

Comparison and Evaluation of Two Analytical Methods for Cation Exchange Capacity and Exchangeable Sodium Percentage of Five Soil Types in Central Sudan

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Received 22 November 2015; accepted 18 December 2015; published 21 December 2015

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Abstract

Twenty-six soil samples were collected from five soil profiles at different climatological and ecological regions in central Sudan. Soil profile was dug in each studied area and morphological profile description was carried out for different horizons. All samples were analyzed using two different methods to determine Cation Exchange Capacity (CEC) and exchangeable sodium percentage (ESP). Statistical analysis (T-test) was used in order to investigate the differences between soil samples for the studied locations. Significant differences appeared when compared the two methods for CEC determination at Gedaref area, Wad Medani and Nile flood plain and that appeared in evaluation of ESP at Nile flood plain and Shambat area. The results also revealed that, the developed method used in this study was more practical, simple and reliable for determination of CEC and ESP as the currently used in most soil laboratories. In addition, it will be safer than the other methods in some problematic soils. The adoption of this developed method is advisable because it is less time consuming as it omits the washing step. In contrast, the old method cannot be a good substitute in laboratories which have no possibility to determine sodium by using flame photometer. We conclude that when the developed method is used to determine CEC and ESP time will be saved, that fewer amounts of chemicals will be used and that accurate results will be achieved.

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How to cite this paper: Elfaki, J., Gafer, M., Sulieman, M. and Ali, M. (2015) Comparison and Evaluation of Two Analytical Methods for Cation Exchange Capacity and Exchangeable Sodium Percentage of Five Soil Types in Central Sudan. *Open Journal of Soil Science*, 5, 311-318. <http://dx.doi.org/10.4236/ojss.2015.512029>

Keywords

Ecological Regions, Central Sudan, Cation Exchange Capacity, Exchangeable Sodium Percentage

1. Introduction

The major soils in Sudan can be divided geographically into three categories: the sandy soils of the northern and west central regions, the clay soils of the central and eastern regions, and the laterite soils of the southern regions.

Most agricultural and environmental planning requires soil analysis, or at least should require analysis for better implementation for any change. Furthermore, better practical analysis methods can rapidly estimate soil properties needed to improve quantitative assessments of land management problems [1].

The basic problem of this research is that the soil laboratories in the Sudan, do not enter the new modern means of analyzing soil, and most of the methods used are very old. Studies have shown the lack of modern efficiency to meet required needs. There are new methods of analysis, with less expenses and time-consuming, and they have not been used in the Sudan.

CEC is important for maintaining adequate quantities of plant available calcium (Ca^{2+}), magnesium (Mg^{2+}) and potassium (K^+) in soils. Under acid conditions ($\text{pH} < 5.5$), aluminum (Al^{3+}) may also be present as an exchangeable cation. While a soil with a higher CEC may not necessarily be more fertile, when combined with other measures of soil fertility, CEC is a good indicator of soil quality and productivity.

The Cation Exchange Capacity is an important property of clay minerals. CEC results are frequently used for characterization and quantification of sorbents in clays and soils. Determination of the CEC and exchangeable cations of soils and clays have been performed since the early work [2].

Numerous publications about various methods reflect the limitation of analytical validity of result obtained by CEC procedures for the wide variety of natural materials. However, common CEC methods like ammonium acetate [3] or barium chloride [4], are time consuming, and results for natural materials are often poor. Recent methodological approaches use the higher selectivity of metal-organic complexes, e.g. silver-thiourea method as a one-step procedure compared to common methods to reduce the time factor [5].

Methods have been proposed for calcareous and gypsiferous soils, [4] [6]-[12]. They are not generally applicable to soils containing both CaCO_3 and gypsum or they are too cumbersome and demanding for routine determinations.

