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Effect of Sulphur application and water salinity on soil and plant properties

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The main objective of this work was to study the effect of sulphur application and irrigation water quality on some soil properties of the calcareous, alluvial and sandy soils. A lysimeter experiment was conducted and filled with calcareous, alluvial and sandy soils to evaluate the impact of using elemental sulfur on the yields and mineral uptake of wheat plant. The experiment was cultivated with wheat plant (*Triticum Vulgare L*.), and irrigated by saline water (diluted sea water recording EC values of 2000, 3000 and 4000 mgl^{-1}). The rate of sulfur applications were 0, 476 and 952 kg Sha-1. The results showed that increasing salinity to 4000 mgl^{-1} gradually and significantly decreased the fresh and dry weights of wheat were as follow: Sandy > alluvial > calcareous soils, and the reductions in the grain yield under the same condition were 27, 15 and 23% relative to the control for calcareous, alluvial and sandy soils, respectively. Salinity levels also significantly reduced the total uptake of NPK of all crops cultivated in different soils under study. Under sulfur application, the fresh and dry weights of wheat significantly increased relative to the control treatment. Under high salinity level 4000 ppm and high rate of sulfur (952 kg Sha-1), the increment in the crop under study and cultivated in calcareous, alluvial and sandy soils were 74, 60 and 46% for wheat grain yield, relative to the control, respectively. Also, sulfur applications significantly increased total uptake of NPK of wheat crop cultivated in different soils, especially calcareous soil. The chemical composition of soils under study after cropping showed that each of electrical conductivity (EC), sodium adsorption ratio (SAR) and soil pH increased with increasing salinity levels in the irrigation water, while, sulfur application decreased each of EC and pH and reduced SAR.

Key words: Water quality, elemental sulfur, Egyptian soils, wheat.

INTRODUCTION

The world population is increasing rapidly and may reach 6 to 9.3 billion by the year 2050 (Mohamed, 2006), whereas the crop production is decreasing rapidly because of the negative impact of various environmental stresses (Mohamed et al., 2007); therefore, it is now very important to develop agricultural management to cope with this upcoming problem of food security. Among a biotic stresses, high salinity stress is the most severe

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environmental stress, impairing crop production on at least 20% of irrigated land worldwide. In addition, the increased salinity of arable land is expected to have devastating global effects, resulting in up to 50% land loss by the middle of the twenty-first century (Mahajan and Tuteja, 2005; Mgdi et al., 2013). The deficiency of nutrients in farming lands affected by salinity in one hand and a weak management in this field has caused significant decrease of agricultural products. It could be said that effective management strategies would control plant growth and prohibits factors such as salinity of the soil. These strategies lower extensive use of fertilizers. Proper irrigation based on weather conditions and the ratio of salinity would result in success in the future (Abdallah et al., 2013; Ahmed et al., 2016).

Generally, plants require about a tenth as much sulfur (S) as nitrogen (N), but sulfur deficiencies restrict plant growth as surely and severely as nitrogen deficiencies (Churka et al., 2013). It is well known that sulfur is a vital macro-element in plant growth. Sulfur is a macro element in plant growth and increases the absorption of micronutrients as pH decreases Sulfur has a very effective and positive role in reducing the effects of salinity and alkalinity stresses via improvement of physicochemical properties of saline and alkaline soil, increasing of permeability, decreasing of pH, loss and removal of irrigation water bicarbonate (Mohamed et al., 2007). With regulation of different enzymes of S-assimilation under salinity stress, sulfur causes of salt resistance in plants. Increases, decreases or remain unaffected sulfur assimilation enzymes by salinity stress has been reported by researchers (Nazar et al., 2011). Stamford et al. (2002) reported sulfur inoculated with *Thiobacillus* reduced pH (8.2 to 4.7) and electrical conductivity of the soil saturation extracts (15.3 to 1.7 mS/cm). The growth of the tropical legumes cowpea and yam bean under the population pressure, plans are being made for further expansion of the cultivated area e.g., in the west of Delta, Sinai, and Upper Egypt. Soils of such areas are sandy and calcareous in nature (Abdallah et al., 2013). In many locations of these areas, farmers may resort to use saline water from ground water, drainage water and recycled wastewater for irrigation due to the limited Nile water source. Such waters contain a variety of dissolved and suspended substances including salts, organic compounds, and soil particles that affects their quality.

