IN SITU SOLUTE TRANSPORT OF CL AND NA AND UNSATURATED HYDRAULIC CONDUCTIVITY OF SOIL UNDER SALINE IRRIGATION WATER+

الانتقال الموقعي لمذاب الكلوريد والصوديوم والايصالية المائية غير المشبعة تحت ري التربة بالمياه المالحة

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Abstract :

Transport of Cl and Na solutes were predicted by convection-dispersion equation (CDE) and its relations with unsaturated hydraulic conductivity, K(Θ) under saline irrigation water. Three field plots were irrigated with seven intermittent pounding of saline water. During irrigation, samples of soil solution were collected at depths of 0.15, 0.30, and 0.45 m and EC , Cl and Na were being measured. The K(Θ) was measured using internal drainage method, utilizing neutron probe and tensiometers.

Results showed that the shape and position of breakthrough curves (BTC) of Cl and Na were differed due to type of ion and soil water characteristics. The BTC of Cl and Na were displaced to the right and Na showed less relative concentration (C/Co) at a given pore volume (V) of water. The CDE provided a fairly good fit to the BTC for both ions. It gave dispersion coefficient (D) of 177.6 cm^2 day^{-1} for Cl and 120-237.6 for Na. Also, Cl and Na curves appear more C/Co at 0.15 m depth in comparison with the other two depths. The fitted exponential curve of K(Θ) showed in general a decreased in magnitude with the use of saline water. The values ranged from 0.02419 to 0.00188 , and 0.01425 to 0.00120 cm h^{-1} for fresh and saline water, respectively.

المستخلص:

درس انتقال مذابات كل من الكلوريد والصوديوم في التربة باستخدام موديل الحمل-التشتت وعلاقة ذلك بالايصالية المائية غير المشبعة تحت الري بالمياه المالحة. رويت ثلاث الواح بالماء المالح بشكل متقطع ولسبع دفعات. جمعت عينات من محلول التربة اثناء الري للاعماق ٠.١٥ و ٠.٣٠ و ٠.٤٥ م وقيس فيها الكلوريد والصوديوم والايصالية الكهربائية للتربة. قيست الايصالية المائية غير المشبعة للتربة بطريقة البزل الداخلي باستعمال المجس النيوتروني واجهزة قياس الشد الرطوبي.

بينت النتائج ان موقع وشكل منحنيات الاختراق للكلوريد والصوديوم اختلف باختلاف نوع الايون وخصائص التربة. فقد ازيحت المنحنيات الى اليمين لكلا الايونين، وقد اظهر الصوديوم تركيزاً نسبياً اقل في المحلول عند اي حجم فراغ. كما اظهر موديل الحمل التشتت تطابقاً جيدا مع منحنيات الاختراق المقاسة لكلا المذابين. وقد اعطى الموديل معامل تشتت بلغ ١٧٧.٦ للكلوريد و ١٢٠-٢٣٧ سم^{٢} يوم$^{-١}$ للصوديوم. كذلك اظهرت منحنيات الايونيين تركيزاً نسبياً اعلى للعمق الاول مقارنة للعمقين الآخرين. كما بينت النتائج ان العلاقة كانت أسية للايصالية المائية غير المشبعة مع

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الرطوبة الحجمية، وان الايصالية انخفضت مع استخدام الماء المالح، وقد تراوحت قيمها بين ٠.٠٢٤١٩ الى ٠.٠٠١٨٨ و ٠.٠١٤٢٥ الى ٠.٠٠١٢٠ سم ساعة$^{-1}$ للماء العذب والماء المالح على التتابع بانخفاض الرطوبة الحجمية للتربة.

Introduction :

The use of saline water irrigation is wide-spread in many arid and semi arid regions of the world. The selection of appropriate practices for salinity assessment under such conditions requires the quantification of the movement of solutes and water in the soil.