In general, analytical problems in CEC methods developed through specific interactions between components of soils and clays with the exchange solutions used. The main sources of errors are soluble (Ca^{2+}) phases and in the faster modern methods, hydrophobic interaction can cause unrealistic CEC values. The objective of this research was to compare and evaluate the results of the [6] and [13] methods for determination of Cation Exchange Capacity (CEC) and Exchangeable Sodium Percentage (ESP) of five soil types in central Sudan.

2. Materials and Methods

2.1. Soil Sampling and Characterization

Twenty-six soil samples were collected from different five soil profiles were dug in central Sudan based on different geographical, climatological and ecological regions, which included; Gedaref area ($14^{\circ}10'64''\text{N } 35^{\circ}38'26''\text{E}$), Soba area ($15^{\circ}52'66''\text{N } 32^{\circ}60'79''\text{E}$), Wad Madani area ($14^{\circ}39'19''\text{N } 33^{\circ}49'30''\text{E}$), College farm ($15^{\circ}64'74''\text{N } 32^{\circ}51'76''\text{E}$), and recent Nile terrace at Khartoum North area ($15^{\circ}65'16''\text{N } 32^{\circ}51'25''\text{E}$).

Each soil profile was studied in the field, and described following the format of the FAO [14], guidelines of soil profile description and sampled according to genetic horizons and classified on the bases of its diagnostic characteristic used at different categories levels of the American system for soil classification [15].

Each sample was kept in a cloth bag, labeled with; collected data, area, soil profile number, sample depth, then, subjected to physical and chemical analyses at the soil laboratories in Khartoum University. Soil pH was determined on the saturated paste and the electrical conductivity of the saturation extraction was used as a measure of soil salinity. The organic matter (OM) was determined used Walkley-Black method [16]. Texture

classes were determined using [17] method. P was analyzed using colorimetric method by spectrophotometer [18].

Flame photometer was used in sodium measurement, after adjusting the flame photometer by the standard solution (100 ppm Na) at 100 reading and distilled water at Zero reading. Extractable Na was obtained by using a known volume of 1 N ammonium acetate and the exchangeable contents of these elements were obtained by difference between the extractable and soluble quantities. While exchangeable sodium percentage (ESP) was calculated, using results of two CEC methods.

$$\text{ESP} = \frac{\text{Exch. Na}}{\text{CEC}} \times 100$$

where: Exch. Na = Exchangeable sodium in meq/100g.

CEC = Cation Exchange Capacity meq/100g.

2.2. Determination of Cation Exchange Capacity (CEC)

According to [6] method, 4 g of each soil sample was placed in centrifuge tube, 33 ml of IM sodium acetate was added, and pH adjusted to 8.2. The soil suspension was shaken for 5 minutes and then centrifuged until the supernatant liquid was clear. The supernatant was then discarded completely. The sample was extracted in this manner a total of four times. Excess salt of sodium acetate washed four times by adding 33 ml 95% ethanol to the tube. The adsorbed sodium replaced by three extractions with 33 ml 1 M ammonium acetate, shaken, centrifuged and supernatant liquid collected in 100 ml volumetric flask. Finally, Sodium concentration was measured used flame photometer.

According to [13] method, 4 g of each soil sample from different profiles was saturated with sodium by four successive equilibrations with 33ml aliquots of a 60% ethanol solution. During each equilibration the soil suspension was shaken for 5 minutes, and then centrifuged for 5 minutes (2000 rpm/min) until the supernatant was clear after which the supernatant liquid was discarded. The Na-saturated samples plus the occluded saturating solution were extracted three times with 33 ml aliquots of 0.5 M pH 7 solution of Mg (NO₃)₂. The exchangeable Na was calculated as the total Na minus the occluded soluble Na that was 5 times the occluded Cl.

2.3. Statistical Analysis

Statistical differences between samples were determined using statistical analysis [19], using T-test with multiple samples where differences were calculated from various measurements. The means of these differences were obtained (\bar{D}), the deviation from each measurement was used to get the standard deviation (s_d). Then, the T value was calculated from the equation below:

$$T = \frac{\bar{D}}{s_d} \sqrt{N}$$

where: T ≡ Calculated T value.

