WATER QUALITY APPRAISAL FOR SOIL-WATER BEHAVIOR IN IRRIGATED CLAY SOIL, EGYPT

Aly S.A. Abdel-Mawgoud

Soil & Water Sci. Dept., Faculty of Agriculture
Al-Azhar University, Assiut, Egypt

ABSTRACT

Irrigation water is not always enough to congerunt the demand of cultivated area in the Northern part of Egypt. Therefore, farmers are obligated to use drainage water to irrigate their fields. The aim is to assessment the water quality for soil-water behavior in irrigated clay soil under shallow saline groundwater condition.

During irrigation interval, watertable level receaded gradually with time while groundwater salinity increased. The changing in soil salinity and sodicty realized only in topsoil (0-60 cm). They decreased by 3 and 12 % in the soil irrigated by canal water, while increased by 26 and 21 % in soil irrigated by drainage, respectively. As a result of using drainage water for irrigation, the drainable and water holding pores decreased, consequently fine capillary pores increased. The reduction in drainable and water holding pores were 29 and 24%, respectively, while fine capillary pores increased by 21%. The bulk density values increased by 17 % in the soil irrigated by drainage water. The soil moisture content at field capacity and wilting point relatively increased while the available water decreased whenever the soil irrigated by drainage water. Barley yield realized almost no change as a result of using drainage water for irrigation during both growing seasons. Sorghum yield decreased obviously as a result of using drainage water for irrigation during both seasons. The fresh weight, grain and straw yield decreased by 23, 15 and 18 %, respectively in the first season (2003). In the second season (2004) the reduction was 27, 22 and 23 % for the corresponding plant characters.

Key Words: Water quality, Clay soil, Soil-water properties, Crop production.

Introduction

Low coastal lands in the northeastern periphery of the Nile Delta are considered problem soils due to composite controversial factors: (i) They are salt affected soils, (ii) the presence of a shallow saline groundwater that constitute a permanent source of threat for soil salinization, (iii) they are heavy clay soils that make salt removal is difficult, (iv) They are assumed to lie in the zone of upward movement of water and (v) They are huge areas representing clay salt-affected soils of poor productivity. Water management in such lands needs much attention, especially for limited land and water resources with incredible growing population. Heavy clay soils posses a high inherent fertility that gives them excellent potential for agricultural production. The area lies on the tail end of the irrigation canal; irrigation water is not always enough to congruent the demand of cultivated area while plenty of drainage water is available. The farmers in these areas are obligated to use the drainage water to irrigate their fields to meet water crop requirements. For these reasons, water table depth plays an important role in soil properties and crop productivity. Unfortunately, poor internal drainage of these soils has led to salt accumulation resulting in reduce yields and/or abandonment of the land (Moukhtar and El-Hakim, 2004).

The use of unconventional waters for irrigation without proper management could produce negative effects on crop-production and soil productivity through deterioration of its quality. In this respect, several management practices are recommended to minimize the hazardous impact of using marginal-quality water in agricultural production. These include the choice of appropriate crop species, modifications in irrigation practices, soil salt leaching, special cultivation practices and water blending (Hartley, 2003). Asch *et al.* (2000) noted that a water salinity of 3.5 dS/m had a significant impact on the yield of rice with a decrease in grain yield compared to rice cultivars irrigated by river water (0.5 – 0.9 dS/m). The salinity of recycled water can impact both on the soil itself, as well as influencing the growth of the crops being irrigated. Salinity in the form of sodium can directly affect soil properties through the phenomena of swelling and dispersion (Halliwell *et al.* 2001). Alternatively water with a lower salinity can be blended with recycled water to reduce the concentration of salt. This involves leaching salt out of the soil profile by occasional irrigation of fields with a water source that has a low sodium concentration to flush accumulated salt out of the soil profile (Slavich *et al.* 2002, Surapaneni and Olsson 2002).

The application of saline irrigation water plays an active role in changing the hydro-physical properties of soils, especially pore size distribution which in turn reflects on the water movement in soil (Talha et al., 1979). Omar and Aziz (1982) found that using saline irrigation water significantly decreased macro-pores, and consequently increased soil bulk density. Curtin et al. (1994) pointed out that, the greater the SAR the greater the potential for aggregate slaking, soil swelling, and clay dispersion, and thus a reduction in hydraulic conductivity. Moustafa et al (1994) reported that drainable pores were the most affected one by water quality especially in surface layer. Khater et al. (2002) found that bulk density value tends to decrease in the soils irrigated with the low quality waters as compared to those irrigated with the Nile water. They also, noticed that the occurred reduction rate depends on the soil texture and salinity of the irrigation water, where its values tended to increase with increasing the water salinity and the finest degree of soil.