The prediction of one dimensional vertical solute transport under saline irrigation water through undisturbed, structured clay soil is difficult because of highly irregular patterns of solute and water movement due to complexity of soil structure [1]. One of the main approaches to modeling one dimensional vertical solute transport through soil is based on the convection – dispersion equation (CDE) [2]. The CDE is based on the mechanisms governing the dispersion plus diffusion of solute moving through homogenous porous media [3], and by mass flow or convection with water as the water moves through the soil [4]. It has been modified for structured soil by the introduction of the mobile-immobile water concept [5], or by anion exclusion and dead-end pores [6]. The models (CDE) describing this mechanistic have been derived and investigated by many researchers [7,8]. The ability of the models to predict the movement of solute in soil and the effect of soil on such movement would be useful in management practices for soils irrigated with saline water. This requires precise knowledge of soil water and solute flow and, therefore of soil physical properties. Hydraulic conductivity (K) is the most important soil physical property describing water transport ability of soils, which in turn controls the rate of transport of solution in soils. On the other hand, the composition of percolating solution have a great influence on the K. The main mechanisms for reduced K are the process of swelling in clayey soils having smectite clay minerals, and dispersion and movement of clay particles resulting in pore clockage [9,10,11,12]. However, the extent to which solute transport parameters are related to soil properties under these conditions is unclear enough. Also the transport of Na and Cl may not adequately studied under heterogeneous porous medium such a soil. There is ample need to study their two concepts. Experiments were therefore , conducted to assess the irrigation with saline water on: first the ability of CDE model to describe transport of Cl and Na through a structured field clay soil, and second how hydraulic conductivity under unsaturated conditions is related to solute transport process.

Theory :

The movement of solute though soil was assumed to be described adequately by the classical one dimensional convection – dispersion equation, CDE (2).

$$R(\partial c/\partial t) = D(\partial^2/\partial x^2) - v(\partial c/\partial x) \quad \text{...}(1)$$

Where R is the retardation factor, c is the solute concentration, t is the time, x is distance from the source, D is dispersion coefficient and υ is average pore velocity which is defined as q/θ , where is q is the water flux density and θ is the volumetric water content of the soil profile.

The initial and boundary conditions are:

$$C(o,t) = C_O(t) \quad and \quad \partial c(\infty,t)/\partial x = 0 \quad \text{..}(2)$$

The analytical solution of equation 1 for the effluent concentration, C/C_O in terms of the Peclet number (P) and number of pore volumes (V) passed through the soil was given by [13]:

$$C/C_o = 1/2 \ erfc\left[\left(\frac{P}{4RV}\right)^{0.5}(R-V)\right] + 1/2 \ \ exp(P)erfc\left[\left(\frac{P}{4RV}\right)^{0.5}(R+V)\right] \ldots(3)$$

and $P = vL/D$ ……………………………………………………………………..(4)
where, erfc is the complementary error function ,and L is the soil depth.

Materials and Methods :

A field experiment of one hectare was conducted at the field of Cukurova University Experimental station in Adana, south of Turkey located at (37.0573° N) latitude and (35.3552° E) longitude at an altitude of 23 m above mean sea level. Table 1 shows some properties of soil. Three plots of 3x3 m were assigned to the investigation under consideration. Neutron access aluminum tubes were installed at the center of each plot. Series of tentiometers with septum stoppers and suction cups (solution samplers) were installed at depths of 0.15 , 0.30 , 0.45 , 0.60 and 0.75 m and 0.15, 0.30, and 0.45 m, respectively. The plots were pounded with fresh water to saturate soil at a depth of about 0.60 to 0.70 m. After percolation of applied water, the soil surface of each plot was covered with plastic layer to prevent evaporation (i.e. upward flux). Soil water content

Table 1. Some characteristics for the field soil

Depth M	Sand g kg^{-1}	Silt g kg^{-1}	Clay g kg^{-1}	Tex.	F.C.	W.P.	Sat.	BD Mg m^{-3}	pH	EC dS m^{-1}	Lime g kg^{-1}	O.M. g kg^{-1}
					cm^3 cm^{-3}							
0-0.3	276	212	512	clay	45.7	27.7	64.6	1.19	7.89	0.21	57	13
0.3-0.6	275	191	534	clay	46.3	30.3	67.3	1.16	7.61	0.12	62	11
0.6-0.9	284	181	535	clay	48.0	31.3	69.3	1.15	7.81	0.14	68	-
0.9-1.2	274	192	535	clay	50.3	32.0	66.5	1.25	7.97	0.13	86	-
1.2-1.5	253	213	534	clay	50.3	31.0	72.4	1.24	7.64	0.18	145	-