\bar{D} ≡ Means of differences.

s_d ≡ Standard deviation.

N ≡ Number of samples.

3. Results and Discussion

3.1. Morphological Properties

The description of the study sites and selected morphological properties of representative soil profiles are presented in (Table 1 and Table 2), respectively. The parent material of Profiles I and II was alluvium/colluvium and old alluvium of the Bule Nile, respectively. While the parent material of profiles III, V, and VI were alluvium. Soil texture of all profiles belong to five textural classes; loam, sandy clay loam, clay loam silty clay and clay. All profiles showed angular/sub-angular blocky structure in the surface horizon and the lower horizons were massive. The quantity of roots in the soil profiles decreased with depth and the boundary between horizons was generally diffused and smooth.

Table 1. Selected site properties of the studied profiles.

Profile No	Location	Coordinates		Parent material	Slope (%)	Land use
		Latitude	Longitude			
P1	Gedaref	14°10'64"	35°38'26"	Alluvium/Colluvium	Flat	Agric.
P2	Soba	15°52'66"	32°60'79"	Old alluvium of the Blue Nile	Flat	Forest
P3	Wad Madani	14°39'19"	33°49'30"	Alluvium	Flat	Agric.
P4	Recent Nile terrace	15°65'16"	32°51'25"	Alluvium	Flat	Agric.
P5	College Farm	15°64'74"	32°51'76"	Alluvium	Flat	Agric.

Table 2. Selected morphological properties of the representative profiles.

Profile No.	Depth (cm)	Color (moist)	Texture ^a (field)	Structure ^b	Roots ^c	Boundary ^d	Diagnostic characteristics
P1	0 - 18	2.5Y 3/2	C	2 fabk	1f	cw	Cracks up to 4 cm
	18 - 48	2.5Y 3/2	C	1 fabk	1f	cw	Cracks at the base of the horizon
	48 - 80	2.5Y 3/2	C	1 fsbk	1f	cw	Cracks up to 3 cm
	80 - 105	10YR 6/3	C	ma	1f	cw	Slicken sides not clearly visible
	105 - 150	10YR 6/3	C	2 csbk	1f	cw	-
P2	0 - 30	7.5YR 4/4	L	ma	2f	cs	-
	30 - 45	10YR 4/4	Cl	1 msbk	2f	is	-
	45 - 107	10YR 4/3	C	2 abk	2f	ds	-
	107 - 150	10YR 5/6	C	2 sbk	-	ds	Slightly cemented
P3	0 - 27	2.5YR 3/2	Cl	2 fabk	1f	cw	Cracks up to 4 cm
	27 - 56	2.5YR 3/2	C	1 fabk	2f	cw	Cracks at the base of horizon
	56 - 84	2.5YR 3/2	C	1 cabk	1f	iw	Cracks up to 2cm
	84 - 130	10YR 6/3	C	ma	1f	cw	-
	130 - 150	10YR 6/3	C	2 csbk	2f	cw	-
P4	0 - 12	10YR 3/3	C	3 fg	4f	cs	-
	12 - 48	10YR 3/3	Scl	1 csbk	4vf	cw	-
	48 - 68	10YR 3/2	Scl	2 abk	3vf	cw	Common krotovina
	68 - 86	10YR 3/3	Scl	ma	3vf	aw	-
	86 - 111	10YR 3/2	Scl	ma	3vf	cw	-
P5	111 - 150	10YR 3/3	Scl	ma	3vf	cw	-
	0 - 12	10YR 3/3	C	2 sbk	3f	cs	Few cracks
	12 - 36	10YR 4/3	Sic	1 msbk	1vf	cs	Few soft CaCO ₃ aggregates
	36 - 57	10YR 3/3	C	1 mabk	1vf	cs	Soft lime aggregates, common termites
	57 - 83	10YR 3/2	C	1 abk	1f	cs	Soft CaCO ₃ , common krotovina
P5	83 - 111	10YR 3/2	C	ma	-	ws	Hard CaCO ₃ concretion and CaSO ₄
	111 - 150	10YR 3/2	C	ma	-	ws	Hard CaCO ₃ s concretion and CaSO ₄

