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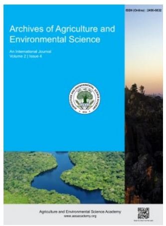

ORIGINAL RESEARCH ARTICLE

CrossMark

Interactive effects of soil salinity and water table depth on soil properties and sorghum (*Sorghum bicolor* L. Moench) production

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ABSTRACT

Soil salinity and water table are the most prevalent and widespread problems limiting crop productivity in irrigated agriculture. Our experiment aims to evaluate the effect of soil salinity and water table on some soil properties, growth, and yield of sorghum (variety Giza 15) grown along two successive seasons. Nine different sites were chosen, representing three levels of soil salinity (i.e. ECe < 4, 4-8 and 8-16 dS m^{-1}). For each salinity level three water table were selected (i.e. shallow ≈ 55 cm, medium ≈ 80 cm and deep ≈ 120 cm). Results revealed that there are main considerable effects of salinity and water table on some soil properties. Increasing of salinity caused significant decreases in plant growth, weight of 1000 grains (g), protein content% and seed yield (t/ha) which decreased by 36.98%, 32.27%, 20.45%, 29.95 % and 57.46% respectively, when salinity increased from S_1 to S_3. On the other hand, decreasing of water table lead to improvement in all mentioned soil properties and plant growth. The results indicated that need to maintain low or moderate salinity and deep water table, which is essential for producing high sorghum grain yield with satisfactory quality.

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INTRODUCTION

An extensive area of land in the world, particularly in arid regions, have gone out of cultivation due to accumulation, build -up of salts, the ground water table rises and fluctuation depth, poor water management, inadequate drainage, precipitation, soil characteristics, vegetation communities, climatic conditions and dissolved salts (FAO, 2005). Such factors are considered to be effective factors causing and confirming soil salinization and consequently accumulation of salts in soils which lead to unfavorable soil water-air-plant relationships and decrease crop productivity**.** Countries such as Australia, Egypt, India, Pakistan, and the United States, all of which have substantial salinity and drainage problems affecting between 15 and 36% of their irrigated lands, are devoting substantial resources toward this problem (Schwabe *et al*., 2006). Approximately one-third of the irrigated land worldwide that provides 40% of the global food production is affected by salinization (United Nations, 2012). Salinity is a major abiotic stress, reducing the growth and yield of a wide range of crops worldwide (Ashraf *et al*., 2008; Hakim *et al*., 2014; Selamat, 2014; Seday *et al*., 2014; Abd El-Mageed and Semida, 2015 and 2016a). Salt stress decreases the osmotic potential of soil water, reducing its availability for plants (Asik *et al*., 2009; Rady *et al*., 2015). It also reduces the availability of essential nutrients for plants due to a poor structure of saline soils (Osman and Rady, 2012, Semida *et al*., 2014 and 2016). Plant morphological and physiological processes are negatively affected by salt stress through osmotic and ionic stress, and different biochemical responses in plants (Abd El-Mageed *et al*., 2016a and 2016b; Semida *et al*., 2017).

Sorghum (*Sorghum bicolor* L. Moench) is an important annual cereal crop grown for both grain and palatable green forage production (Kumar and Chopra, 2013). It comes at the fifth most important cereal crop in the world after wheat, maize, rice, and barley in terms of importance and production. The most important global countries for grain sorghum production are Nigeria, USA, and India, while Egypt has ranked fifteen in this respect (FAO, 2012). It is grown throughout the arid and semi-arid tropical regions of the world. It represents the major food for low-income people in Africa, South Asia, and Central America. Grain sorghum has huge potential for wider use for human consumption, animal feeds, poultry nutrition, fuel, building materials and for some industrial products (Dogget, 1998; Alagarswamy and Chandra, 1998; Taylor *et al.*, 2006). Sorghum can be grown as important dual purpose crop for grain and forage yields in many arid and semi-arid regions of the world, due to its advantages over. These advantages include high water use efficiency and could be a good alternative to maize under limited water in the semi-arid conditions (Marsalis *et al.*, 2010). It is also of low consumption of nitrogen (Olanite *et al.*, 2010); adapted to hot and dry environments (Yan *et al.*, 2012) and high salt tolerance (Lagudah and Schachtman, 2002); Yan *et al.*, 2012; Saberi, 2013). Stable nutritive and several harvests offer sorghum as alternative silage crops compared to corn (Qu *et al.*, 2014). These features are very important particularly with increased cost of unit value of water and chemical fertilizers. In Egypt, grain sorghum is the fourth cereal crop, after wheat, maize, and rice, especially after the introduction of early maturing and high yielding hybrids. Fast re-growth after cutting makes sorghum a reliable and profitable summer and fall crop for food and feed productions. Thus, it is greatly preferred by most farmers, where it widely cultivated in middle and Upper Egypt during summer and autumn in the area reached 140.000 ha in 2010 season. The crop is adapted to the arid and semi-arid tropics and dry-temperate areas of the world (Kidambi *et al.*, 1990; Blum, 2004). Sorghum is better suited to biochemically and physiologically withstands high temperatures and low moisture conditions than other cereals (Farré and Faci, 2006). Also, it is one of the most important cereal crops in Upper Egypt and it is a major cereal crop in southern Egypt (area 150000 ha: production 800 thousand tons). Effect of soil salinity on sorghum grain yield has been assessed all around the world and it is well accepted that if soil salinity surpasses a certain threshold level, crop growth, yields and quality are reduced (Maas and Hoffman, 1977; Maas, 1993; Netondo *et al.*, 2004). In African countries with a similar agro-ecological climate as Fayoum region, Egypt, long-term assessments showed a high influence of degraded soils on sorghum grain yields in countries such as Burkina Faso (0.5–0.8 t ha^{-1} with yields increasing over the years), Niger (0.3–0.6 t ha^{-1} with declining yields), Sudan (0.4–0.9 t ha^{-1}; tendency declining) and Tanzania (0.9–1.9 t ha^{-1}) FAO 1994). Yet, little is known about the combined effect of water table depth and salinity on sorghum production. Therefore, studying the relationships and effects of soil salinity and water table depth levels on soil properties are of utmost importance for managing salt-affected soils. Soil salinity and ground water table and their effects are likely to introduce a number of problems in soils which lead to decrease crop productivity. The objectives considered in this study were: To establish the associated and close relationship between both soil salinity levels and ground water table depth with some soil physical properties and to determine the effects of different soil salinity levels and ground water table depth on plant growth and yield of sorghum (*Sorghum bicolor* L. Moench).