was monitored periodically for the 0.2-1.2 m depth every 0.1 m using neutron moisture meter (CPN503DR). The neutron moisture meter was calibrated in situ for 0.10 and ≥ 0.20 m depths. Also, tensiometer readings were taken together with water content measurements. After the end of above mentioned stage, saline water has electrical conductivity (EC) of 7.0 $dS.m^{-1}$, Na, 422, Ca, 29.5, Mg,19.9 and Cl 28.7 $mmol.L^{-1}$ (SAR=9.1) was ponded with seven intermittent portions. Sample of soil solution were collected periodically for 0.15, 0.30 and 0.45 m depth and measured for EC, Na and Cl. Also, saturated extract were used to measure solution composition at end of the experiment.

Unsaturated hydraulic conductivity, $K(\theta)$ was determined in the soil profile before and after irrigation with saline water using the internal drainage method following the equation [4]:

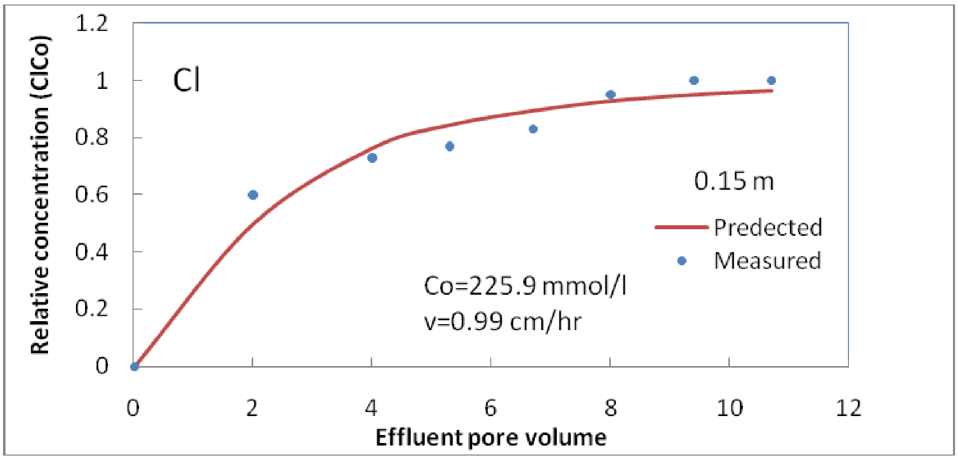
$$K(\theta) = \left[\frac{d/dt}{dH/dX}\right]_{X=L \quad X=L,t} \ldots\ldots(5)$$

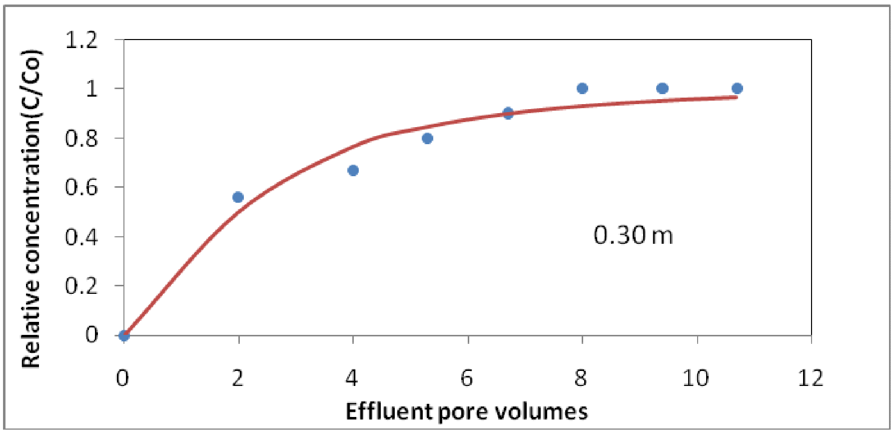
where , Θ is soil water content , t is time, H is total soil water hydraulic head, X is soil depth measured positively downward (L) ($X=L$).

