Al-Qadisiyah Journal For Agriculture Sciences (QJAS)
ISSN : 2618-1479 Vol.13, Issue. 2 ,(2023), pp. 127-135
https://jouagr.qu.edu.iq/

Reversibility of Saturated Hydraulic Conductivity under Soil Sodicity and High Electrolyte Concentration

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Abstract. We investigated the effect of sodicity on the reversibility of saturated hydraulic conductivity (Ks) under high electrolyte concentration (HEC) EC ≥16 dS/m. This laboratory investigation consisted of measurment of Ks using the permeameter of McNeal and Reeve (1964) by varying sodicity. We increased sodicity, expressed by Sodium Adsorption Ratio (SAR), in steps from a min of 0 to a max of 30, and then we followed the same procedure, but then backwards. Measurement of soil dispersion was carried out for all the SAR values used in the measurement of Ks using the method of Velasco-Molina et al. (1971). Under HEC Ks decreased as sodium adsorption ratio (SAR) increased. SAR increment of +/- 15 causes the most important decrease. However, when decreasing the SAR again, Ks does not show an increase, it is irreversible for these conditions of experimentation.In contrast; soil dispersion (SD) shows an increase with increasing SAR, but then also decreases again when SAR is lowered. This decrease is not sufficient to compensate the irreversibility of Ks.

Keywords. Saturated hydraulic conductivity, Reversibility, SAR, Dispersion, Electrical Conductivity.

1. Introduction

Soil structure is essential for its adequate functioning and can be defined as the result of the union of primary particles in aggregates and the porous space formed between them [24]. Soil sodicity can degrade soil structure which can reduce Ks. Soil sodicity occurs when soil solution SAR and or exchangeable sodium percentage (ESP) is greater than 15 and solution EC is low (4 dS m-1). Different sources say threshold ESP or SAR varies between 6 and 15. Reduction of Ks, expressed in $cm.h^{-1}$, is affected by two mechanisms, dispersion of clay particles and their swelling [7, 10, 13]. Dispersion results in the reduction of attractive forces between colloidal clay and organic matter particles when they are wetted [12]. Dispersed clay particles can move and block pores leading to a reduction of Ks [29].

The partial saturation by exchangeable sodium increases dispersion of soil aggregates [2, 11, 12, 20]. Dispersion can occur for an ESP lower than 15% and low total electrolytes concentration [22, 24]. Soil texture [21], type of clay mineral [6, 16, 25] and organic matter (OM) [19] influence dispersion of soil aggregates. Plant root growth increased the formation of large water-stable macroaggregates (> 2000 µm), which would lower clay dispersion by reducing the exposure of clay particles to water [32]. On

DOI: 10.33794/qjas.2023.144396.1146

the other hand, root growth reduced soil Ks, which in turn increased clay dispersion from aggregates [32].

OM can have a positive and a negative effect on Ks [28]. This is due to the variation of organic components in soil [7]. Many researches speak about the progress of Ks in saline and sodic conditions but few of them mention its reversibility or irreversibility. Mc Neal and Coleman [16] said that it is irreversible. Sumner [28] confirms that its decrease under the effect of dispersion is irreversible, but there are some changes in relation to soil swelling which are reversible and they influence Ks. In soil, swelling, dispersion or the two mechanisms can cause the reversibility of Ks [3]. Thus, the objective of this research is to study the influence of sodicity on the reversibility of the Ks under HEC.

2. Materials and Methods

2.1. Materials Used in the Study

The soil sample was collected from the 0-30 cm depth of a Solonchak from the Bas Cheliff zone (Algeria). This soil sample constitutes the first horizon of a reference profile studied by Saidi [26]. The sample was air dried and sieved through 2 mm sieve. Table 1 provides soil physical and chemical characteristics. The particle size analysis was carried out using the international method with Robinson pipette without decarbonation for the sample < 2 mm [8]and with decarbonation for the sample ≤ 1 mm. Cation Exchange Capacity (CEC) was determined using the saturation method with ammonium acetate [14] and the exchangeable bases were determined as described by Jackson [9]. Measurement of Electrical Conductivity (EC) was done by the electrical method on the soil saturated paste extract [30]. The pH was determined by the potentiometric method on the soil extract soil/water of 1/1.25[14]. The determination of OM was made by the Ann method [1] and the estimation of the saturation moisture content was carried out on the saturated paste extract.

Table1. Chemical and physical characteristics of soil sample.