The long continued use of saline water in irrigation increasing soil salinity which pass a serious threat to irrigated agriculture and may result in deteriorating the soil. Crop production is reduced when excessive accumulation of soluble salts exist in soils. Reductions in crop yields result from osmotically produced water stresses that plants encounter when grown under saline irrigation water conditions, specific nutritional imbalances and toxicities that are created when certain salt constituents, such as chloride, sodium and boron, are individually in excess. In addition, excessive sodium may indirectly decrease plant growth by its deleterious effect on soil structure (Helmy et al., 2013). The role of elemental sulfur on controlling the hazards of soil salinity under use of saline irrigation water and it's contribute on improving soil properties, crop yields and plant composition (Abdallah et al., 2013).

Elemental sulfur was used in a series of field and laboratory experiments in different countries to study its effect as a source of this element for plant and as a soil amendment to improve chemical and physical properties of alkali and calcareous soils (Mohamed et al., 2007). In this respect Mohamed (2006) stated that the oxidation of elemental sulfur and its compounds plays a major role in delineating the behavior of sulfur in alkali and calcareous soils. In this process sulfur changes its oxidation number and hydrogen ions are produced; sulfur compounds undergo both chemical and biological oxidation in a soil environment. However, biological oxidation is more important; El-Kholy et al. (2013). Abdallah et al. (2013) and Ahmed et al. (2016) stated that sulfur compounds have been used for reclaiming sodic soils. These materials supply Ca directly or dissolve calcium carbonate due to hydrogen ions, thereby, enhancing the replacement of Na from the exchange site when followed by leaching. The structure of the sodic soils improves as exchangeable Ca increases. Improvements in the soil structure enhance water penetration and thus help to leach the salt more easily and effectively.

El-Kholy et al. (2013) and Qiongqiong et al. (2016) stated that irrigation water with higher salinity, under sulfur application condition, tends to cause particles to stay together and soil structure is maintained. For instance, soil with well-defined structure will contain a large number of macrospores, cracks, and fissures, which allow for relatively rapid flow of water through the soil. Also, Mohamed (2006) concluded that the application of amendments, such as sulfur and manure, to soil irrigated with saline water, either individually or in combination increased the volume of quickly and total drainable pores, water holding pores and total useful pores of the soil following the intermittent leaching. S application rates of 0 to 600 ppm caused a significant decrease in soil pH under different water quality regimes. Also, S application significantly increased the electrical conductivity and solubility of SO_4^{-2}, $H_2PO_4^-$ and K^+ of the soil water extracts during the period of incubation and under varying conditions of water quality (Mohamed, 2006; Mohamed et al., 2007).

Mohamed et al. (2007) reported that at all the different levels of applied sulfur; there was a marked drop in pH of leachate for sandy soil and for alkaline clay loam soil. However, the drop in leachate pH for calcareous soil was slight. The magnitude of the drop in leachate pH was in the following order: Alkaline clay loam >sandy soil> calcareous soil. They added that the most practical consequences of reducing soil pH and permanently

Figure 1. Map showing the locations of samples.

increasing the CO_2 concentration are increasing the solubility and the availability of plant nutrients and improving some soil physical properties. The objective of this study to studied the effect of sulphur application (three rates) on some soil properties and wheat composition in sandy soil under salinity water (Nile water, 2000, 3000 and 4000 mgl^{-1}).

MATERIALS AND METHODS

The experiment was carried out at the Farm of Faculty of Agriculture, Suez Canal University, Ismailia (30° 36' 15 N - 32° 16' 20 E) Egypt. Height above sea level of Ismailia is 14 m. Figure 1 showed the locations of samples: location 1: Alluvial soil from El-Tal El-Kebeer Center, Ismailia Governorate; location 2: Sandy soil from the Farm of Faculty of Agricultural Suez Canal University, Ismailia Governorate; location 3: Calcareous soil from Wadi El-Arish, El-Arish City North Sinai Governorate. Three representative soil samples from three areas were selected for the current investigation: One representing calcareous, alluvial and sandy soils. Lot of surface soil samples (0-30 cm) was collected from the different soils to fill some lysimeters which were established in the Farm of Agricultural Faculty at Ismailia. The lysimeters dimensions were 60-cm length, 60-cm width and 100-cm depth. These lysimeters were packed carefully with soils without changing soil intensity. The main characteristics of these three selected soil samples are shown in Table 1. Saline irrigation waters were prepared by diluting sea water taken from Suez Canal with fresh water taken from Ismailia canal (Nile water). The diluted waters recorded EC values of 3.13, 4.69 and 6.25 dSm^{-1} (2000, 3000 and 4000 mgl^{-1}) respectively.