MATERIALS AND METHODS

Locations and installation

The field work was conducted at nine different sites, selected from Fayoum region, Egypt (Figure 1). Representing three levels of salinity (i.e. EC_e< 4.0, 4-8 and 8-16 dS m^{-1}) namely S_1 and S_2. For each salinity level, three groundwater table levels were selected (i.e. shallow water table »55 cm, medium water table » 80 cm and deep water table » 120 cm, namely W_1, W_2 and W_3, respectively. The depth of water table varies from 50 cm to 140 cm from the surface. Thirty-six piezometers were installed on almost straight transects to measure periodically the fluctuation of the groundwater level all over the year.

Crop management

Sorghum (*Sorghum vulgaris L.* variety Giza15) seeds were planted manually in the 20th and 25th May in 1st and 2nd season, respectively in hills 20 cm apart from each other. The distance between rows was 60 cm. Harvesting of plants was after 120 days from planting for each season. Other cultural management practices for the grown sorghum have been conducted as the same and typically carried out under such conditions following the recommendations of the Egyptian Ministry of Agriculture as being mentioned before. Also, it is worthy to mention that the grown crop at each site (in each season) was received fertilizers i.e., 375 kg ha^{-1}, superphosphate (15.5% P_2O_5) was added prior to cultivation, 500 kg ha^{-1}ammonium nitrate (33.3%N) was added in two doses: 250 was added at the first irrigation date and

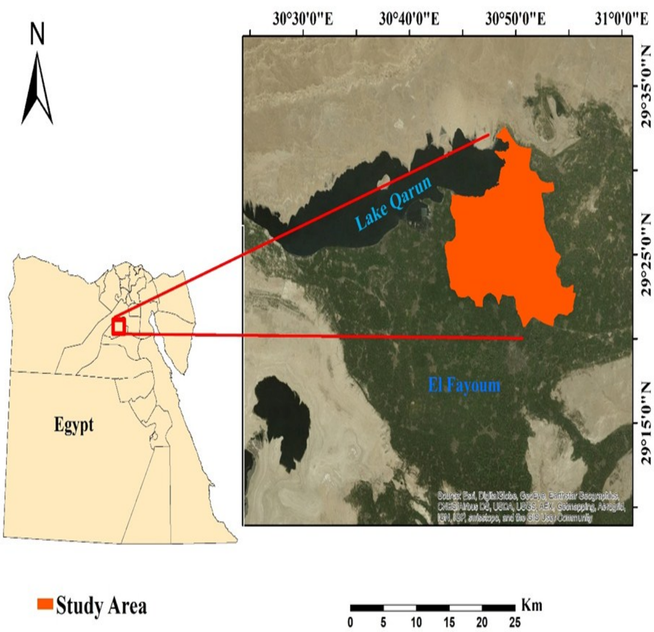


Figure 1. *Map of study area showing sampling sites.*

250 kg was added at the second irrigation date, and potassium sulfate (52% K_2O), at the rate of 125 kg ha^{-1}.

Collection of soil sample and analysis

From each site, soil samples were collected according to the water table levels at 0 – 20 cm and 20- 40 cm in the sites (1and 4) and at 0-20 cm, 20-40 cm and 40-60 cm in other sites after harvest at the end of the season to determine the physical and the chemical properties of the soil. Disturbed and undisturbed soil samples were collected from the mentioned depths before planting and after sorghum crop harvesting. Measurements and calculations of some soil properties have been done on the collected soil samples, as follows:

Determination of soil physical properties: Measurements and calculations of soil physical properties have been conducted according to the procedures described by Klute (1986)

Structure factor (SF): The structure factor was determined after Klute (1986) and calculated as follows:

$$SF = \frac{\text{Clay \% (with dispersion)} - \text{clay \%(without dispersion)}}{\text{caly \% (with dispersion)}}$$

Pore size distribution: The pore size distribution was calculated for soil sample according to (Deleehneer and De Boodt, 1965) using the following equation:

$$P = \frac{2 \propto \text{Cos}\theta}{\text{r}}$$

Where: r = the pore radius (cm), α = the surface tension (dyne / cm), q = the contact angle of soil/water, and *P* = the applied pressure (P_a)

Thus, the size range of pores can be calculated by the volume of water removed between consecutive steps, as it will be equal to the soil pore volume drained, pore size distribution was then classified according to their diameters into. Quickly drainable pores, QDP (> 30.0m), Slowly drainable pores, SDP (30.0-9.0m), Volume drainable pores, VDP (> 9.0 m), Water holding pores, WHP (9.0-0.2 –m), Fine capillary pores, FCP (< 0.2 m), Useful pores (30-0.2 m), Capillary pores, CP (<9.0m).

Hydraulic conductivity: The saturated hydraulic conductivity (K_{sat}.) was measured in the laboratory using the metal cores on the basis of Darcy's law (Klute, 1986):

$$q = K\frac{dH}{dz}$$

Where:

q = the water flux density, cm. sec^{-1}, dH/dz. = the hydraulic potential gradient, cm of water cm sec^{-1} and K= the hydraulic conductivity coefficient of soil, cm sec^{-1}.