Characteristics		C(%)	FS (%)	CS (%)	FS (%)	CS (%)
Particle size analysis	Sample ≤ 2 mm Without decarbonation	32.45	38.94	13.52	14.60	2.09
	Sample ≤ 1 mm Without decarbonation	38.34	31.86	13.50	15.86	3.05
	Fraction ≤ 1mm with decarbonation	23.59	23.39	24.26	23.99	1.53
Exchange complex Capacity (meq 100g of soil)		Ca^{++} 13.18	Mg^{++} 2.33	Na^{+} 2.17	K^{+} 0.97	ECC 18.65
EC (dS m^{-1}) at 25 °C				1.97		
Total calcium carbonate(%)	Sample ≤ 2 mm			20.33		
	Sample ≤ 1 mm			17.71		
pH				7.8		
Carbon(%)				1.33		
Saturation moisture content(%)				53		

C: Clay, FS: Fine Silt, CS: Coarse Silt, FS: Fine Sand, CS: Coarse Sand, EC: Electrical Conductivity,

2.2. Methods of Study

2.2.1. Saturated Hydraulic Conductivity (Ks)

Ks was estimated using the method of Mc Neal and Reeve [15]. Soil sample was packed in tubes of 2.6 cm to a bulk density of 1.03 g/cm^3 for a height of 2.5 cm so the mass was of 54.658 g. The mass sample was divided into four parts to reach a total sample height of 2.5 cm. A filter paper was added at the top of soil to avoid its compaction.

2.2.1.1. Percolating Solution

EC of percolating solutions was about 16 dS/m. AHEC can limits the dispersive effect of sodium; this is why it has been chosen. The percolating solution was made by mixing NaCl and $CaCl_2 2H_2O$ in

DOI: 10.33794/qjas.2023.144396.1146

different proportions to obtain pure Ca (160 meq/l) with SAR (0, 5, 10, 15, 20, 25, 30) with Na and Ca. The different proportions are summarized in Table 2.

The percolating solution was added to soil sample by fractions of 32.44 ml and EC of the percolate solution was measured the equilibrium between the leached solution and the percolated one is reached after a number of poral volumes. The poral volume is the number of volumes of solution, which depends on the total porosity of soil sample in percolation tube.

Table 2. Proportions of salts required to make each SAR percolating solution.

SAR	Na		Ca	
	Na (meq L^{-1})	NaCl (g L^{-1})	Ca (meq L^{-1})	$CaCl_2 2H_2O$ (g L^{1})
0	0	0	160	11.761
5	38.906	2.273	121.094	8.901
10	67.870	3.966	92.13	6.772
15	89.228	5.213	70.772	5.200
20	104.939	6.131	55.061	4.046
25	116.539	6.809	43.461	3.194
30	125.178	7.315	34.822	2.558

2.2.1.2. Ks Measurement

Measurment of Ks was done for all the increasing and decreasing values of SAR following three types of increments +/- 5, +/-15, and +/-30:

First step: 0, 5, 10, 15, 20, 25, 30
Second step: 30, 25, 20, 15, 10, 5, 0
Third step: 0, 15, 30
Fourth step: 30, 15, 0
Fifth step: 0, 30
Sixth step: 30, 0

The experiment was conducted using triplicate samples. Ks was calculated following the Darcy law.

2.2.2. Measurement of Dispersion

Measurement of soil dispersion was carried out for all the SAR values used in the measurement of K_s. Soil samples were saturated as indicated by Galindo and Bingham [5] then the dispersion measure was carried out following the method of Velasco-Molina *et a*l. [31]. The relation calculated percentage of dispersion $D\% = \left(\frac{m}{M}\right) * 100$, where D is the dispersion percentage, m is the mass of the dispersed particles, and M is the mass of soil sample.

3. Results and Discussion

3.1. Ks

The equilibrium between soil solution and the exchange complex is reached after percolation of four poral volumes. The statistical analysis shows that the difference of EC between the initial solution and the percolated solution is not significant from the fourth poral volume for the first equilibrium. We have continued to add the volume of percolating solution until the two EC become similar. This needs 10 to 19 poral volumes.

Table 3 shows results on Ks for the six increments of SAR.

Ks values expressed with trust interval (TI) of 95%. This TI is calculated by multiplying the standard error (ES) by t1-α/2 critical (α =0.05) for freedom degree of n-1.

$$TI = ES * t1{-}\propto/2$$

ES was calculated by the formula$ES = \delta\sqrt{n}$

δ: Standard deviation

n: number of repetitions per measure (3).

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Table 3. Ks for all SAR increments.