Texture^a: C: clay; Scl: Sandy clay loam; Sic: silty clay; Cl: clay loamy; L: loam. Structure^b: 1: weak; 2: moderate; 3: strong; f: fine; m: medium; c: coarse; sbk: subangular blocky; abk, angular blocky; ma: massive. Roots^c: 1: very few; 2: few; 3: moderate; 4: common; f: fine; m: medium; c: coarse. Boundary^d: a: abrupt; c: clear; d: diffuse; i: irregular; s: smooth; w: wavy.

3.2. Physical and Chemical Properties

Some of the physical and chemical properties of the representative profiles were presented in (Table 3). Gadarif area soil was non-saline, non-sodic and calcareous, while Soba area soil at Khartoum state was saline-Sodic and calcareous. The soil of Agricultural Research Corporation Farm, Gezira State is non-saline at the depth of 0 - 84

Table 3. Some physical and chemical properties of the representative profiles.

Profile No	Depth cm	Clay %	Silt %	Sand %	Texture Class	pH Paste	E C dSm ⁻¹	P ppm	O.M %	CEC Cmol (+)/kg	ESP	CaCO ₃ %
Gedaref Area	0 - 18	65.9	12	22.1	Clay	7.9	0.75	4.7	0.073	58.5	1.67	9.59
	18 - 48	63.1	11.5	25.4	Clay	7.97	0.7	5.7	0.056	56.1	8.05	8.82
	48 - 80	63.1	11.2	25.7	Clay	7.85	2.13	5.8	0.036	56.2	2.66	8.42
	80 - 105	62.5	11	26.5	Clay	7.8	2.9	3.8	0.033	55.9	6.26	7.47
	105 - 150	65.1	10.8	24.1	Clay	7.9	1.75	4.6	0.031	57.8	10.17	13.46
Khartoum Area	0 - 30	39.5	13.6	47	Sandy Clay	8.17	3.2	5.7	0.057	35.1	32.23	7.46
	30 - 45	49.1	12.8	38.1	Clay	8.27	22	5	0.038	43.7	35.05	6.42
	45 - 107	57.2	12.6	30.2	Clay	8.17	17	4.3	0.036	49.2	34.55	7.88
	107 - 150	57.2	12.1	30.7	Clay	8.4	8.5	5.6	0.034	49.3	38.42	8.31
Gezira State Area	0 - 27	49.8	13.7	36.5	Clay	8.15	1.45	4.8	0.055	44.1	15.19	8.13
	27 - 56	51.5	13.5	35	Clay	8.3	1	6.3	0.043	45.5	20.1	7.93
	56 - 84	58.2	13.1	28.7	Clay	8.35	3.3	4.8	0.041	50.1	25.84	9.32
	84 - 130	63.3	12.9	23.8	Clay	8.11	6	4.7	0.036	55.2	24.76	5.47
	130 - 150	63.3	12.5	24.2	Clay	8.12	8.7	5.6	0.034	55.1	34.52	5.19
Khartoum North Area	0 - 12	54.4	14.6	31	Clay	7.51	1.8	7.6	0.076	47.8	3.49	4.41
	12-48	54.4	14.1	31.5	Clay	7.8	0.7	5.5	0.097	47.6	3.09	4.31
	48 - 68	26.3	14.1	59.6	Sandy Clay	8.12	0.4	4.7	0.095	23.1	3.2	5.2
	68 - 86	26.3	14	59.7	Sandy Clay Loam	8.14	0.35	5.7	0.088	22.9	3.1	4.51
	86 - 111	26.3	14	59.7	Sandy Clay Loam	8.1	0.35	5	0.069	23.1	3.03	3.99
	111 - 150	26.3	14	59.7	Sandy Clay Loam	8.1	0.3	5.6	0.069	23.4	3.03	4.12
College of Agricultural Studies Farm	0 - 12	51.1	11.9	37	Clay	8.1	1.4	4.1	0.074	6.21	45.8	29.96
	12-36	51.5	11.7	36.8	Clay	8.17	1.85	4.9	0.067	6.46	45.5	20.29
	36 - 57	51.2	11.5	37.3	Clay	7.97	3.4	5	0.059	7.05	45.3	16.69
	57 - 83	52.1	11.2	36.7	Clay	8.17	3	5.1	0.06	6.3	45.6	20.17
	83 - 111	54.4	11.1	34.5	Clay	8.07	4.9	5.1	0.053	5.89	45.1	28.76
111 - 150	50.4	11.4	38.2	Clay	7.94	6.1	5	0.052	5.97	45.2	34.58	