Monitoring of water table depth: Measurements of water table depth (WTD, cm) were conducted using the observation pizometers by means of graduated tape during the growth season crop (Morrison, 1983).

Determination and calculation of soil chemical properties: The measurements and calculations of soil chemical properties were conducted using the techniques described by Page *et al.* (1982).

Plant growth parameters: Measurements of plant parameters that are listed below were carried out during the vegetative stages of the grown development and after harvesting of sorghum crop:

Plant height (cm): The plant height was measured from the cotyledonary at the head (panicle), b) Dry 1000 grain-weight (g), c) Length of panicle (cm). d) Dry grain yield (t/ha), determined from the seed yield of the whole plot of each treatment and f) Grains protein content %. The grain protein content was determined by estimating the total nitrogen percentage calorimetrically by using the Orange dye method, according to the method described by Hafez and Hikkelsen (1981). As follows:

The dye solution was prepared by dissolving 1g Orange G dye (87% assay) in one liter of distilled water followed by the addition of 21gcitric acid (which acts as a buffer to maintain proper pH) and 2.5 ml thymol 10% in alcohol (as a microbial inhibitor). Powdered dry material (0.2g) plus 20 ml of dye solution was placed in a test tube and shocked monitoring key for 15 minutes, thereafter it was filtered after filtration, the solution was diluted 100 times with distilled water and absorbance was measured at wave length of 482 nm by a photometer (Spectronic 20 Bauch and Lomb).

The calculation was as follows:

$$Dye\ absorbed\left(\frac{g}{100g}\right) = \frac{(a-b)}{a} \times \frac{cfv}{w} \times 100$$

Where: a =absorbance at 482 nm of dye reagent solution diluted 100 times, b = absorbance at 482 nm of dye solution after shaking with the plant, material, filtrated and diluted 100 times, c = concentration of dye reagent 1g/100 ml, f = purity factor of dye reagent solution i.e. 96/100. v = volume of dye reagent solution used, w = weight of dye plant material in grams (0.2g).

Statistical analysis

Statistical analysis was performed through the GLM procedure of Gen STAT (version 11) (VSN International Ltd, Oxford, UK). Least significant difference (LSD) at 5% probability ($P \leq 0.05$) level was used as mean separation test.

RESULTS AND DISCUSSION

Soil properties in relation to soil salinity levels and water tale depth

Soil bulk density: Dry weight of unit volume of soil inclusive of pore spaces is called bulk density. Figure (2) shows the effect of the interaction of the soil salinity and water table depth on bulk density of the studied soil. The variations in bulk density values with increasing soil salinity levels were significant (Figure 2). Islam *et al.* (2014) found most soils had high bulk density in coastal agricultural soil and influences by soil physical (texture, porosity) and chemical (organic matter, constituent minerals) properties. Such findings may be attributed to the fact that soil bulk density is the ratio of the mass dry solids to the bulk volume of the soil and it is closely related to the proportions of solid and pore- space in a soil. Generally, the values of soil bulk density ranged from 1.47 to 1.76 g cm^{-3}. It was also noticed that the increasing of soil salinity resulted in lowering the bulk density values because of their pronounced hydrations. Such findings fall in line with those of Jury *et al.* (1991) and disagree with Muhammad *et al.* (2002) they found that bulk density values increases with increase in salt levels.

Water movement: Saturated hydraulic conductivity values (K_{sat} cm hr^{-1}) for the studied sites were shown in Figure (3). Values of saturated hydraulic conductivity decreased with depth increments for all studied soil samples. These findings may be attributed to the association with the increase in the soil bulk density and the reduction in the total porosity, in addition to compaction of subsurface layers which resulted in reduction and discontinuity in large pores and consequently linked to the reduction of the hydraulic conductivity. The EC_e values are very high which prevent free swelling of colloids by reducing the equality of cation and anion concentration at their medial plane, as well as, the osmotic and hydrostatic pressure differences. By the presentation of free swelling, the soil pores remain open and the hydraulic conductivity values are encouraged. The values of saturated hydraulic conductivity slightly increased with decreasing water table depth (Figure 3) due to the improvement of soil structure in deep water table depth than that high water table depth. The obtained trends fall in line with those of Jury *et al*. (1991**)** who found significant increases in K_{sat} values as a result of increasing soil salinity levels, particularly, soils with higher in concentrated solutions and low Na^+/Ca^{++} ratio. The variation of hydraulic conductivity values (cm hr^{-1}) with increasing soil salinity, water table depth, and their interactions are illustrated in Figures (3). In this concern Singh *et al.* (2011) reported that the presence of Ca^{++} and Mg^{++} ion in equal percentage with the sodium ion in the soil reduces the acute influence of Na^+ on the hydraulic conductivity value. The values of K_{sat} increased with increasing soil salinity by 63.31 and 84.45 % at shallow water table depth, 117.37 and 67.37 % at medium water table depth and 25.94 and 87.22 % at deep water table depth when soil salinity levels increased from S_1 to S_2 or S_3, respectively.

Soil structure factor: Soil structure factor values of the studied soils are shown in Figure (4). Values of soil structure factor (%) decreased with depth increments for all studied soil samples. Also, increasing soil salinity levels resulted in decreased values of soil structure factor by13.48 and 23.96 % at shallow table depth, 0.14 and 23.97 %at medium water depth and 1.98 and 24.42 % at deep water table depth when soil salinity levels increased from S_1 to S_2 or S_3, respectively. These findings may be attributed to soil salinity levels affect the aggregation formation and aggregation index, particularly when increasing both soluble and exchangeable sodium. Also, the values of soil structure factor increased with increasing water table depth due to the improvement in soil aeration and biological activity, (Figure 4). Such findings and statements are in confirmation with those reported by Jury *et al.* (1991).

