Sig.(2-tailed)	.473	.0473	.835	.0000	.695	.261	.000	.369	
SAR	-0.090	0.129	-0.091	-0.554**	0.065	-0.099	0.930**	0.165	0.942**
Sig.(2-tailed)	.486	.319	.484	.0000	.616	.446	.000	.199	.000

** Correlation is significant at the 0.01 probability level (N = 26).

*Correlation is significant at the 0.05 probability level (N=26).

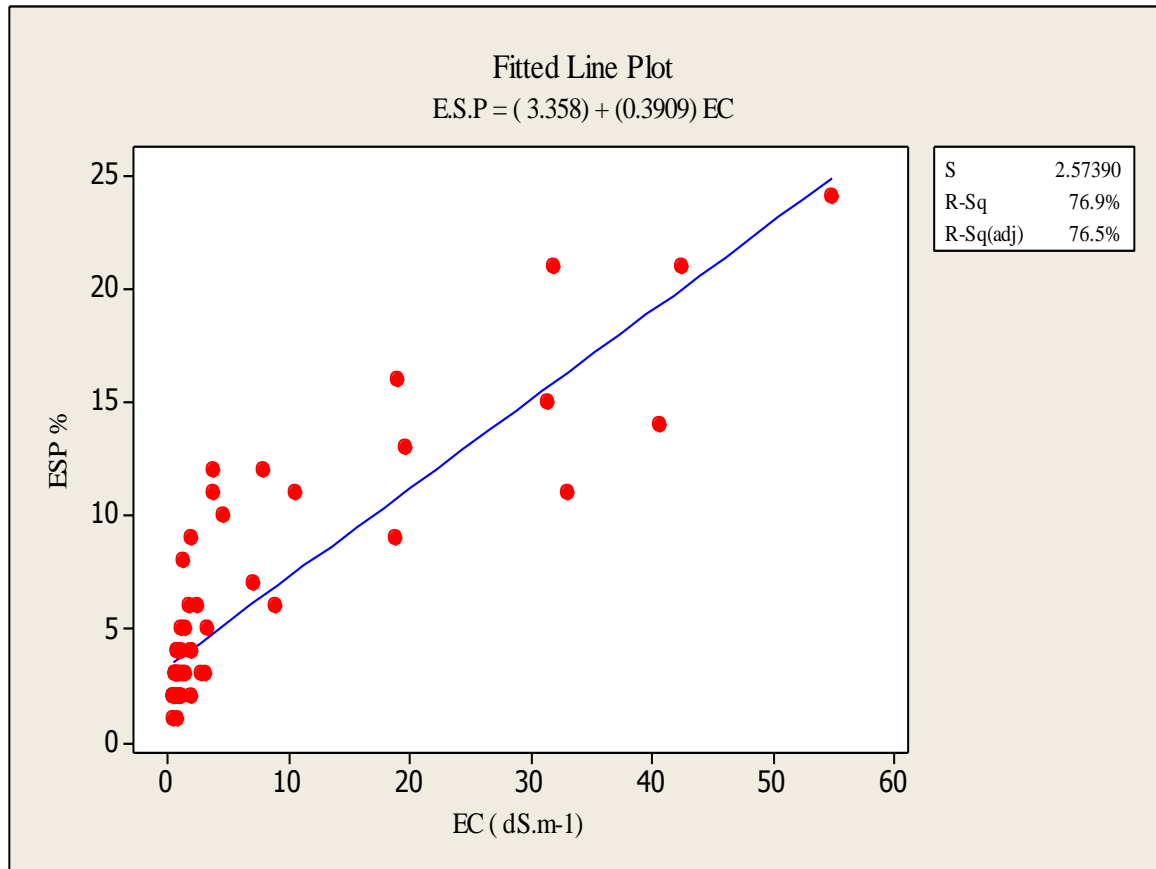


Figure 2. The regression equation of EC and ESP of tested soil samples

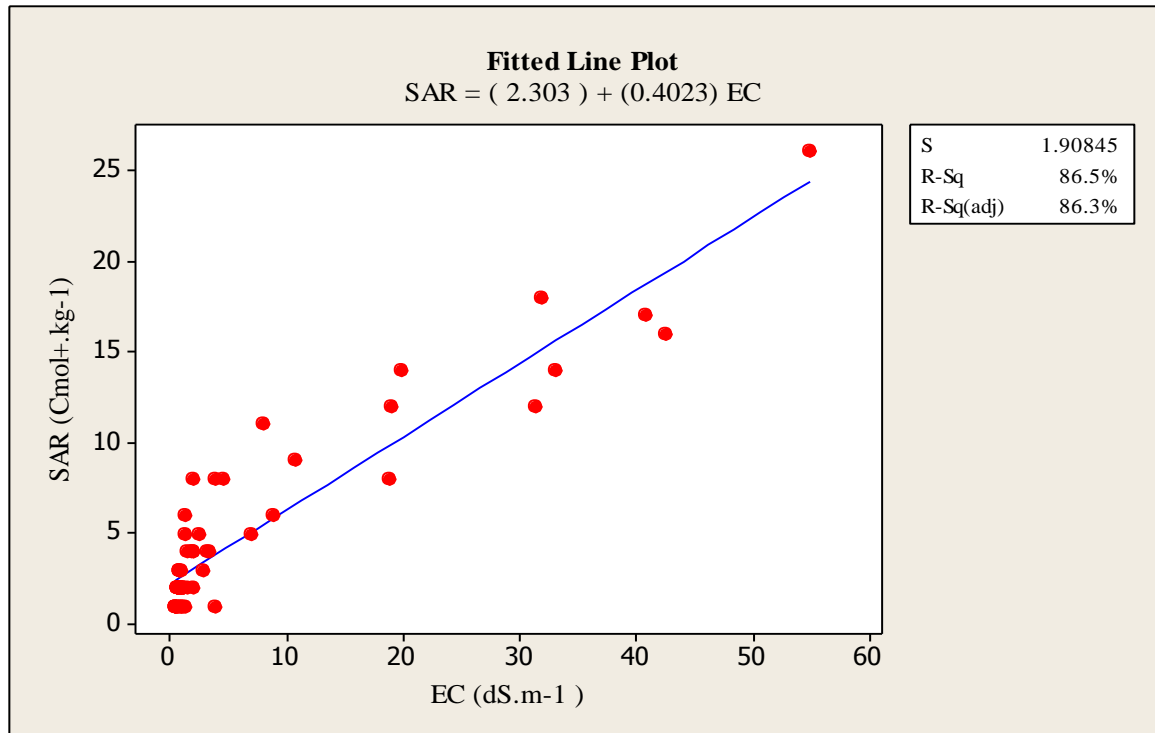


Figure 3. The regression equation of EC and SAR of tested soil samples

investigation area, from “The study and evaluation of the vegetation cover of Jabal Al Akhdar “ (Omar Al-Mukhtar University, 2005). The statistical analyses of soil physical and chemical properties of these soil samples are presented in Table (3).

A paired samples t-test and mean difference confidence interval approach were used to compare between predicted and measured ESP and SAR values. The results of comparison analyses are presented in Table (4).

The outcomes of the paired samples t-test analyses indicated that there were no significant differences between predicted and measured ESP and SAR values (Rashidi and Seilsepour, 2008).

As, there were no significant differences between predicted and measured ESP and SAR values, thus, the predicted values were plotted against the measured EC. The, ESP and SAR are quite proportional with the EC (Fig. 4).