The chemical analysis of sea water and the diluted sea waters, as well as Ismailia canal are presented in Table 2. Mineral sulfur was used as soil amendment; it is added at the rate of 475 and 950 kg Sha-1 before cropping to the lysimeters and thoroughly mixed with the top at 20 cm depth of the soil surface. Wheat (*Triticum turgidum*) was cultivated in the lysimeters. After sowing all the lysimeters irrigated as follows: At first week irrigated with fresh water (Nile water), the second week irrigated with 2000 mgl^{-1} salinity in the irrigation water and the first treatment (2000 mgl^{-1}) continuously irrigated with the same concentration of salinity. At the third week, second and third treatments (3000 and 4000 mgl^{-1}) were irrigated with 3000 mgl^{-1} salinity irrigation water for one week. After that third treatment (4000 mgl^{-1}) irrigated was done continuously with 4000 mgl^{-1} salinity in the irrigation water up to the plant maturity. The number of soil samples after the end of the experiment 36 samples, with four replicates, the total soil samples 144 sample. The design of experiment is Randomized completely Block Design (RCBD). All samples were taken after the end of experiment from all lysimeters and analyses according to American Public Health Association, APHA (2005). Statistical analysis of the experiment was done using the ANOVA test.

RESULTS AND DISCUSSION

Saline irrigation water on shoot and grain yields of wheat

Effect of different levels of saline irrigation water on the shoot and grain yields of wheat cultivated in calcareous, alluvial and sandy soils are shown in Table 3. The data showed that shoot yield significantly and progressively decreased with increasing salinity level in the irrigation water. Wheat plant cultivated in sandy soil exhibited the highest decrement in shoot yield under different levels of

Table 1. Some physical and chemical analysis of investigated soils.

Parameter	Alluvial	Calcareous	Sandy
Sand, %	78.10	81.73	90.93
Silt, %	12.51	12.16	8.52
Clay, %	9.39	6.11	0.55
Textural class	Sandy loam	Loamy sand	Sandy
Saturation percent, %	73	44	24
pH*	7.65	8.10	7.50
EC**, dSm^{-1}	1.72	1.70	1.45
Soluble cation, ppm**			
Ca^{2+}	150	130	130
Mg^{2+}	60	66	66
Na^{+}	104	98	56
K^{+}	34	44	29
Soluble anion, ppm**			
CO_3^{2-}	45	-	-
HCO_3^{-}	458	458	366
Cl^{-}	195	195	336
SO_4^{2-}	120	192	96
Total $CaCO_3$, %	4.00	55.5	0.80
Total N, %	0.3	0.2	0.15
Available P, ppm	9.0	3.0	6.0
Available K, ppm	13.0	7.00	7.00
CEC, Cmol kg^{-1}	29.56	9.50	3.80
Organic matter, %	14.6	11.4	6.7

*In soil-water suspension 1:2.5; **In soil paste.

Table 2. The chemical analysis of Nile water, seawater and diluted seawaters, used for irrigation.

Water	Cations, ppm				Anions, ppm				EC dSm^{-1}	SAR
	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	CO_3^{2-}	HCO_3^{-}	Cl^{-}	SO_4^{2-}		
Nile water	20	14	41	6	-	149	46	-	0.40	1.25
Sea water	510	1500	8050	332	-	397	14378	6000	48.5	40.4
2000	50	60	575	28	-	207	675	514	3.13	12.9
3000	68	96	881	39	-	226	1243	696	4.69	16.1
4000	100	120	1270	51	-	244	1775	898	6.25	20.2

salinity in irrigation water which reached to 25, 34 and 39%, relative to the control treatment for 2000, 3000 and 4000 mgl^{-1} salinity levels in the irrigation water, respectively. While the lowest reduction in the shoot growth was found in the wheat plant cultivated in calcareous soil which was 4, 16 and 29% for 2000, 3000 and 4000 mgl^{-1} salinity levels in the irrigation water, respectively. Generally, the decrement in shoot growth of wheat plant irrigation with saline irrigation water (up to 4000 mgl^{-1}) could be arrange and cultivated in different soils as follows: Sandy> alluvial> calcareous soils. The reduction in dry weight of shoots may be due to suppressing cell enlargement and division and also to the inhibition of enzyme activities by salt, especially Na^{+} ions as reported by Malik and Srivastava (2005). Moreover, El-Kholy et al. (2013) and Abdallah et al. (2013) reported that increasing water salinity may increase the osmotic pressure of plant cells to cope with salinity of the soil solution around roots, and this, in turn, results in a general retardation of the enzymatic and photosynthetic processes.