Breakthrough curves (BTC) are developed by plotting the results on a normal graph with pore volumes (V) along X axis and C/C_O along the Y axis. Equation.3 was fitted to experimental Na and Cl BTC using curve fitting procedures [7,15]. MathCAD software program was used to determine R and P by trial and error in which the parameter values are varied to best describe the experimental BTC. Dispersion coefficient (D) then calculated from Eq.4.

Results and Discussion:

Figs. 1 and 2 show measured and predicted Cl and Na breakthrough curves BTC as a function of pore volume (V) for depths of 0.15, and 0.30 and 0.45cm. Results showed that the shape and position of BTC differed based on soil depth and type of ion. The BTC of Cl were displaced to right of one pore volume and showed more tailing and dispersion for the three depth. Generally, typical BTC were not obtained for Cl (passage one V is sufficient to displace 50% of Cl ($C/C_O = 0.5$) out of the depth. In these curves the passage of 8.0 to 10.7 V were displaced most of applied Cl (all Cl were displaced in soil solution). On the other hand, the BTC of Na were more displaced to the right in comparison with Cl and showed less relative concentration (C/C_O) for a given pore volume of water. Also, Cl and Na curves appear more C/Co at 0.15 m depth compared with 0.30 and 0.45 m. The passage of 10.7 V were displaced 83, 65 and 38% of applied Na for 0.15, 0.30 and 0.45 m, respectively. The results of Cl indicated that ion exclusion may had occurred (small effect) due to negatively charged soil surface which resulted in a faster leaching of Cl comparison with Na [16,17]. Also, the results showed that the BTC for Cl and Na were asymmetric . The asymmetry of BTC indicated that field soil had heterogeneous porous media. Based on the shape of BTC Cl and Na were transported through the major portion of soil occupied by immobile or stagnant regions. Gonzalez-delgado and Shukla [18] Indicated that the presence of higher immobilization volumetric water caused asymmetry of NO_3^- and Cl^- transport in soil columns due to the presence of higher immobilization volumetric water content. The heterogeneity of the porous





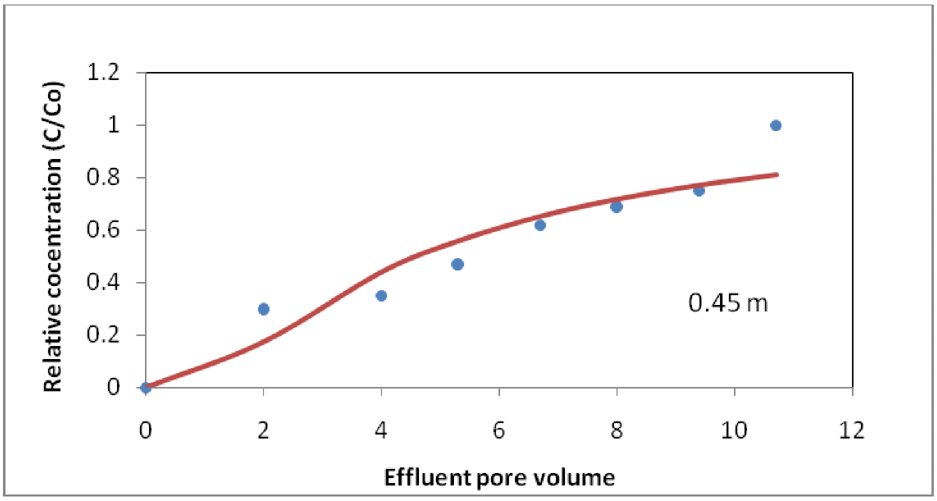
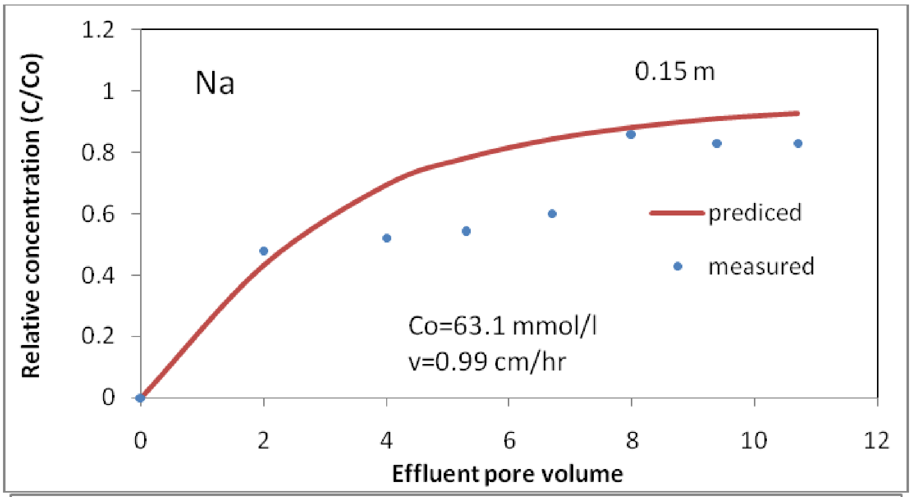
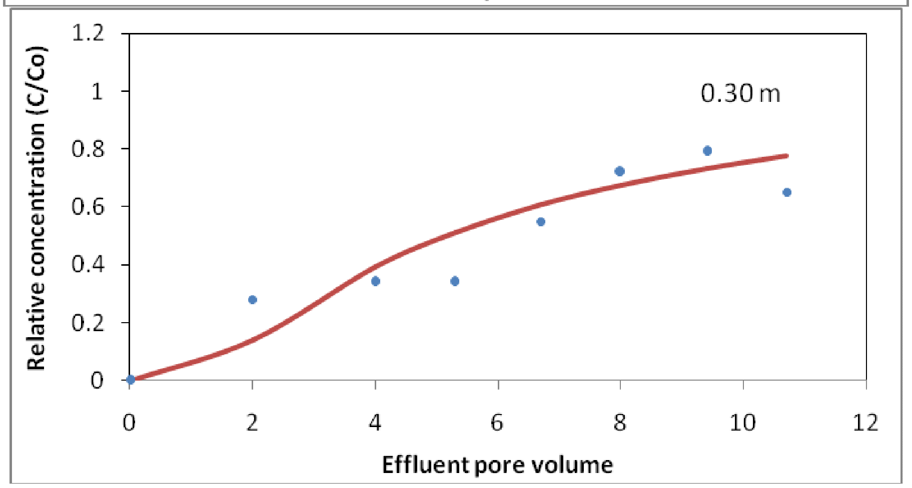