Regarding the relation between yield and salinity, Nelson and Ham (2000) noticed that there was significant negative correlation. Grain crops such as wheat have been observed to be more resistant to saline irrigation of soils with less drop in yields over a wide range of electrical conductivities compared with other more sensitive crops (Toze, 2004). Other cereals such as maize were less resistant to increases in salinity with large reductions in yield with increases in salinity (from electrical conductivity values of 2 dS/m up to 7 dS/m). Toze (2004) also noted that the soils type could influence yield with loamy soil having a greater yield than clay soils irrigated with water that had similar salinities.

The present study is an attempt to water quality assessment for soil-water behavior in irrigated clay soil under shallow saline groundwater condition.

MATERIALS AND METHODS

A field experiment was conducted at El-Serw Farm, north of El-Dakahlia Governorate as a representative area of northern lands. The area is situated at latitude of 31° 14' N and the longitude is 29° 15' E. Therefore, it lies in the coast area according to the agro-climatologically division (Rijetema and Abokhaled, 1975). The farm boundaries are El-Harrana main drain in the north, and El-Serw main drain in the south, both meeting at the drainage pumping station, El-Serw Lower station and lift the drainage water to El-Manzala Lake. The site is deep alluvium with a clay texture (clay content ranges from 45.2 and 56.9% up to 1.5 m depth). The electrical conductivity (EC) values increased with soil depth and ranged between 3.5 and 7.5 dS/m while the exchangeable sodium percentage (ESP) values ranged between 15 and 26. The hydraulic conductivity value of the top soil (40 cm) is considered low (K_{sat} 0.0733 m/day). Saline groundwater (EC = 25 – 50 dS/m; mainly sodium chloride) is the main source of soil salinization. The dominant salt either in the groundwater or in the soil is sodium chloride; magnesium ions exceed calcium. The investigated area could be classified as Aquic chromuderts, fine, montomorillonitic, thermic (Abdel-Aal, 1995).

The irrigation treatments were (i) irrigation water from El-Shoka canal and (ii) drainage water from El-Harna drain. Barley (*C.V. 89*) was grown in the winter seasons of 2002/03 and 2003/04; while sorghum (*Giza-1*) was grown in the summer seasons of 2003 and 2004. The common agricultural practices were followed as recommended in the region. Before irrigation at the main field entrance, water samples were periodically collected during both seasons from each treatment. The main chemical analyses of water samples are presented in Table (1). The soil was sampled prior to barley cultivation (October, 2002) and after sorghum (October, 2003 & 2004) from each treatment to 120 cm depth in 20 cm increments down to 60 cm and in 30 cm increments for deep layers, then air-dried and ground to pass a 2 mm screen. Water and soil chemical analyses were carried out according to Page et al. (1982). Also, undisturbed samples were collected to determine the bulk density according to Black (1982). Hydraulic conductivity (K) was measured in two layers (0-20 & 20-40 cm) by the inversed auger hole method according to Van Bears (1979). Pore size distribution was calculated from soil moisture retention curve (Stakmman, 1966) according to De-Leenheer and De-Boodt (1965).

Table (1). The chemical analyses of used water for irrigation during growing seasons

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Irrigation source	Time	EC (dS/m)	Soluble ions (meq. /L)								SAR
			CO_3	HCO_3	Cl	SO_4	Ca	Mg	Na	K	
Canal water	Nov. 2002	0.61	0.54	2.32	2.46	1.16	2.49	1.26	2.48	0.25	1.81
	May 2003	0.63	0.48	2.32	2.51	1.26	2.34	1.36	2.65	0.22	1.95
	Nov. 2003	0.66	0.53	2.35	2.55	1.46	2.45	1.42	2.79	0.23	2.01
	May 2004	0.64	0.51	2.34	2.61	1.37	2.52	1.46	2.61	0.24	1.85
	Mean	0.64	0.52	2.33	2.53	1.31	2.45	1.38	2.63	0.24	1.91
Drainage water	Nov. 2002	2.77	1.16	2.85	21.36	4.00	2.45	6.14	20.23	0.55	9.76
	May 2003	3.28	1.00	4.15	25.41	3.25	3.52	7.81	21.87	0.61	9.19
	Nov. 2003	2.65	1.22	2.80	22.04	2.67	3.65	7.15	17.29	0.64	7.44
	May 2004	3.74	0.95	4.75	26.17	6.59	3.56	8.11	26.20	0.59	10.85
	Mean	3.11	1.08	3.64	23.75	4.13	3.30	7.30	21.40	0.60	9.31