With regard to the effect of saline irrigation water on the grain yield of wheat cultivated in soils under investigation, the data in Table 3 showed clearly that grain yield progressively decreased with increasing salinity levels in the irrigation water. The reduction in grain yield varied

Table 3. Effect of irrigation water salinity and sulfur applications on wheat.

Water salinity level (ppm) of wheat plant	Calcareous soil			Alluvial soil			Sandy soil		
	Sulfur, kg/ha.			Sulfur, kg/ha.			Sulfur, kg/ha.		
	0	475	950	0	475	950	0	475	950
Shoot weight (ton/ha)									
Control	6.66	10.38	12.65	7.16	7.87	11.90	6.20	6.85	9.68
2000	6.42	6.90	8.66	6.74	7.42	9.77	4.65	4.92	5.46
3000	5.63	5.87	7.24	5.78	6.37	6.50	4.07	4.36	4.66
4000	4.74	5.02	5.47	4.70	4.85	5.11	3.79	4.02	4.06
Grain weight (ton/ha)									
Control	6.00	8.59	10.71	5.73	6.30	10.25	5.40	5.65	7.74
2000	5.16	6.67	7.71	5.49	7.00	8.80	3.96	4.18	4.85
3000	4.95	5.00	5.95	5.40	5.82	5.95	3.45	3.59	3.93
4000	3.84	4.25	4.55	4.17	4.28	4.38	3.06	3.34	3.43

	LSD $_{0.05}$				
	Soil (S)	**Salinity (L)**	**Sulfur (E)**	**L × E**	**S × L × E**
Shoot yield	0.11	0.13	0.11	0.22	0.38
Grain yield	0.11	0.12	0.11	0.21	0.37

according to the soil type in which wheat was cultivated. At low salinity level in the irrigation water (2000 mgl^{-1}), the reduction of grain yield of wheat cultivated in calcareous alluvial and sandy soils were 14, 4 and 27% relative to the control treatment, respectively. While at moderate level of salinity (3000 mgl^{-1}) in the irrigation water these figures were 18, 6 and 36%, respectively. Under the high salinity level of irrigation water (4000 mgl^{-1}) the reduction in grain yield of wheat plant cultivated in calcareous, alluvial and sandy soils were 36, 27 and 43%, respectively. These results indicated that using saline irrigation water for wheat plant cultivated in sandy soil must not increase more than 2000 mgl^{-1}. While wheat cultivated in calcareous and alluvial soil could be irrigated with saline water, its salinity level reached more than 3000 mgl^{-1}.

Sulfur and salinity effective on shoot and grain yields of wheat

The effect of sulfur applications on the shoot of wheat plant cultivated in the three soil types and irrigated with saline irrigation water are shown in Table 3. The data showed clearly that shoot yield of wheat cultivated in different soils significantly increased relative to the control treatment (0 kg Sha-1). Under fresh irrigation water, shoot yield of wheat cultivated in calcareous soil increased with 90%, relative to the control for soil treated with 950 kg Sha-1. While shoot yields of wheat plant cultivated in alluvial and sandy soil increased with 66 and 56%, respectively. This result indicated that calcareous soil greatly responses to sulfur application at the rate of 950 kg Sha-1.