Fig. 1. Breakthrough curves of Cl in soil profile irrigated with saline water.





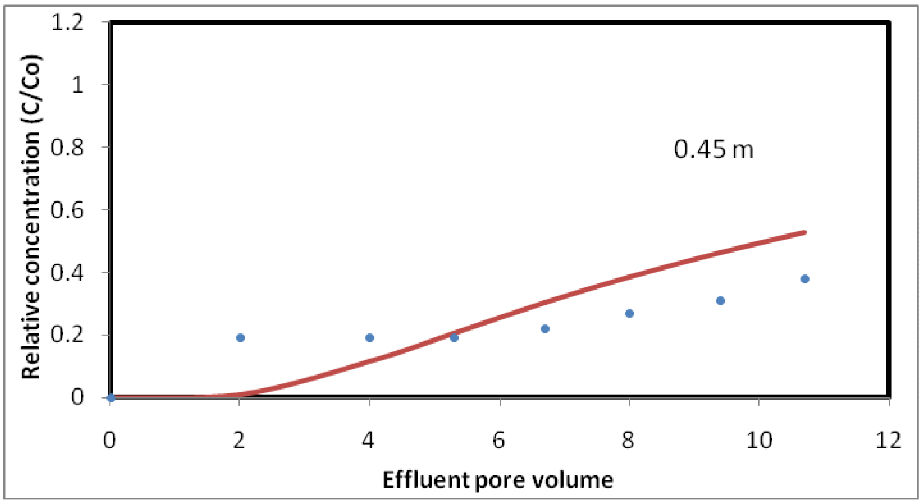


Fig.2. Breakthrough curves of Na in soil profile irrigated with saline water.

media may be the results of a wider distribution of clay particles responsible for variation in water flow and solute movement.

The model CDE provided good fit to BTC of both solutes. It was able to describe the BTC of both solutes under saline irrigation of soil. It gave correlation coefficient (r) ranged from 0.877 to 0.986 between measured and predicted C/C_O (Table 2) and least

Table 2. Transport parameters estimated by CDE model.