cm, slightly saline at the bottom depth 84 - 150 cm, sodic and slightly calcareous. The Nile flood plain soil was non-saline, non-calcareous and non-sodic; it was very suitable for agriculture. The soil of Shambat area—College of Agricultural Studies Farm is non-saline at the top surface 0 - 83cm, and slightly saline at the bottom 83 - 150 cm, sodic and slightly calcareous soil.

3.3. Determination of Cation Exchange Capacity by (Bower *et al.*, 1952) and (Mario and Rhoades, 1977) Methods

The only method used for determination of Cation Exchange Capacity (CEC) in Sudan is [6], which is not replaced or changed although errors can result during measurement of CEC. Errors observed during saturation step with adsorb cation, in the washing step of the excess cation with alcohol, and in the decantation step. [13] mentioned that; during saturation step in Bower *et al.*, (1952) the adsorb Na^+ could not be complete saturated in the soil, because of the competence of other cation at the exchange sites, e.g. Ca^+ which is abundant in calcareous soils. (The study areas of Gedaref, Gezira contained high amount of CaCO_3), these areas the most important agricultural areas in Sudan, so accurate results for CEC should be obtained.

During washing step, adsorb Na^+ may be lost by hydrolyses and replaced by other cations (e.g. Ca^+ and gypsum) [10] [13] [20]. Probably, the significant differences at Gedaref and Wad Medani areas when used two methods are due to the above-mentioned reasons.

[13] also mentioned that the loss of organic matter from the soil at the washing step using alcohol, or at the decantation step where some clay minerals could lost, which have a significant role in CEC, especially two layers clay minerals. In this study, the soil samples are poor in organic matter, so what have been mentioned of these lost not affect in the results obtained. Two layers clay minerals (e.g. montmorillonitic, Na^+ ions may trapped between the two layers could not be replaced or washed by alcohol, leads to wrong CEC reading). Soil rich in zeolites and feldspars, and vermiculites assists Na^+ to be trapped at the center extraction [13]. This can affect the CEC readings and spontaneously affect exchangeable sodium percentage (ESP).

[13] method alleviate many errors that could occur in applying Bower method, plies its simplicity and more or less accuracy in calcareous and gypsiferous soils. In addition, [13] omitted the washing step to remove excess sodium. **Figure 1** showed the differences in CEC and ESP of the two methods.

Significant differences appeared in Gedaref area, Wad Medani and Nile flood plain when used these two methods for determination CEC (**Table 4**). Significant differences also appeared in ESP at Nile flood plain and Shambat area (**Table 5**), that may be due to; effect of several washing solution lead to significant dissolution of O.M, which lowered the CEC systematically, agreed by [21]. The permanently added Ca^{2+} ions compete successfully with NH_4^+ during the washing step lead to underestimation of CEC [13]. High layers charge density allows slow cation exchange when NH_4^+ was used.