In this respect Mohamed et al. (2007) and Abdalla et al. (2013) reported that shoot yield of wheat plant increased with increasing sulfur application up to 950 kg Sha-1. He added that the addition of elemental sulfur which transformed by different bacteria to sulfuric acid had led to desirable effect in the area where $CaCO_3$ was found; while under saline irrigation water, sulfur application up to 950 kg Sha^{-1} significantly increased the shoot yield of wheat plant, but this increment decreased with increasing salinity level in the irrigation water. Shoot yield of wheat cultivated in calcareous soil significantly increased with increasing sulfur application up to 950 kg Sha^{-1} but these increments decreased with increasing salinity level in the irrigation water with 35, 29 and 16% relative to the control treatment for wheat plant irrigated with 2000, 3000 and 4000 mgl^{-1} saline water, respectively. These decrements for wheat plant cultivated in alluvial soil were 45, 12 and 9%, respectively. Although shoot yield of wheat cultivated in sandy soil treated with 950 kg Sha-1 increased relative to the control treatment, but it decreased progressively with increasing salinity levels in the irrigation water up to 4000 mgl^{-1}. These decrements in shoot yields of wheat were 18, 15 and 7% relative to control treatment for salinity in the irrigation water 2000, 3000 and 4000 mgl^{-1}, respectively.

With regard to the effect of sulfur applications on the grain yields of wheat plant irrigated with different saline irrigation water and cultivated in different soils, the data in Table 3 showed clearly that grain yield significantly increased with increasing sulfur applications, relative to the control treatment. The increments in the wheat grain cultivated in calcareous, alluvial and sandy soils and irrigated with fresh water were 79, 79 and 44%, respectively. In this respect, Bauder and Brock (2001), Mohamed et al. (2007), Abdallah et al. (2010), Rahman et al. (2011), Abdelhamid et al. (2013), Kubenkulov et al. (2013), Manesh et al. (2013) and El-Kholy et al. (2013) reported that the percentage of increment in grain yield of wheat plant cultivated in calcareous soil relative to the control (without treatment) was more than 70%. Increasing salinity in the irrigation water to 2000 mgl^{-1} grain yield increased with sulfur application to 50, 60 and 23%, relative to the control treatment (0 Sha^{-1}) for wheat plant cultivated in calcareous, alluvial and sandy soils, respectively. Under water salinity (3000 mgl^{-1}) these increments were 20, 10 and 14%, respectively. While under high salinity level in the irrigation water (4000 mgl^{-1}) these increments were 19, 5 and 12%, respectively. It could be concluded from these result that under low salinity level, sulfur application was more effective in alluvial and sandy soils. While under high salinity in the irrigation water (up to 4000 mgl^{-1}), sulfur application more effective in calcareous soil.

Salinity effective on NPK content of wheat plant

Data in Table 4 show the effect of different salinity levels in the irrigation water on the N, P and K content of shoot for wheat plant cultivated in calcareous, alluvial and sandy soils. The data showed clearly that each of N, P and K content significantly decreased progressively with increasing salinity levels in the irrigation water up to 4000 mgl^{-1} for wheat plant cultivated in all soils under investigation. Nitrogen content of shoot decreased with 9, 14 and 19% relative to the control under low salinity level in the irrigation water for wheat cultivated in calcareous, alluvial and sandy soil, respectively. These decrements under moderate saline level of irrigation water (3000 mgl^{-1}) were 13, 24 and 31%, respectively, while under high salinity (4000 mgl^{-1}) reached to 20, 40 and 55%, respectively. From these results it could be concluded that N content of wheat cultivated in sandy soil greatly affected and decreased more than that found in calcareous and alluvial soils. At the same time, the lowest decrement in N content of shoot was found in calcareous soil. In contrary, P content of wheat cultivated in calcareous soil decreased with increasing salinity levels in the irrigation water upto 4000 mgl^{-1} and its decrement reached to 67% relative to the control and it was more than that found in alluvial and sandy soils. Potassium content of wheat plant significantly decreased in the shoot with increasing salinity levels in the irrigation water. These decrements were almost equal in wheat cultivated in calcareous and sandy soils which reached 1, 5 and 16% relative to the control under saline irrigation water levels 2000, 3000 and 4000 mgl^{-1}, respectively. While these figures were high and reached 9, 13 and 17% for shoot K content of wheat cultivated in alluvial soil. These results, as mention before, may be due to the effect of Na^+ ion in the soil solution which exchanged with K^+ ion on clay and subsequently reduced plant uptake of K^+ which depend greatly on the exchangeable K in soil. With regard to the effect of different salinity levels in the irrigation water on the N, P and K content of wheat grains; data in Table 4 showed that N, P and K content significantly and gradually decreased with increasing salinity levels in the irrigation water. These decrements in NPK content resulted from salinity level 2000 and 4000 mgl^{-1} been 37 and 52% for N, 43 and 48% for P and 9 and 25% for K in wheat plant cultivated in calcareous soil, respectively. These figures for wheat plant cultivated in alluvial soil were 10 and 33% for N, 43 and 65% for P and 9 and 57% for K, respectively. Wheat plant cultivated in sandy soil exhibited more reduction in NPK content with increasing salinity level from 2000 to 4000 mgl^{-1} in the irrigation water which reached to 21 and 54% for N, 30 and 59% for P and 27 and 65% for K, respectively. The effect of sulfur application on the N, P and K content of wheat plant cultivated in calcareous, alluvial and sandy soil are shown in Table 4. The data showed clearly that sulfur application significantly increased the N, P and K content of the shoot and grain under different salinity levels of irrigation water and cultivated in all soils under investigation. Also, the difference between the N, P and K content resulting from the first rate of sulfur (475 kg Sha-1) and the second rate of sulfur (950 kg Sha-1) were significant in all shoot and grain under the same conditions. Similar conclusion was reported by Abdallah et al. (2010), Rahman et al. (2011) and Abdelhamid et al. (2013).