Soil depth M	D $cm^2 d^{-1}$	P	R	α cm	r*	RMS***
			Cl			
0.15	177.6	2.0	2.6	7.5	0.983**	0.0025
0.30	177.6	2.0	2.6	7.5	0.896**	0.0024
0.45	177.6	2.0	6.0	7.5	0.947**	0.0029
			Na			
0.15	237.6	1.5	3.8	10	0.941**	0.0031
0.30	177.6	2.0	6.7	7.5	0.933**	0.0035
0.45	120.0	3.0	11	5.1	0.877**	0.0046

***Correlation coefficient between measured and predicted relative concentration (C/Co)**
****all r-values are significant at the 0.01 level of probability**
*****Residual mean square**

residual mean square (RMS) ranged between 0.0024 to 0.0046. The results summarizes the experimental transport parameters and values for D, P and R of the Cl and Na. While D is decreasing from 237.6 to 120 cm^2/d with depth for Na, and it is 177.6 cm^2/d for Cl for three depths (Table 2). An average value of D is 177.6 and 178.4 cm^2/d for Cl and Na, respectively. The high D values for both ions indicated that the movement took place through micro pores and the macro pores had less role in transport of solutes. Lee et al. [19] reported that sandy soil columns had less D than columns repacked with finer porous material in study conducted with beach sand and soils from the Mollisol order. The soil in our study is clay (Table 1) so that means soil had large percent of small pores which caused decreasing in movement of Cl and Na and caused increasing in D values.

The relation between D values and Peclet number (P) is another important factor for recognizing the effect of P on solute mixing. Although, the effects of both diffusion and dispersion on solute mixing are difficult to be separated. Fried and Combarnous [20] suggested that when P is more than 20, the diffusion is at minimum value. Data in Table 2 showed that P ranged from 1.7 to 2.4 for Cl, and 4.5 to 5 for Na. This may be indicates that convective transport was low in comparison with dispersive transport, and that the diffusion is the dominant process in transport of Cl and Na [21]. Also, this was attributed to some of the pore water that may not effective in solute transport due to dead-end pores and more water is retained by soil with many small pores [22] which caused non equilibrium conditions that promoted of immobile water region and caused the high value of D and small P. The results also showed that P decreased with increasing depth for Na, but showed no change for Cl (Table2). This result is due to the consistent change in D. Despersivities (α=D/v) followed a similar trend to D and had high values. Although solutions of equation 1 are successful in predicting solute redistribution with depth (Figs 1 and 2 and Table 2), the deviation of predicted from observed values of Na (Fig. 2) are often attributed to macro pores flow [23], as well as to the type of ion. Na is reactive solute and its movement is affected by the characteristics of soil. In applying Eq. 1 it is usually assumed that the soil water content remains constant so that the microscopic pore water velocity (v) is fixed and all of the variability in solute transport is incorporated in D [24]. However, in our study this problem may be unwieldy because of unsteady unsaturated flow (intermittent flow) which is common enough in field soils, because v then vary.

The retardation factor, R of Cl was less than of Na. This difference in R is the result of soil characteristics and type of ion. Note that R values for Cl and Na are high and ranged from 2.6 – 6.0 and 3.8 – 11.0 for two ions, respectively. The high values for both ions indicate that these two ions had been strongly retarded. Such retardation caused the displacing of Cl and Na effluent curves to the right of one V of water (Figs 1 and 2). Under the unsaturated conditions of this experiment, the presence of solute in an immobile phase may be retards leaching because diffusion between mobile and immobile regions never reaches equilibrium. In spite of high clay content in soil (Table 1), the Cl moved slowly and anion exclusion did not affect (or had small affect) its transport, therefore its R value are large comparison with other studies. [18, 25, 26, 27, 28]. These studies indicated that R values were about 1.0. This indicates that Cl is not ideal tracer under undisturbed and unsaturated filed conditions. Also, the quantity of Cl was large due to its addition as a saline water (not tracer) which caused high retardation of soil for Cl.