Pore size distribution: The distribution of pore sizes is presented in Figures 5 and 6. In this respect, moisture absorptions curves were determined from undisturbed soil samples and were used to calculate the size – distribution. The diameter of pore- spaces were calculated and classified according to Deleehneer and DeBoodt (1965). Based on the diameter at the narrowest point, pores may be classified into macropores and micropores. Pore - size distribution is the most meaning term related to soil productivity because, for example, the macropores are mostly the inter-aggregate cavities which serve as the principle aneanves for the infiltration and drainage of water and for aeration. While the micropores are the inter-aggregate capillaries responsible for the retention of water and solutes. However, the demarcation is seldom truly district, and separation between macropores (>30 μ) and micropores (<0.2 μ) is often arbitrary. the results revealed that increasing the EC_e values under the current investigation conditions leads to significant decreases in the volume drainable pores (>9 μ) by 3.53 and 11.50 %, at shallow water table depth and 4.67 and 0.46 % at medium water table depth and 0.34 and 2.09 % at deep water table depth when soil salinity levels increased from S_1 to S_2 or S_3 levels, respectively. The values of useful pores (30u-0.2 μ) decreased by zero and 20.06 %, at shallow water table depth and zero and 23.03 % at medium water table depth and 15.87 and 32.67 % at deep water table depth when soil salinity levels increased from S_1 to S_2 or S_3 levels, respectively. The values of quickly drainable pores (> 30 μ) decreased by 14.19 and 21.41 at shallow water table depth and 8.22 and 8.78 % at medium water table depth and 6.11 and 21.30 % at deep water table depth when soil salinity levels increased from S_1 to S_2 or S_3 levels, respectively. As increasing the soil salinity levels the values of water holding pores (9-0.2 μ)decreased by 9.57 and 36.50 % at shallow water table depth and 6.64 and 41.52 % at medium water table depth and 24.48 and 46.43 % at deep water table depth when soil salinity levels increased from S_1 to S_2 or S_3 levels, respectively. However, in all sites (1-9) all pores of different diameters have been slightly increased in layer (20-40 cm depth), while they decreased at the layer (40-60, cm depth). Also increasing soil salinity levels decreased capillary pores, Muhammad *et al.* (2002). However, the results in Figure (5) showed the maximum values of total porosity at the medium soil salinity levels (i.e., ECe 4-8 dS m^{-1}) in all sites. As general, pore size distribution, shape and geometry are reduced with depth increments and with increasing EC_e values of the studied soil at all locations with different sites. Such reduction may be due to recharge and repacking of soil particles closer together, in addition to the reorientation of soil pores. These findings are in agreement with those of Prathapar and Mayer (1993).

Water table depth of the studied soils: The weighted average of ground water table depth (WTD) has been calculated from the ground water monitoring using the observation pizometers by means of graduated tape during the two successive seasons. (Morrison, 1983).The obtained results are shown in Table (2). The used ground water table depths were detected to be ≤ 55 cm, 60-80 cm and ≥120cm. Therefore, it can be mentioned that the shallow water table depth has been considered when it was < 55 cm; the medium was ranged from 68 to 85 cm, while the deep water table depth was taken as > 120 cm for two successive seasons. It can be revealed from Figure (7). The fluctuations of water table depth for shallow level are high at the soil profiles that had low salinity levels, while the fluctuations were nearly constant at the soil profiles that had medium or high salinity levels.

The chemical composition of the studied water table depth: The ground water samples that collected from some sites of the studies soils to be used in this experiment were (i.e., (≈ 55, 80 and 120 cm) subjected to chemical determination, i.e., pH, EC, soluble cations and soluble anions. According to the data in Table (3), the EC values were increased from 3.05 dS m^{-1} at normal soil to 8.24 dS m^{-1} at high saline soil profiles for shallow water table depth. On the other hand, the EC values were increased from 2.90 dS m^{-1} at normal soils to 6.49 dS m^{-1} at high saline soils for deep water table depth. It has the dominant cation Na^{+} followed by Mg^{++} and/or Ca^{++}, particularly, in shallower water table depth, in addition, the dominance of the anion Cl^{-} followed by SO_4^{-} has been observed. Thus, as it appeared in Table (3), salts content of the shallow ground water table were the highest which shows its reflection upon the intact soils. Figure 8 shows the relationship between salinity of water table and the salinity of soil layers. Similarly, some soluble cations and anions contents in the ground water reflected on the studied soils.