In the midway between two drains (30 m apart), auger holes (10 cm diameter and 1.50 m depths) were dug in each treatment. A piece of hard plastic tube 40 cm length and 12.5 cm diameter (slightly larger than the hole) was pressed around the hole into the soil to a depth of 20 cm, the rest length was left above the soil surface to prevent direct surface flow of irrigation water into the hole (Ritzema, 1994). At different recorded water table positions, samples were taken several times during irrigation interval from the upper groundwater layer (20 cm) for electrical conductivity measurements. Plants (barley or sorghum) in area of 12 m^2 (3x4m) were harvested from each treatment in three replicates to yield record.

RESULTS AND DISCUSSION

Groundwater Depth and Salinity Behavior

Prior to barley cultivation, as the soil was left fallow for two months, the groundwater was at 80 cm soil depth and its salinity was 50.2 dS/m. The variations in grounwater salinity at different water table positions due to irrigation water quality treatments is shown in fig.(1). In general, within an irrigation interval, water table level came close to soil surface and then receaded gradually. The watertable level went deep during the irrigation interval (15 days) to reach a depth of 72 cm for both treatments. In both treatments, groundwater salinity increased as the water table depth increased. Groundwater salinity is relatively higher in the soil irrigated by drainage water than that irrigated by canal water. Genrally, it is noticed that the irrigation water that recharge the groundwater deluited its surface especially in the soil irrigated by canal water. These data are in agreement with that obtained by El-Hakim et al (1990).