The use of saline water for long time (35 days and seven portions) caused clear effect on unsaturated hydraulic conductivity $K(\theta)$ (Fig.3). The fitted exponential curves of $K(\theta)$ (r^2 = 0.477 and 0.430 before and after saline irrigation, respectively) explain a a significant decrease (at P 0.05) in magnitude of ($K\Theta$) with the use of saline water. The values ranged from 0.0019 to 0.0142 cm/hr for saline water irrigation. Also, $K(\theta)$ decreased when θ decreased from 0.3990 to 0.2650. The reasons for reduced K in the soil profile seem to be aggregate slaking, clay dispersion, and the simultaneous movement of dispersed clay to block the conducting pores. These effects have been demonstrated in many soil types varying in their mineralogy and binding agents when leached with saline water [9, 11 , 12]. The results of $K(\theta)$ confirm that the transport of solutes had occurred in micro pores which caused large retardation and diffusion of Cl and Na.

The values of EC for soil profile after leaching course were ranged from 8.34 at 0.15 m depth to 4.0 dS m^{-1} at 0.75 m and averaged of 5.29 dS m^{-1} for whole soil profile. To prevent hazard of built up of salinity in soil profile it is preferred to leach the soil with fresh water before the next using.

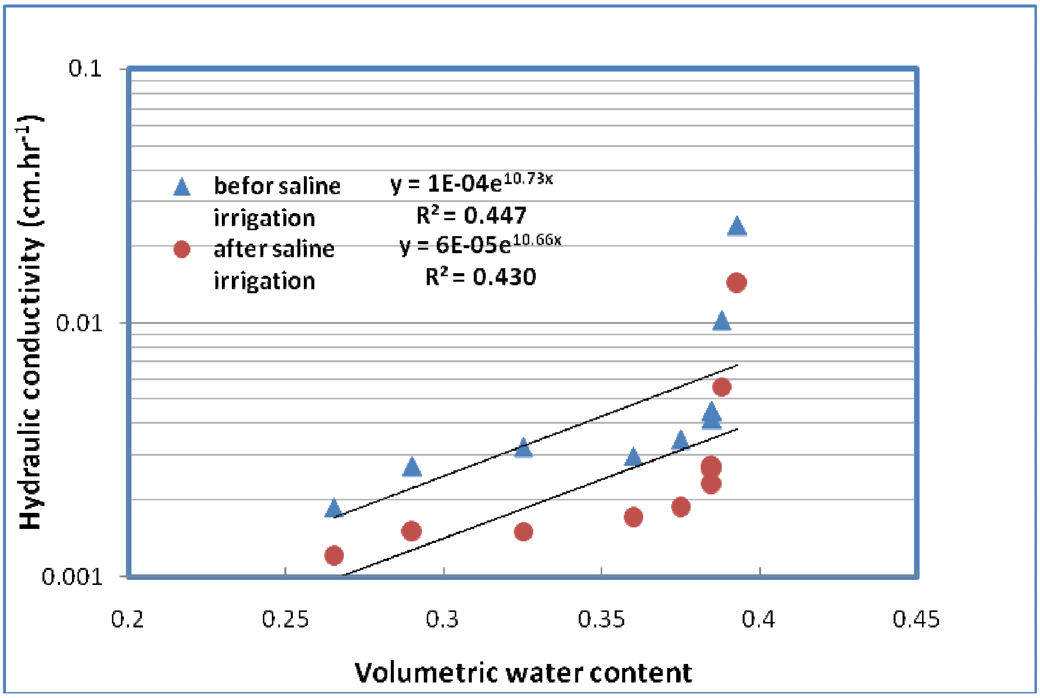


Fig.3. Effect of saline irrigation on unsaturated hydraulic conductivity of soil.

Conclusions :

Field experiments were conducted to predict the transport of Cl and Na in soil using CDE and its relation with K(Θ) under saline irrigation water. The CDE adequately described measured Cl and Na BTC. The transport behavior was differed and relatively asymmetric for both solutes. The D values were higher for Na than for Cl under unsaturated conditions and increased for Na with depth. The field K(Θ) seems to be a good measure for assessing the transport of Cl and Na in the field soil. The K(Θ) was decreased with the use of saline water. Further experimental work should concentrate on relating other parameters such as the infiltration rate to quantify solute transport in field for better saline irrigation management.

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