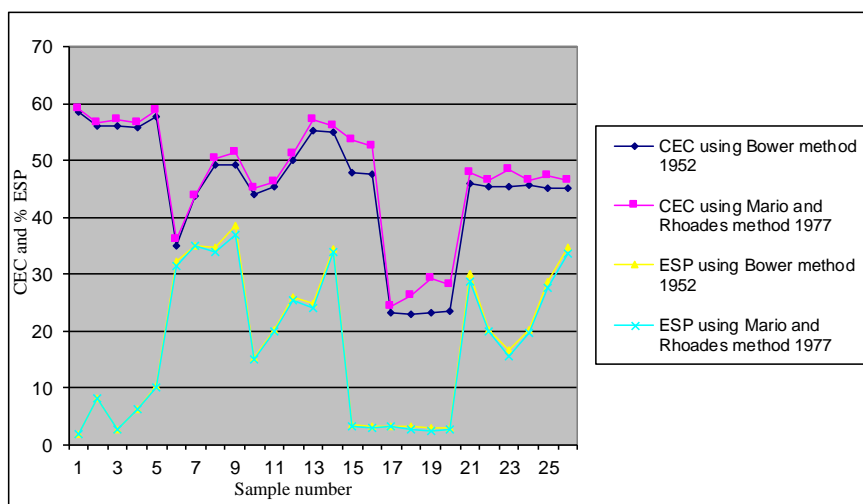


Figure 1. The difference between results by using (Bower *et al.*, 1952) and (Mario and Rhoades, 1977) methods for determination of CEC and ESP.

Table 4. Statistical comparison between CEC results using (Bower *et al.*, 1952) and (Mario and Rhoades, 1977) methods.

Location	Tabulated T-value	Calculated T-value
Gedaref Area	5.598	7.100*
Khartoum Area	7.453	2.730 ^{N.S}
Gezira State Area	5.598	5.813*
Khartoum North Area	4.773	5.244*
College of Agricultural Studies Farm	4.773	4.730 ^{N.S}

^{N.S}Non significant. *Significant at (P < 0.05).

Table 5. Statistical comparison between ESP results using (Bower *et al.*, 1952) and (Mario and Rhoades, 1977) methods.

Location	Tabulated T-value	Calculated T-value
Gedaref Area	5.598	3.011 ^{N.S}
Khartoum Area	7.453	2.798 ^{N.S}
Gezira State Area	5.598	5.565 ^{N.S}
Khartoum North Area	4.773	5.3245*
College of Agricultural Studies Farm	4.773	5.1412*

^{N.S}Non significant. *Significant at (P < 0.05).

Yaalon *et al.*, (1962) reported that, the use of NH_4^+ salts should be avoided because of the possibility of NH_4 fixation and release of fixed potassium resulting in underestimation of CEC.

It can be stated that, the newly developed method of Mario and Rhoades used in this study is more practical, simple and reliable for determination of CEC as the currently used Bower method, but will be safer than Bower method in some problematic soils. The adoption of Mario and Rhoades method is advisable because it is less time consuming as it omitted the washing step. It cannot be a good substitute in laboratories which no possibility to determination sodium by flame photometer.

4. Conclusion

After compared and evaluated of Bower *et al.*, (1952) and Mario and Rhoades (1977) methods for determination of Cation Exchange Capacity (CEC) and Exchangeable Sodium Percentage (ESP), we conclude that when Mario and Rhoades (1977) method is used to determine CEC and ESP time will be saved, that less amount of chemicals will be used in laboratories and that accurate results will be achieved.

Acknowledgements

Special thanks to the staff of the laboratories of the Land and Water Research Centre at the Agricultural Research Corporation, Wad Medani, and the Staff of Soil Science and Water Department at College of Agricultural Studies, Sudan University of Science and Technology, for availing their laboratories facilities and for their technical advice.

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