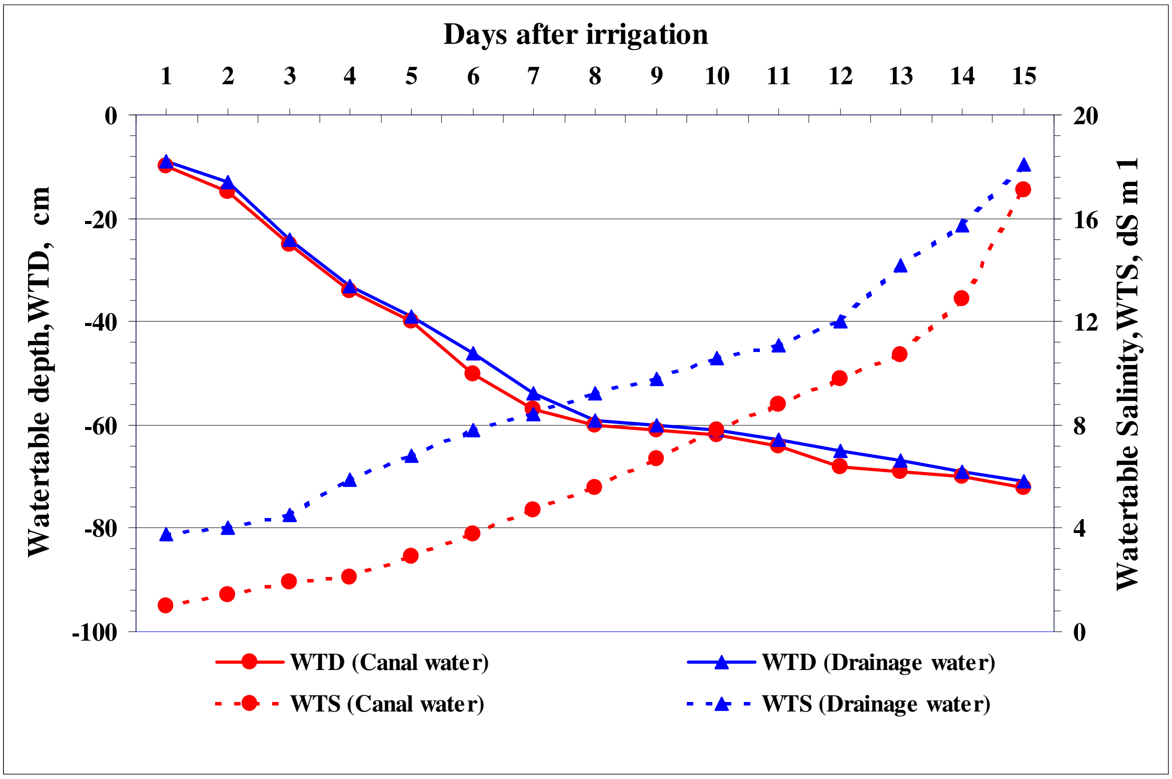

Fig. (1). Water table depth and its salinity for different irrigation water quality during an irrigation interval.

Soil Chemical Characteristics

The soil salinity results (Fig. 2) indicated that the soil profile divided into two main parts, distinguished by their EC values: (i) the upper part, from 0 to 60 cm soil depth in which the EC values were relatively low and (ii) the lower part, from 60 to 120 cm soil depth where the EC values were high. The data indicated that the changing in soil salinity was realized only in topsoil (0-60 cm). In both years, the average reduction in topsoil salinity in soil irrigated by canal water was 2.89 %. While the average increasing of salinity in topsoil irrigated by drainage water was 25.74 % in the same period. In the subsoil (60-120 cm), salinity status remained almost unchanged followed the same trend of the initial values (EC ~ 5.5-7.5 dS/m) during both years. These results pointed out that soil salinity built up is influenced not only by salt concentration of irrigation water but also by the permanent saline groundwater (Ben-Hur et al., 2001).

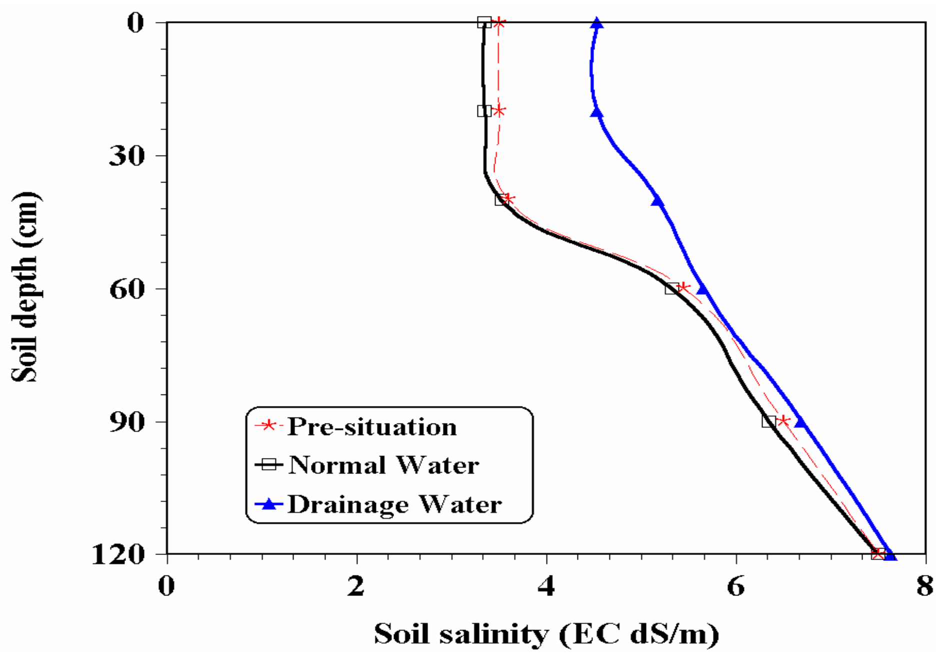

Fig. (2). Soil salinity (EC dS/m) along soil profile as affected by irrigation water quality

The data presented in Fig. (3) indicated that the ESP value tends to be higher in the soil irrigated with drainage water. Where the average reduction of ESP value in topsoil (0-60 cm) irrigated by canal water was 12.09 % in both years given an indication for soil desodification. While the increasing average of ESP value in topsoil irrigated by drainage water was 20.63 % in the same period encouraging the sodification processes. In the subsoil (60-120 cm), alkalinity status remained almost unchanged followed the same trend of the initial values (ESP ~ 24-26) during both years. The behavior of alkalinity status is confirmed by the relative high values of soluble sodium and SAR in the used low quality water. This stimulates more displacement of Ca and Mg by Na on soil colloidal complexes. Therefore, the efficient field drainage system and suitable soil amendment, as gypsum should be applied during the usage of low water quality to avoid the alkalinity hazard.