Soil salinity and water table depths effects on some plant characters of the sorghum crop: The interaction effect of both water table depth and soil salinity levels on some plant characters and grain yield are shown in Tables 4 and 5. Water tables depths (55and 80 cm) reduce both growth and grain yield of sorghum, while the depth of 120 cm gave the highest yield even in saline soils (EC_e 4- 8.0 dS m^{-1}). The more drastic and severe reduction in sorghum growth and yield was noticed in the locations where water table depths and soil salinity (EC_e) contents were 55 cm and > 8.0 dS m^{-1}, respectively. Therefore, it can be stated that, as the ground water depth, salt content, its fluctuations and capillary rise potential of the soil are actively causing salinity hazards of the soils, the more pronounced effect was associated with the shallow water table depth compared to the deep water table depth and with the high saline soils compared to normal soils. Based on the obtained results of the current study, it can be stated that the water table depth plays a vital role in the formation of soil salinity hazard, especially under Fayoum conditions (arid region), as it frequently contains amounts of dissolved salts which may be sufficient to cause salinity of the whole soil profile through capillary rises. The main effect of water table depth in soil salinization depends on its depth, fluctuations and dissolved salts, in addition to the evaporation from the soil surface (Morrison, 1983 and Selassie *et al.*, 1992). Additionally, the water table depths, seasonal variations, salt concentrations, and fluctuations have mutual effects with physical, chemical and biological properties of soils, as well as, with growth, yield, and quality of the grown crop. This current study concerns with sorghum growth and its yield quality under Fayoum conditions. Thus, before discussing the obtained results, it is important to note that major factors controlling crop quality are fixed genetically, However, some environmental factors such as soil salinity, water table depth, nutrition, water and other factors are able to influence this crop quality. Data presented in Tables 4 and 5 showed the effects of the interactions of soil salinity levels and ground water table depth on some plant characters of the sorghum crop. As can be seen in those Tables, the highest values of the plant height cm), panicle length (cm), weight of 1000 grain (g), protein content % and grain yield (t ha^{-1}) were 284.23, 22.85, 42.48, 11.36 and 6.33 respectively in first season and 282.76, 22.93, 43.30, 11.88 and 6.16 in the second season. The highest yield was obtained from normal soils (S_1) with deep water table depth (W_3). On the other hand, the low values of sorghum plant height (cm), panicle length (cm), weight of 1000 grain (g), protein content % and grain yield (t ha^{-1}) are 148.05, 12.25, 30.60, 6.30 and 1.79, respectively in 1^{st}season and it were 149.75, 12.40, 29.63, 6.89 and 1.54, respectively in 2^{nd} season. The low values were presented in highly saline soils (EC_e 8-16 dS m^{-1}) (S_3) with shallow water table depth (55 cm, W_1). The results indicated that there exist significant differences among the quality measurements as a result of variation in water table depth and EC_e values in two studied sites. The combined effects of shallow water table depth (i.e., 55 cm) and EC_e values (> 8.0 dS m^{-1}) were found to severely reduce the grain quality measurements (Table 4). The more pronounced effect was indicated at the sites where water table depth is shallow and soil salinity contents are highly (> 8.0 dS m^{-1}). Deep water depth with low salinities levels leads to significantly increase all sorghum quality measurements (Tables 4 and 5).These results may be attributed to the fact that exposure to salinity during growth induces stunted growth and structural changes at various levels of the organization. Also, increasing the salt osmotic concentration in root rhizosphere at the saline and highly saline soils led to decreasing absorb and availability of water and nutrients. In addition to either toxic effects of Na and /or Cl accumulation or the osmotic potential of the soil solution particularly at highly saline soils (S_3) with shallow water table depth (W_1). Multiple regression analysis was applied to determine the partial quantitative effect of each soil. The decrement in grain yield/hectare by increasing salt concentration may be attributed mainly to the harmful effect of salinity on growth of sorghum plants as previously noticed from Tables (4 and 5). Similar results were obtained by Munns *et al.* (2002), Thimmaiah (2002), Ibrahim (2004), Netondo *et al.* (2004), Parlak and Parlak (2006), Almodares *et al.* (2008) on sorghum and Rady *et al.* (2016) on cotton. They concluded that increasing soil salinity decreased significantly sorghum yield and most of its components. The relations between plant parameters (y) and soil salinity levels (x_1) and water table depths (x_2) for two successive were shown in Table 5. It can be noticed from Table 4 everyone dS m^{-1} increase in soil salinity or 10 cm decrease in water table depth lead to decrease or increase the values of grain yield (t ha^{-1}) of sorghum crop by 0.809 and 0.843 at first season and by 0.889 and 0.674, respectively. Our results, showed that yield (t ha^{-1}), protein content%, weight of 1000 grains (g) can be linked with maturity. Sorghum is grown in soil with a low level of soil salinity (EC_e < 4.dS m^{-1}) and deep water table depth (> 120 cm) grow rapidly all season and are mature at harvesting time. This results in higher yields, greater protein content % in grains and higher weight of 1000 grain than for sorghum that doesn't mature so early. Therefore, the highest and best optimum sorghum grain yield and quality were obtained at the water table depth of 120 cm compared to the depths (55 and 80 cm), in addition to low soil salinity (EC_e) which produces maximum sorghum grain yield with higher quality.

Table 1. Physico-chemical properties of different study sites.

Site No.	pH (soil ext.1:2.5)	ECe dS m^{-1}	$CaCO_3$ %	O.M* %	Particle size distribution Sand %	Silt %	Clay %	Texture class
1	7.97	3.52	5.08	1.01	79.25	10.00	10.75	loamy sand
2	7.86	3.41	4.39	0.82	77.54	11.30	11.16	sandy loam
3	8.06	2.94	3.59	0.79	81.14	7.96	10.90	loamy sand
4	7.79	6.32	3.73	0.86	79.09	11.06	9.85	loamy sand
5	7.81	7.29	4.83	0.66	75.6	13.10	11.30	sandy loam
6	7.90	6.57	3.33	0.85	77.53	10.10	12.37	loamy sand
7	7.78	14.75	3.99	1.08	78.53	9.12	12.35	loamy sand
8	7.90	11.69	3.33	0.62	78.14	9.21	12.65	loamy sand
9	7.94	11.17	5.42	0.80	81.26	8.29	10.45	loamy sand

O.M* is the organic matter content %

Table 2. Weighted average of water table depth (cm) for sorghum crop in the two successive seasons (as averages).

Soil salinity dS m^{-1}	Water table depth, cm Shallow	Medium	Deep	Shallow	Medium	Deep
	I[st] season			2[nd] season		
S1 (<4) dS m^{-1}	48.13	68.31	140.3	49.75	72.35	136.40
S2 (4-8) dS m^{-1}	54.50	84.24	115.51	52.31	82.62	123.15
S3 (8-16) dS m^{-1}	49.70	79.34	118.2	51.51	81.13	112.30

Table 3. Chemical characteristics of water table depths samples of the studied soil profiles.