SAR Increm -ent	Ks (cm.h^{-1}) SAR 0	Ks (cm.h^{-1}) SAR 5	Ks (cm.h^{-1}) SAR 10	Ks (cm.h^{-1}) SAR 15	Ks (cm.h^{-1}) SAR 20	Ks(cm.h^{-1}) SAR 25	Ks (cm.h^{-1}) SAR 30
+5	0,978 ±0,302	1,386±0,040	1,386±0,140	1,366±0,121	1,182±0,394	1,040±0,183	0.754 ±0,327
-5	0,182 ±0,302	0,308 ±0,313	0,352±0,279	0,408 ±0,355	0,489±0,239	0,550±0,299	0,754 ±0,327
+15	1,355 ±0,552	-	-	0,450 ±0,757	-	-	0,265 ±0,400
-15	0,122 ±0,120	-	-	0,265 ±0,400		-	0,265 ±0,400
+30	0.958+0.114	-	-	-	-	-	0.506±0.267
-30	0,530 ±0,048	-	-	-	-	-	0,506 ±0,267

3.1.1. Ks in Function of Increasing Sodicity

Results (Figure1, 2, 3) show that increasing SAR induce reduction in Ks for all SAR and confirms those obtained by Dang et al. [4].

For increment +5, variance analysis of one factor indicates that the effect of increasing sodicity on Ks is significant ($p = 0.018$). The Newman-Keuls test separates homogenous groups:

Group A: SAR 5, SAR 10, SAR 15
Group B: SAR 0, SAR 20, SAR 25
Group C: SAR 30

This effect is insignificant for the increments +15 and +30.

The variation of SAR between 0 and 5 caused a little increase in Ks. This can be due to the liberation of trapped air, which blocked the conductive pores [14,16].Between SAR 5 and SAR 15, a stability of Ks is observed, it can be due to HEC(160 meq/l) which maintain the flocculated aspect of clays. When SAR exceeds 15, Ks decreases, this is due to the dispersion of clay particles [13, 28]. It can be due to swelling which is determinant from SAR 15 [12].

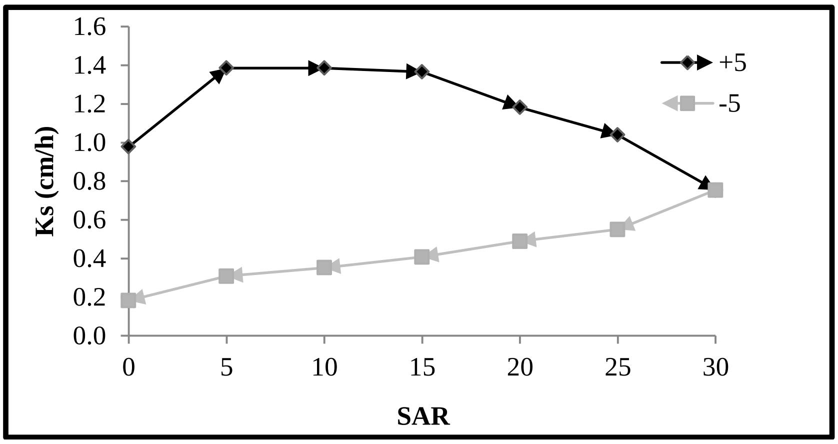

Figure 1. Variation of Ks for the increment +5/-5""PM.

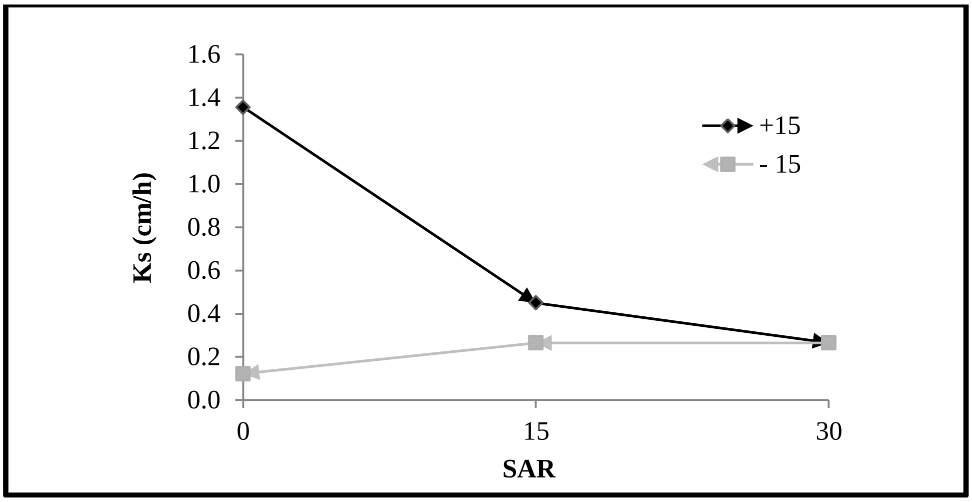

Figure 2. Variation of Ks for the increment +15/-15.