Soil Physical Characteristics

Bulk Density

Bulk density is a function of different factors, *i.e.*, particle size distribution, specific ions, total salts, soil compaction, total porosity and moisture content. The data presented in Table (2) revealed that the bulk density values increased in the soil irrigated by drainage water. The increasing average of bulk density value was 16.8 % at surface (0-20 cm) and subsurface (20-40 cm) layer in both years. This data agreed with that obtained by Omar and Aziz (1982). They found that using saline irrigation water significantly decreased macro-pores, and consequently increased soil bulk density. Kandil (1990) interpreted the above mentioned phenomenon on the basis of using low quality water enhanced the dispersion of soil particles, which is largely affected by the relatively high Na+ and SAR values. This condition increased the particle orientation, which blocked the conducted pores and, in turn increased soil bulk density and decreased the hydraulic conductivity of soil.

Pore Size Distribution

Moreover, the irrigation by drainage water plays an active role in changing the hydro-physical properties of soils; especially pore size distribution, which in turn reflects on the water movement in soil (Talha et al., 1979). It is easily noticed that as a result of using drainage water for irrigation the drainable and water holding pores decreased consequently the fine capillary pore increased (Table 2). Comparing to pre-situation, the drainable and water holding pores reduced by 28.28 and 24.27%, respectively while fine capillary pores increased by 21.26% (Fig. 4).

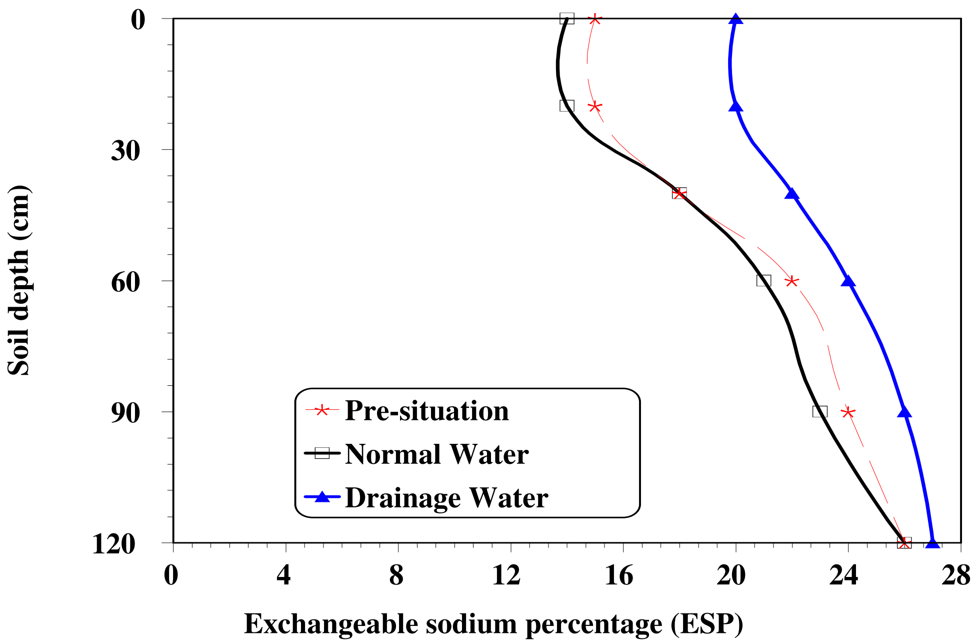

Fig. (3). Soil alkalinity (ESP) along soil profile as affected by irrigation water quality.