Site No.	pH	EC dS m^{-1}	Soluble cations, (Meq/L.) Ca^{++}	Mg^{++}	Na^{+}	K^{+}	Soluble anions, (Meq/L.) $CO_3^{=}$	HCO_3^{-}	Cl^{-}	$SO_4^{=}$	SAR
1	8.39	3.05	6.80	10.20	13.50	0.53	-	2.30	18.50	10.23	4.63
2	7.89	1.78	4.00	5.00	8.84	0.73	-	5.09	8.01	5.47	4.17
3	8.19	2.90	5.60	4.92	18.60	0.71	-	3.50	17.00	9.00	8.11
4	7.85	6.81	13.10	8.98	44.91	1.67	-	5.33	38.59	24.74	13.52
5	7.41	5.71	15.00	12.50	29.70	0.43	-	3.85	34.50	19.28	8.01
6	8.06	4.84	14.00	7.00	27.51	0.51	-	4.24	28.51	16.27	8.49
7	7.95	8.24	21.00	18.20	43.40	0.30	-	3.33	44.00	35.57	9.80
8	7.78	9.21	21.50	27.10	43.00	1.31	-	3.85	52.65	36.41	8.72
9	7.95	6.49	16.40	15.70	33.34	0.55	-	4.16	34.45	26.83	8.32

Table 4. Effects of the interactions of soil salinity levels and water table depths on some plant characters of the sorghum.

Site No	1[st] Season Plant height (cm)	Panicle length (cm)	Weight of 1000 seed (g)	Protein content %	Yield t ha^{-1}	2[nd] Season Plant height (cm)	Panicle length (cm)	Weight of 1000 seed (g)	Protein content %	Yield t ha^{-1}
1	176.58e	16.35d	34.80c	8.52c	2.96d	174.68d	16.45c	37.05c	7.91c	2.88e
2	260.98b	20.66b	41.05a	9.68b	5.51b	262.70b	19.93b	40.73b	9.75b	5.77b
3	284.23a	22.85a	42.48a	11.36a	6.59a	282.76a	22.93a	43.30a	11.88a	6.42a
4	170.80e	14.65e	32.88c	7.87d	2.6de	171.15d	15.93c	36.05d	7.61cd	2.76e
5	190.20d	16.10d	36.40b	8.28c	4.66c	178.05d	16.80c	36.65cd	7.66cd	5.09c
6	219.95c	18.12c	36.60b	8.32c	4.91c	218.35c	17.35c	37.88c	7.73cd	4.92d
7	148.05f	12.25f	30.60e	6.30d	1.87f	149.75e	12.40de	29.63f	6.89e	1.61f
8	151.02f	14.08e	33.35cd	6.85d	2.2ef	152.15e	13.95d	32.28e	7.00d	2.0f
9	153.05f	14.50e	32.63d	7.11d	2.31e	154.5e	13.51d	31.95e	7.26cd	2.08f

Table 5. Regression equations and correlation coefficient of plant growth, grain yield and grain yield quality of the grown sorghum with soil salinity levels and water table depths.

Parameters	1st Season		2nd Season	
	The regression equations	Correlation Coefficient	The regression equations	Correlation coefficient
Plant height , cm	$Y=210.691-8.661X_1+0.590X_2$	-0.844	$Y=207.908-8.420X_1+0.587X_2$	-0.827
Panicle length, cm	$Y= 17.609-0.631X_1+0.04564X_2$	-0.894	$Y=18.953 - 0.658X_1+0.03066X_2$	-0.894
seed yield t ha^{-1}	$Y = 10.912-0.809X_1+08427X_2$	-0.855	$Y = 11.685-0.889X_1+0.06742X2$	-0.847
1000-seed weight , g	$Y= 40.33-0.974X_1+0.0308X_2$	-0.778	$Y=38.971-0.859X_1+0.04335X_2$	-0.913
Protein content, %	$Y=10.192-0.295X_1+0.03149X_2$	-0.756	$Y = 9142-0.258X_1+0. 01182X_2$	-0.681

Y= plant character, X_1= soil salinity level dS m^{-1} and X_2 = water table depth, cm.

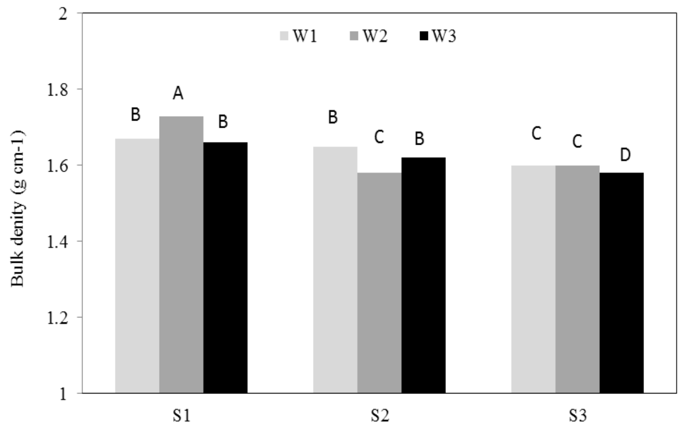


Figure 2. *Effect of soil salinity levels and water table depths on bulk density (g cm^{-3}).*

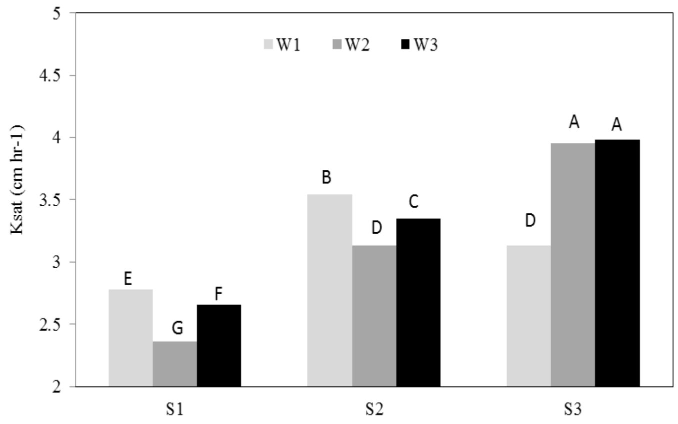


Figure 3. *Effect of soil salinity levels and water table depths on hydraulic conductivity (cm hr^{-1}).*