CONCLUSIONS

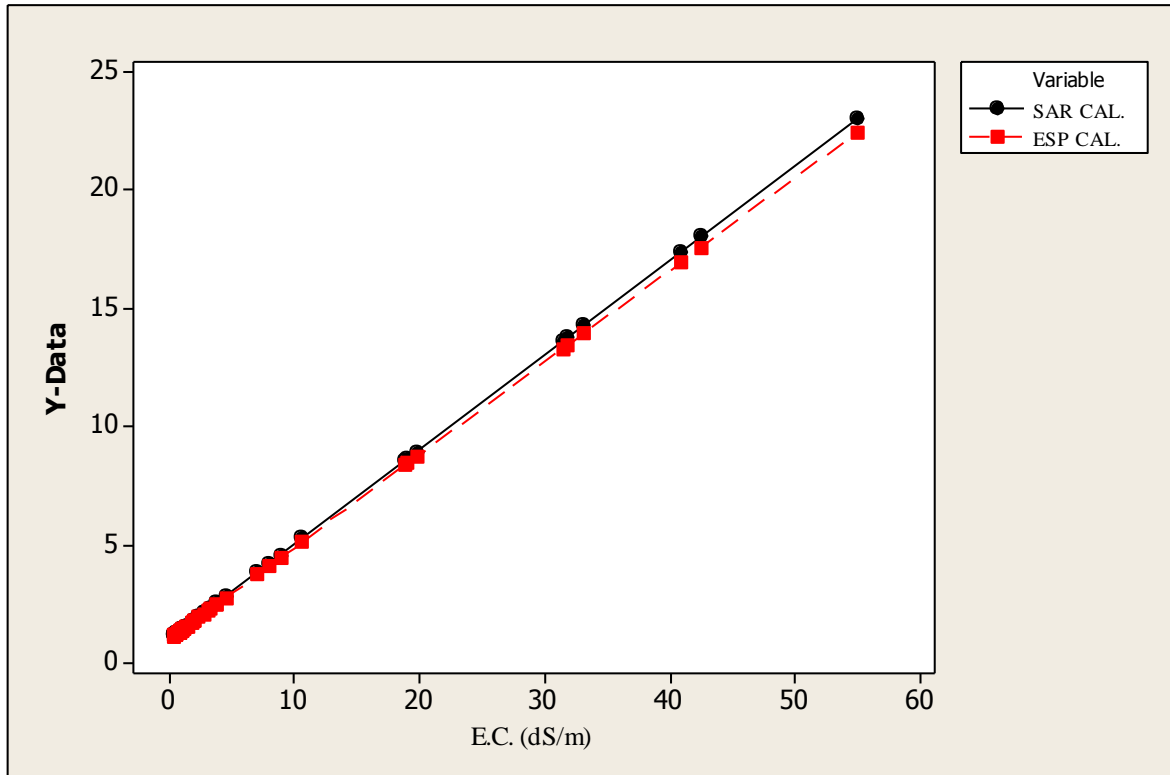
Because of the opportunity of mistakes during the laboratory tests, time consuming and the costs of the investigations, it can be concluded that, regression equations showed a valuable and economical tool to predict the ESP and SAR values with high accuracy levels under the similar environmental conditions.

Table 3. Statistical analysis of the soil samples used for the verification

Parameter	Minimum	Maximum	Mean	Standard Deviation	Coefficient of Variation (CV %)
Sand (%)	13.37	60.75	25.33	10.2	40.28
Silt (%)	26.92	48.04	37.75	6.02	15.94
Clay (%)	9.35	53.92	36.92	10.83	29.36
pH	7.26	8.59	7.84	0.32	4.06
EC (dS.m ⁻¹)	1.40	9.30	2.83	1.65	58.51
CEC (C mol ⁺ .Kg ⁻¹)	10	28.83	18.98	5.91	31.3
ESP (%)	1.51	7.13	3.78	1.6	42.3
SAR	1.51	7.13	3.78	1.6	42.3

Table 4. Paired samples t-test analyses on comparing soil ESP & SAR determinations methods

Property	Mean	St .Dev.	SE Mean	p-value	t-value	95% CI for the mean difference
ESP (%)	0.308	1.60	0.313	0.335	0.98	(- 0.338 , 0.954)
SAR	-0.125	0.852	0.167	0.463	-0.75	(- 0.469 , 0.219)