Table (2). Hydraulic conductivity, bulk density and pore size distribution of the studied soil in relation to irrigation water quality

Treatments	Soil depth cm	K m/day	Bulk density g/cm^3	Pore size distribution (%)				
				QDP	SDP	VDP	WHP	FCP
Pre-situation	0-20	0.0752	1.25	13.58	6.73	20.31	27.48	52.21
	20-40	0.0714	1.31	13.54	7.22	20.76	24.24	55.00
	average	**0.0733**	**------**	**13.56**	**6.98**	**20.54**	**25.86**	**53.61**
Canal water	0-20	0.0774	1.28	13.90	6.90	20.65	27.30	50.57
	20-40	0.0761	1.31	13.52	7.38	20.90	28.39	51.80
	average	**0.0768**	**------**	**13.71**	**7.14**	**20.78**	**27.85**	**51.19**
Drainage water	0-20	0.0483	1.16	10.33	5.28	15.11	20.20	64.20
	20-40	0.0456	1.23	9.62	5.10	14.23	19.46	65.82
	average	**0.0470**	**------**	**9.98**	**5.19**	**14.67**	**19.83**	**65.01**

QDP: Quickly drainable pores (> 28.8 u) SDP: Slowly drainable pores (28.8-8.62 u)
VDP: volume drainable pores (QDP+SDP) WHP: Water holding pores (8.62 - 0.19 u)
FCP: Fine capillary pores (<0.19 u)

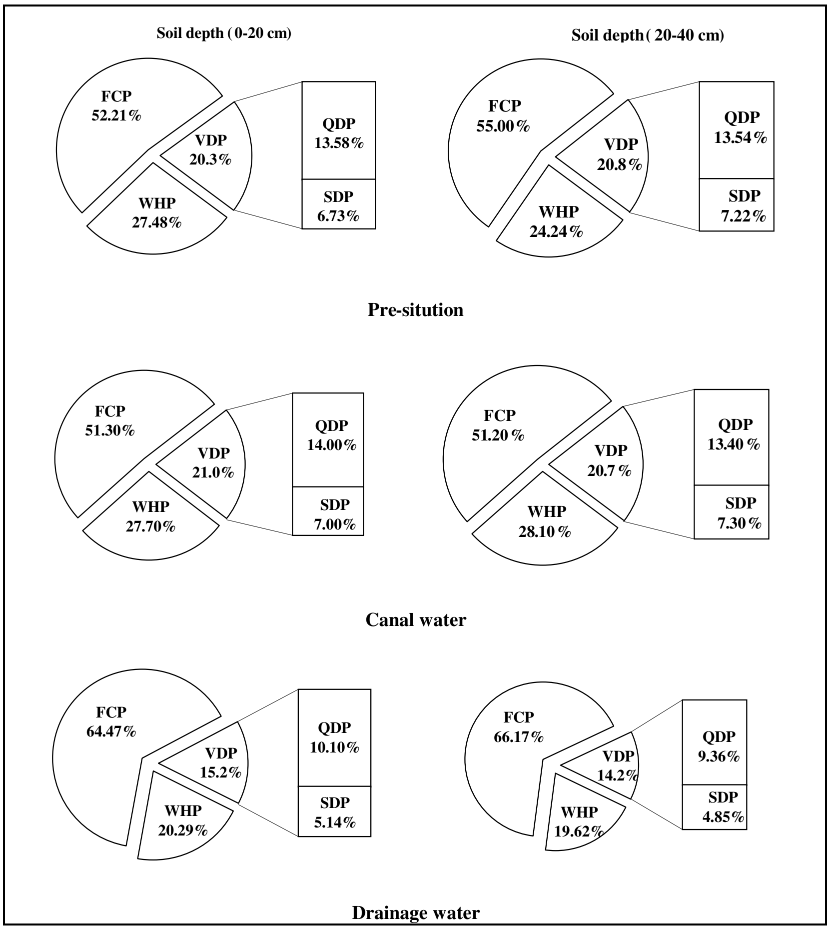

Fig. (4). Pore size distribution in surface and subsurface soil as affected by irrigation water quality treatments

Saturated Hydraulic Conductivity

One of the important phenomena to be considered in soil and water management for agriculture practice is the soil's hydraulic conductivity. The hydraulic conductivity of a soil fundamentally depends on soil porosity, pore size distribution and degree of saturation. Data of saturated hydraulic conductivity, K_{sat}, under various treatments of irrigation water quality are shown in Table (2). In general, results indicated that hydraulic conductivity values are considered low (< 0.10 m/day). The soil irrigated by canal water showed slightly higher K_{sat} values than that irrigated by drainage water. The saturated hydraulic conductivity is mainly affected by soil texture, structure, soil tillage and biological environmental activity such as roots decayed as well as numerous small cracks (Mace and Amrhein, 2001).