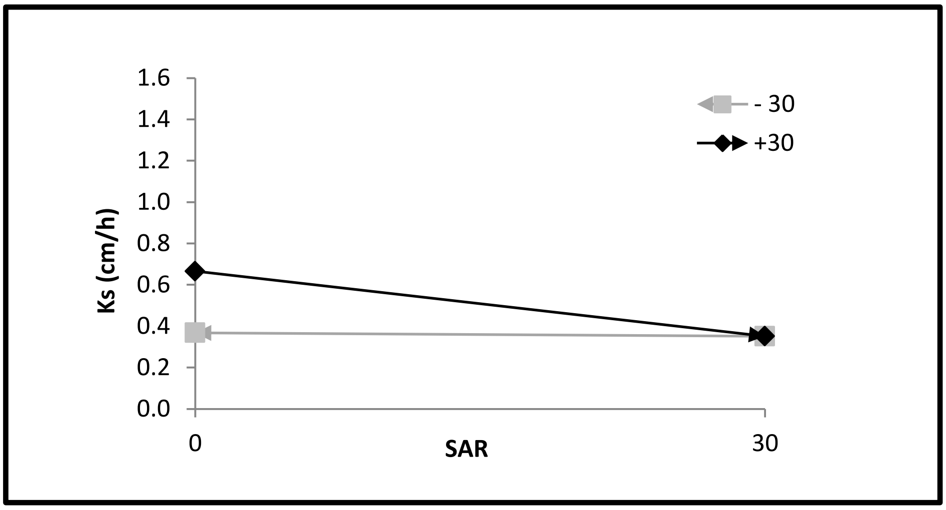

Figure 3. Variation of Ks for the increment +30/-30.

3.1.2. Ks in Function of Decreasing Sodicity

Decreasing SAR does not increase Ks for all the increments (Table 3). Little variation is noted. It can be explained by dispersion of clay particles [13].Figures1, 2 and 3 represent the variation of K_S.

Variance analysis of one factor which is the decreasing sodicity for a probability threshold α of 0.05 indicates that the effect of decreasing sodicity on Ks is insignificant for increments -5 (p = 0.272), -15 (p=0.797) and -30 (p=0.956).

3.1.3. Reversibility of K_S

Increasing sodicity decreases Ks**.** This effect is significant only for the increment of +5.Decreasing sodicity has not a significant effect on Ks. The comparison between Ks was done by the LSD test (Least Significant Difference). Results are given in table 4.

The reversibility of Ks has a heterogeneous behaviour. It is observed for:

- SAR 25 and SAR 20 when the increment is ±5,
- SAR 15 when increment is ±15, and
- SAR 0 when increment is ±30.

The situation of saturated soil can explain the irreversibility of Ks. Dane and Klute [3]confirm that the soil desiccation increases Ks because of rearrangement of soil particles that influence porosity and solute circulation.

Table 4. Results LSD test of Ks for increasing and decreasing SAR for different increments.

SAR increment	SAR	Ks± TI Increasing SAR	Ks ± TI Decreasing SAR	Calculated difference	LSD
±5	0	0,978 ± 0,154	0,182 ± 0,154	0,797	0,836
	5	1,386 ± 0,020	0,308 ± 0,160	1,078	0,489*
	10	1,386 ± 0,071	0,352 ±0,142	1,035	0,580*
	15	1,366 ± 0,062	0,408 ± 0,181	0,958	0,661*
	20	1,182 ±0,201	0,489 ± 0,122	0,693	0,877
	25	1,040 ±0,093	0,550 ± 0,153	0,489	0,668
±15	0	1,355 ± 0,281	0.122 ±0,061	1.602	0.930*
	15	0,450 ± 0,386	0.265 ± 0,203	0.185	1.233
±30	0	0.958 ± 0,174	0.530 ± 0,073	0.428	0.673

* significant

3.2. Influence of Sodicity on SD

Table 5 gives results of soil dispersion percentage for all increments of SAR. The results are expressed with trust interval (TI) of 95%. The effect of sodicity on SD is summarized in figure3

SD depends on sodicity: Increasing sodicity increase SD and decreasing sodicity decreases SD, this is observed for all increments and it confirms the conclusion of Sumner [28] and Rengasamy [210] that dispersion has been reported to be highly correlated with sodic soil behaviour