**Figure 4: The relationship between EC, ESP and SAR****REFERENCES**

- Al-Busaidi A.S., and P. Cookson (2003). Salinity - pH relationships in calcareous soils. *Agriculture and Marine Sciences*. 8: 41-46.
- Bell M.A. and J.V. Keulen (1995). Soil pedotransfer functions for four Mexican soils. *Soil Sci. Soc. Am. J.*, 59:865-871.
- Bouma J. (1989). Using soil survey data for quantitative land evaluation. *Advances in soil science*.9:177-213.
- Brady, N. C., and R. R. Weil (2002). *The Nature and Properties of Soils* (13th Edition). Upper Saddle River, NJ: Prentice-Hall, Inc. pp: 415-431
- Bresler E, Mcneal BI, and D.L. Carter (1982) 'Saline and sodic soils: principles, dynamics, modelling'. (Springer-Verlag: New York).
- Donahue .R.I., M.W.Raymond and J.C. Chickluna (ed.), (1990). *Soils : An introduction to soils and plant growth*. Prentice Hall of India .pp :667.
- Drake E.H. and H.L. Motto (1982). An analysis of the effect of clay and organic matter content on the cation exchange capacity of New Jersey soils. *Soil Sci.*, 133: 281-288.
- Emerson W.W. and A.C. Bakker (1973). The comparative effects of exchangeable calcium, magnesium and sodium on some physical properties of red-brown earth sub-soils. II. The spontaneous dispersion of aggregates in water. *Australian Journal of Soil Research*. 11 : 151-157.
- Evangelou V.P. and M. Marsi (2003) . Influence of ionic strength on sodium-calcium exchange of two temperate climate soils. *Plant and Soil* .250: 307-313.
- Gopalibardhan , S.K. Chaudhari and P.K. Mohapatro (2007). Effect of irrigation water quality on saturated hydraulic conductivity of Typic Haplustert, Vertic Haplusterept, and Lithic Ustorthen soils. *Jour.Agric. Physics*,vol.7, pp.38-46.
- Ismail, A., (2007). The phenomena of drought in the Libyan region of Jabal Al Akhdar (Climatic Study). Ph.D. Thesis. Faculty of Arts. Jordan University
- Levy R. and D.Hillel (1968). Thermodynamics equilibrium, constants of sodium-calcium exchange in some Israel soils. *Soil Science*. 106:393-398.
- Manrique L.A., C.A.Jones and P.T.Dyke (1991). Predicting cation-exchange capacity from soil physical and chemical properties. *Soil Sci. Soc.Am.*, 55: 787-794.

- Omar Al-Mukhator University (2005). The study and evaluation of the vegetation cover of Jabal Al Akhdar . Final Report.
- Oustan S., A.Jafarzadeh and N.Aliasgharzarad (2007). Electrical conductivity as a salient factor in saline-sodic soils of Tabriz plain. Bioclimatology and Naatural Hazards .International Scientific Conference, Polana nad Detvos,Slovakia, September 17-20 .
- Rashidi M. and M.Seilsepour 2008). Sodium adsorption ratio pedotransfer function for calcareous soils of varamin region. Int. J. Agri. Biol. 10: 715-8.
- Richards L.A.(1954) .Diagnosis and improvement of saline and alkali soils. USDA Washington DC.
- SSSA (1997). Glossary of Soil Science Terms; Soil Science Society of America: Madison, WI ; 134 pp.
- Szabolcs, I. (1998). Salt buildup as a factor of soil degradation. In Methods for Assessment of Soil Degradation; Lal, R., Blum, W.H., Valentine, C., Stewart, B.A., Eds.; CRC Press: Boca Raton, FL, 253–264.
- U.S.D.A. (2011). Soil Survey Laboratory Information Manual. Rep.45 , Version 2.0.

الملخص العربي

استخدام وظائف نقل البيانات الارضية للتنبؤ بكل من النسبة المتوية للصوديوم المتبادل ونسبة

الصوديوم المدمص في بعض الأراضي الجافة في شرق ليبيا

أحمد يوسف هبيل

المعلومات من بعض خصائص التربة سهلة التقدير مثل التوصيل الكهربائي (EC).

في هذا البحث، وضعت نماذج الانحدار الخطي باستخدام EC باعتباره مؤشرا لتقدير ESP و SAR. و من أجل التحقق من صحة هذه النماذج، تم تطبيقها على التنبؤ بـ ESP و SAR من EC لعينات التربة التي تم جمعها من منطقة العزيات بالجبل الأخضر - شرق ليبيا. وأظهرت اختبارات الفروق الإحصائية أنه لا يوجد فرق كبير بين القياسات المختبرية وتلك المقدرة من قبل نماذج الانحدار.

معظم الأساليب المتبعة لتحديد النسبة المتوية للصوديوم المتبادل (ESP) ونسبة الصوديوم المدمص (SAR) هي مضیعة للوقت ومكلفة في بعض الأحيان، وخاصة في التربة الجيرية، وذلك بسبب ذوبان بعض كربونات الكالسيوم والمغنيسيوم خلال التحليل الكيميائي والذي قد يؤدي إلى زيادة قيمة الكاتيونات المتبادلة. في محاولة للتغلب على هذه المشاكل، استخدم العديد من الباحثين وظائف نقل البيانات الأرضية Pedotransfer (PTFs) لمحاولة التنبؤ بهذه