In general, the behavior of tested physical parameters may be illustrated as small amount of internal swelling will narrow the pores and allow for more entrapment of slaked and dispersed particles. Internal swelling reduces the number of large free-draining pores, which are mostly responsible for saturated water movement. The change in water holding capacity was a good measure of this change in pore geometry. Water flow in soil pedality depends on many factors, especially the volume of drainable pores. Thus, decreasing the values of these pores, as a result of increasing soil salinity and alkalinity, decreases the values of hydraulic conductivity (Mace & Amrhein, 2001 and Khater et al., 2002).

Soil Moisture

The data presented in Table (3) reveal that the soil moisture content was relatively affected in the soil irrigated by drainage water compared to that irrigated by canal water. The soil moisture content at field capacity and wilting point increased while the available water decreased whenever the soil irrigated by drainage water. This may be because of drainage water has high salt and consequently build up soil salinity which raised the osmotic pressure of soil solution which put on more stress on plant to adsorb water (Abdel-Hadi, 1974).

Table (3). Soil moisture content of the studied soil in relation to irrigation water quality

Treatments	Soil depth (cm)	Soil moisture content (%)		
		Field capicity	Wilting point	Available water capacity
Pre-situation	0-20	44.85	21.34	23.51
	20-40	43.15	23.12	20.03
	average	**44.00**	**22.23**	**21.77**
Canal water	0-20	44.86	22.50	22.36
	20-40	43.73	22.19	21.45
	average	44.30	22.35	21.91
Drainage water	0-20	47.47	29.33	18.14
	20-40	46.52	28.18	18.34
	average	**47.00**	**28.76**	**18.24**

Crop Yield

Data of barley plant characters (total yield, grain and straw) as affected by the irrigation water treatments during two growing seasons are presented in Table (4). The obtained results indicated that there was almost no change in total, grain and straw yield of barley as a result of using drainage water for irrigation during both growing seasons. This may be attributed to the barley is considered a tolerant crop.

Data of sorghum plant characters (fresh weight; grain and straw yield) as affected by the irrigation water treatments during two growing seasons are presented in Table (4). The obtained results indicated that there was obvious decrease in fresh weight, grain and straw yield of sorghum as a result of using drainage water for irrigation during both seasons. The reduction in sorghum plant characters was more pronounced in the second season (2004). The fresh weight, grain and straw yield decreased by 23.17, 14.97 and 18.19%, respectively in the first season (2003). In the second season (2004), the reduction was 26.57, 22.28 and 23.05% for the corresponding plant characters. This may be attributed to the sorghum is considered a sensitive crop as a result of the harmful effect of salinity stress that could be referred to highest growth inhibition under the continuous irrigation by saline water (drainage water).

Table (4). Barley and sorghum plant characters as affected by drainage water through two growing seasons

Treatment	Year	Barley plant characters (ton/fad)			Sorghum plant characters (ton/fad)		
		Total yield	Grain yield	Straw yield	Fresh weight	Grain yield	Straw yield
Canal water	2003	6.722	2.047	4.675	9.235	0.394	9.612
	2004	6.817	2.101	4.716	9.386	0.413	9.802
	Average	6.770	2.074	4.696	9.311	0.404	9.707
Drainage water	2003	6.758	2.156	4.587	7.095	0.335	7.864
	2004	6.781	2.077	4.704	6.892	0.321	7.543
	Average	6.770	2.117	4.646	6.994	0.328	7.704

It is worthy to conclude that in such soil condition, using drainage water for irrigation is quite practical although its use showed in a tendency of soil deterioration. It might be essential to conduct trials and models considering the environmental impacts to manage low water quality for sustainable agriculture.

REFERENCES

Abdel-Aal, A.N. (1995). Macro and micro morphological studies on the water table affected layers in some soils of Egypt. Ph.D. Thesis, Fac. Agric., Cairo Univ., Egypt.

Abdel-Hadi, J.A. (1974). Factors affecting available moisture to plant. M.Sc. Thesis, Fac. Agric., Cairo Univ., Egypt.

Asch F, M. Dingkuhn, K. Dörffling and K. Miezan (2000). Leaf K/Na ratio predicts salinity induced yield loss in irrigated rice. Euphytica, 113, 109-118.

Ben-Hur, M.; F.H. Li; R. Keren; I. Ravina and G. Shalit (2001). Water and salt distribution in a field irrigated with marginal water under high watertable conditions. Soil Sci. Soc. Am. J. 65: 191-198.