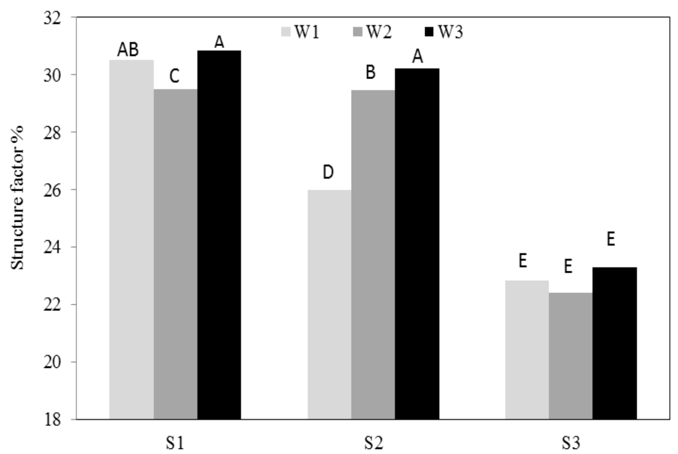


Figure 4. *Effect of soil salinity levels and water table depths on structure factor (%).*

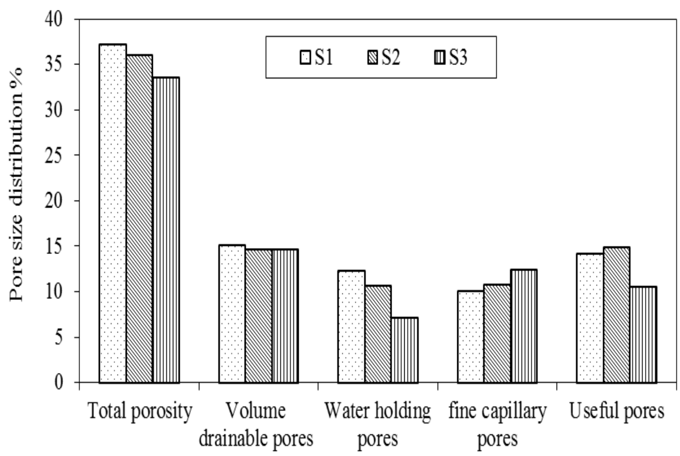


Figure 5. *Effect of soil salinity levels on pore size distribution (%).*

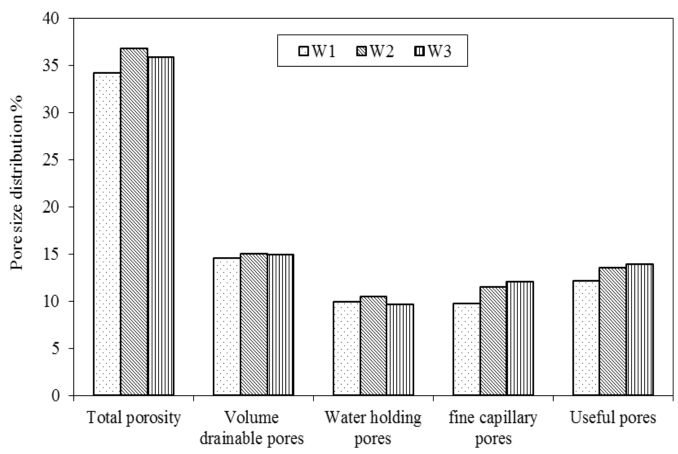
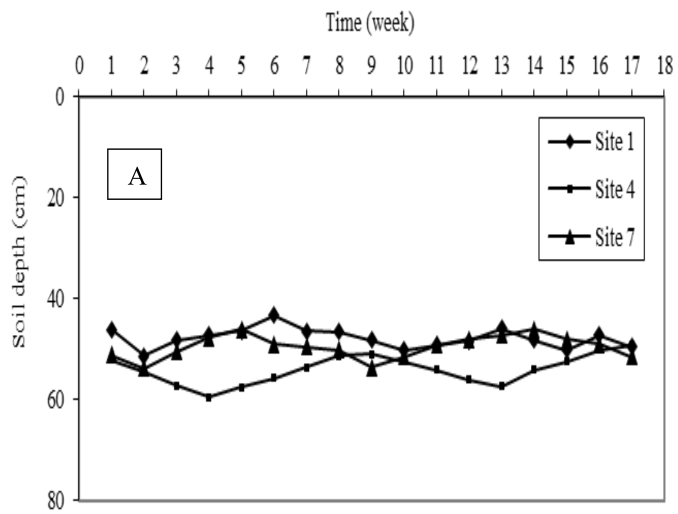