Variance analysis of one factor which is the increasing sodicity for a probability threshold α of 0.05 indicates that the effect of increasing sodicity on SD percentage is significant (p <0.001) for all the increments. The Newman-Keuls test separates:

- Three homogenous groups for +5 increment: Group A (SAR 0, SAR 5, SAR 10, SAR 15), Group B (SAR 20) and Group C (SAR 25, SAR 30).
- Two homogenous groups for +15 increment: Group A (SAR 0, SAR 15) and Group B (SAR 30).
- Two homogenous groups for +30 increment: Group A (SAR 0) and Group B (SAR 30).
- Five homogenous groups for -5 increment: Group A (SAR 0), Group B (SAR 5, SAR 10), Group C (SAR 15), Group D (SAR 20) and Group E (SAR 25, SAR 30).
- Three homogenous groups for -15 increment: Group A (SAR 0), Group B (SAR 15) and Group C (SAR 30).
- Two homogenous groups for -30 increment: Group A (SAR 0) and Group B (SAR 30).

Table 5. SD for all SAR increments.

SAR Increm -ents	SD (%) SAR0	SD (%) SAR5	SD (%) SAR10	SD (%) SAR15	SD (%) SAR20	SD (%) SAR25	SD (%) SAR30
+5	1.456±0.058	1.433±0.236	1.467±0.834	3.483±3.339	13.233±6.769	19.033±1.673	22.567±1.879
-5	1.025±0.675	4.700±1.876	5.517±0.941	8.683 ±0.377	16.950±1.323	20.767±0.849	22.567±1.879
+15	1.456 ±.058	-	-	3.800 ±1.538	-	-	18.235±2.631
-15	1.550±0.170	-	-	11.000±2.967	-	-	18.235±2.631

3.3. Reversibility of SD

Table 6 gives the percentages of SD for all the increments and the results of the LSD test for increasing and decreasing sodicity. Results show that SD for different decreasing level of sodicity are higher than those of increasing level of sodicity. Increasing sodicity increases soil dispersion for all SAR increments. Decreasing sodicity causes decrease in soil dispersion percentage. The difference between this two is variable. The reversibility of dispersion depends on variation of SAR.

DOI: 10.33794/qjas.2023.144396.1146

3.4. Relation between Ks and SD

Figure 4 represents results of simple correlations between Ks and SD. The equation of regression shows that the variance of Ks is explained by 4.6% by the variance of SD percentage. The obtained equation is $y = 0.010x + 0.791$ with $R^2 = 0.042$ and n = 24, variation which is independent of SD.

Table 6. Results of LSD test of SD for increasing and decreasing SAR for different increments ($\alpha \leq 0.05$).

SAR increment	SAR	SD ± TI Increasing SAR	SD± TI Decreasing SAR	Calculated difference	LSD
±5	0	1.456 ±0.029	1.025 ±0.344	0.431	1.015
	5	1.433± 0.120	4.700 ±0.957	3.267	2.925*
	10	1.467±0.426	5.517 ±0.480	4.050	2.459*
	15	3.483±1.704	8.683±0.192	5.2	5.147*
	20	13.233±3.468	16.950±0.675	3.717	11.249
	25	19.033±0.854	20.767±0.433	1.734	3.494
±15	0	1.456 ±0.029	1.550±0.087	0.094	0.315
	15	3.8±0.785	11.000±1.514	7.2	6.242*
±30	0	1.456 ±0.029	1.933±0.073	0.477	0.277*

LSD: Least Significant Difference, SD: Soil Dispersion, SAR: Sodium Adsorption Ration, TI: Trust Interval, * significant

Conclusion

This research was carried out under HEC by varying SAR to study the possibility of reversibility of Ks. Results show that increasing sodicity decreases Ks in HEC for all SAR increments. The most important decrease is noted for the increment +15. The effect of increasing sodicity on Ks is not significant and increase in Ca concentration does not ameliorate it. This increase in sodicity has increased SD percentage but it depends on the SAR increment studied. At SAR 30, D% =22.56% for+5 increment, 18.23% for +15 increment and 15.91% for +30 increment. Decrease sodicity decreases SD percentage but they remain higher than those of increasing sodicity.

This research shows that Ks is in general irreversible. This irreversibility can be explained partially by the observed irreversibility of SD even if there is no correlation between these two parameters in statistics.

This study was carried out with increasing and decreasing sodicity cycle. The Ca concentration was not sufficient to restructuration of soil. The soil may be restructured by wetting drying cycle. The drying may ameliorate soil structure.

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