Black, C. A. (1982). "Methods of Soil Analysis". Soil Sci. Soc. Amer., Inc. Pub. Madison, Wisconsin, USA.

Curtin, D., H. Stephun and F. Selles (1994). Structural stability of chernozemic soils as affected by exchangeable sodium and electrolyte concentration. Can. J. Soil Sci. 74: 157-164.

De-leenher, L. and De-Boodt, (1965). "Soil Physics". Inter. Training Centre, Gent, Belgium.

El-Hakim, M.H., M.M. Moukhtar, K.H.M. Moustafa and M.B. El-Shewikh (1990). Groundwater table salinity variation during irrigation intervals in northeastern Delta. Egypt. J. Appl. Sci., 5 (6): 140-149.

Halliwell, D.J, K.M. Barlow and D.M. Nash (2001). A review of the effects of wastewater sodium on soil properties and their implications for irrigation systems. Aust. J.Soil Res. 39, 1259-1267.

Hartley, T.W. (2003). Water Reuse: Understanding public perception and articipation. Water Environment Research Foundation, Alexandria, Virginia.

Kandil, N.F. (1990). Effect of using drainage water on soil chemical, physical and hydrological properties on some soil of Egypt. Ph.D. Thesis, Fac. Agric., Cairo Univ., Egypt.

Khater, E.A., T.S. Abdel Aal and F.R. Farrag (2002). Potential effects of low quality water for irrigation in El-Fayoum Governorate, Egypt. Egypt. J. Soil Sci., 42, (1): 161-183.

Mace, J.E. and C. Amrhein (2001). Leaching and reclamation of a soil irrigated with moderate SAR waters. Soil Sci. Soc. Am. J. 65: 199-204.

Moukhtar, M.M., M.H. El-Hakim (2004). Drainage, moling and subsoiling in heavy clay soil under saline watertable, Egypt. First African Regional Conference on Drainage (ARCOD): challenges and opportunities for enhancing quality of life. December 6-9, 2004, Cairo, Egypt.

Moustafa, K.H.M., A.S. Abdel-Mawgoud, M.M. Moukhtar and Sh, Sadek.(1994). Soil pores system and hydraulic conductivity as affected by amelioration technique. Egypt. J. Appl. Sci. 9:301-310.

Nelson, P.N. and G.J. Ham (2000). Exploring the response of sugar cane to sodic and saline conditions through natural variation in the field. F.C. Res., 2000, 66: 3, 245-255.

Omar, M.S. and M.A. Aziz (1982). The use of saline irrigation water, its effect on soil properties and plant growth. I- Soil aggregation. Egypt. J. Soil Sci., 22, 11.

Page, A.I., R.H. Miller and D.R. Keeney (1982). "Methods of soil analysis". Part 2: Chemical and microbiological properties, 2nd ed Amer. Soc. of Agron., Madison, Wisconson, USA.

Ritzema, H.P. (1994). "Drainage principles and application". ILRI Publication 16, Wagengingen, The Netherlands.

Rijetema, P.E. and A. Abu-Khaled (1975). "Research on crop water use, salt-affected soils and drainage in The Arab Republic of Egypt". Published by FAO, Cairo.

Slavich, P.G, G.H. Petterson and D.Griffith (2002). Effects of irrigation water salinity and sodicity on infiltration and Lucerne growth over a shallow watertable. Aust. J. of Experimental Agric. 42, 281-290.

Stakmman, W. P. (1966). The use of pressure membrane apparatus to determine soil moisture content. Inst. for Land and Water Management Res. Note No. 159.

Surapaneni, A and K.A.Olsson (2002). Sodification under conjunctive water use in the Shepparton Irrigation Region of northern Victoria: a review. Aust. J. Soil Res. 42, 249-263.

Talha, M., A.C. Abdel-samiey and M.S. Omer (1979). Factors affect in water movement in alluvial soils of Egypt. Egypt. J. Soil Sci., 18, 2.

Toze, S. (2004). Reuse of effluent water – benefits and risks. Proceedings of the 4th International Crop Science Congress, Brisbane, Australia, 26 Sep. – 1 Oct. 2004.

Van Bears, W.F. J. (1979). The auger hole method. A field measurement of the hydraulic conductivity of soil below the water table. Rev. Ed. ILRI Bull., Wageningen, The Netherlands.