Figure 6. *Effect of water table depths on pore size distribution (%).*



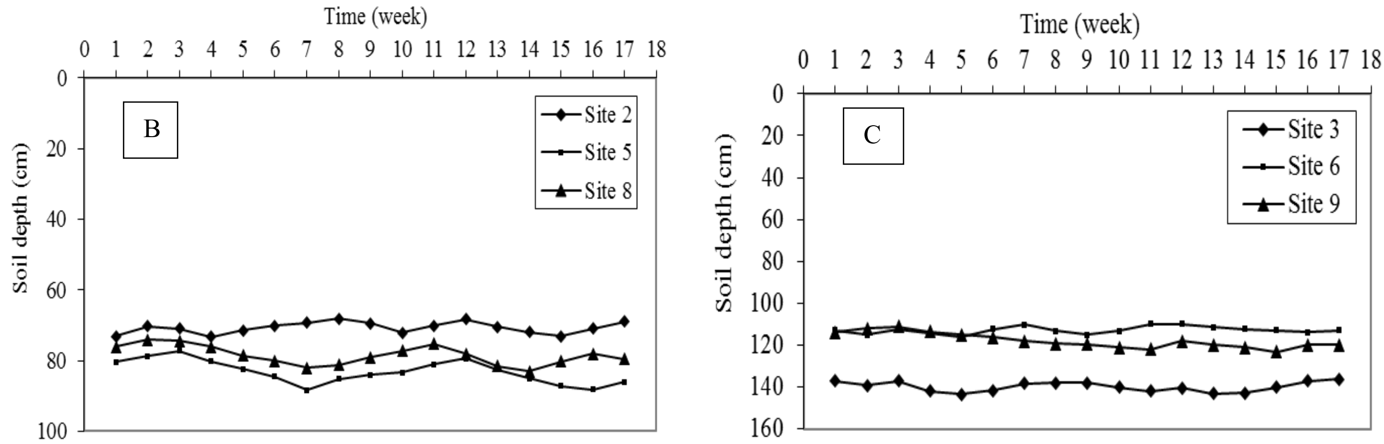


Figure 7. *Fluctuation of water table depths, A for shallow levels (Sites 1, 4, 7) B, for medium levels (Sites 2, 5, 8) and C for deep levels (Sites 3, 6, 9) during growth season.*

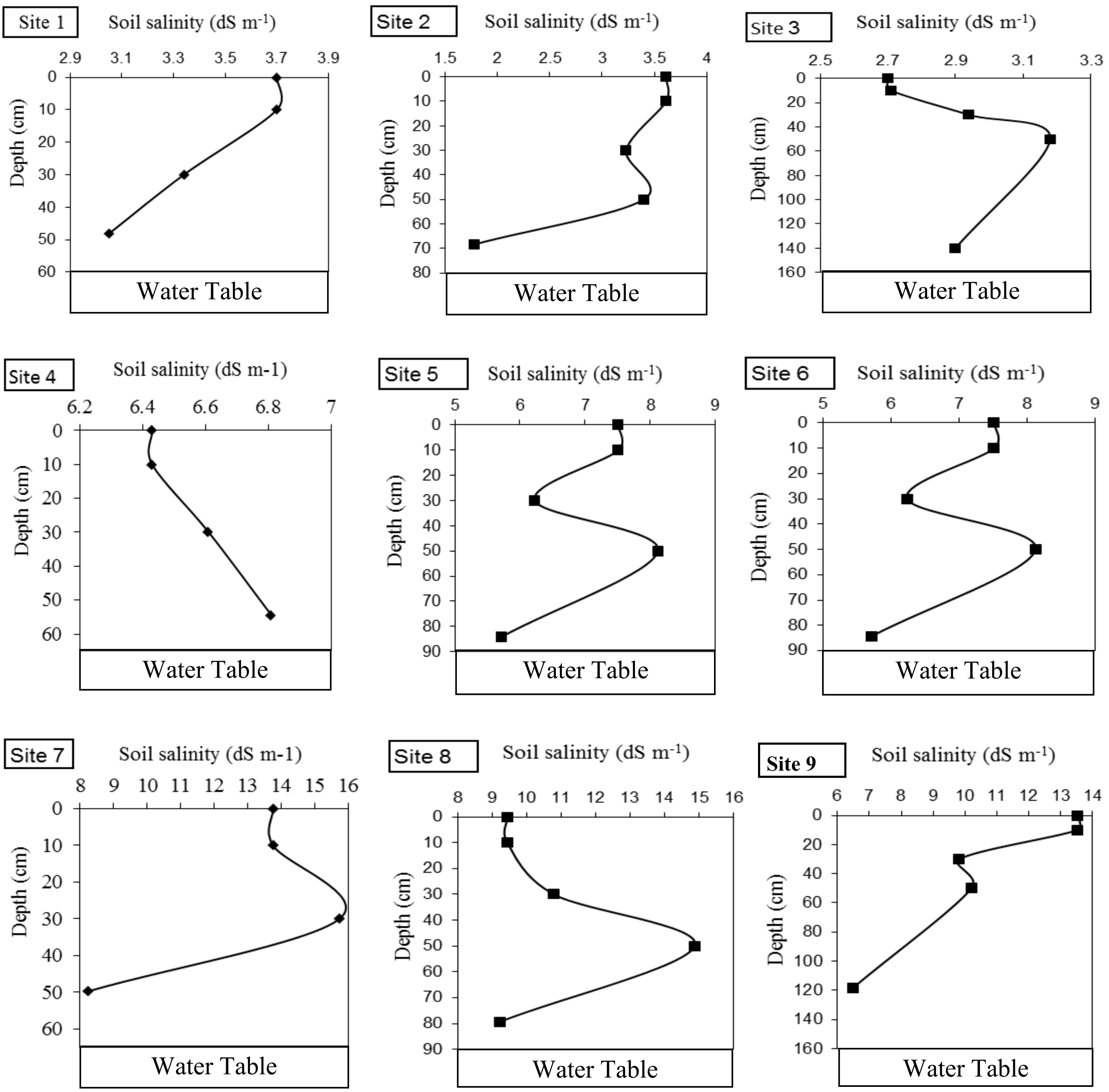


Figure 8. *Relationship between salinity of water table and the salinity of soil layers at different sites.*

Conclusion

The obtained results revealed that there was a slight or insignificant effect on soil physical properties (i.e. soil bulk density values structure factor and pore size distribution particularly water holding pores and useful pores) with increasing the salinity levels of the studied soils by soil salinity. According to the above – illustrated results and discussion, it can be in general concluded that the best results of growth, yield, and quality of grains of sorghum crop require that all environmental factors be favorable. Therefore, under conditions of this study in Fayoum region, the results incited the need to maintain low salinity levels and deep water table depth which is necessary for producing maximum grain yield of satisfactory quality. Finally, high-quality water is recommended for salt leaching during the irrigation season.

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