Kubenkulov et al. (2013), Manesh et al. (2013) and El-Kholy et al., (2013) found that increasing sulfur application rate up to 1190 kg Sha-1 significantly increased P and K in both shoot and grain of wheat plant. The wheat plant cultivated in sandy soil and treated with sulfur application, recorded the higher percentage of increment in N content of shoot which reached to 36 and 69%, relative to the control treatment, for plant irrigated with 3000 and 4000 mgl^{-1} saline irrigation water, respectively. These figures for calcareous soil were 42 and 13% and for alluvial soil they were 28 and 37%, respectively. While calcareous soil recorded the highest shoot content of P under different levels of salinity in the irrigation water. The increment resulting from 950 kg Sha-1 were 82, 122 and 87%, relative to the control treatment and salinity levels of 2000, 3000 and 4000 mgl^{-1}, respectively.

With regard to K content of shoot of wheat plant, cultivated in different soils, the data showed that K content increased with increasing salinity levels in the irrigation water. This result may be due to the increase of Na ions in saline irrigation water which exchanged with K of soil and increased its availability to plant. Sulfur applications up to 950 kg Sha^{-1} increased N and K content of grain of wheat plant cultivated in calcareous and alluvial soils with increasing salinity levels in the irrigation water. While P content of the grain was

Table 4. Effect of irrigation water salinity and sulfur applications on NPK content of wheat.

Water salinity level (ppm)	Calcareous soil			Alluvial soil			Sandy soil		
	Sulfur (kg/ha)			Sulfur (kg/ha)			Sulfur (kg/ha)		
	0	475	950	0	475	950	0	475	950
Shoot									
N gkg^{-1}									
Control	11	14.6	20.1	11.7	12.6	17.2	12.4	15.6	17
2000	10	10.7	13.8	10.1	11.4	14.5	10	12.7	14.6
3000	9.6	10.1	13.6	8.9	9.8	11.4	8.6	11.4	11.7
4000	8.8	9.4	9.9	7	9.6	9.6	5.6	8.2	9.5
P (gkg^{-1})									
Control	3.55	4.25	5.75	3.85	3.85	4.16	4.09	5.47	5.67
2000	3.06	3.26	5.57	2.95	3.2	3.87	3.63	4.3	4.53
3000	2.06	2.67	4.57	1.85	2.92	3.06	3	3.53	4.26
4000	1.17	1.56	2.19	1.4	1.56	2.1	1.5	1.76	2.79
K (gkg^{-1})									
Control	20	21	25	20	21	21.1	21.2	23.2	26.3
2000	20	20.1	21	18.3	18.4	20.1	21	21.8	23
3000	19	20	20.1	17.5	18.1	18.3	20.1	20.1	21.7
4000	17.2	19.1	20	16.6	16.7	18	17.9	18.5	20.1
Grains									
N (gkg^{-1})									
Control	61.5	67.2	69.5	52.1	60.1	69.1	55	60.5	63
2000	34.8	47.5	50.5	46.1	50.8	54	41.6	53.2	57.2
3000	28.5	37.6	50.2	42.1	44.7	50.1	31.5	35.1	36.2
4000	24.6	36.3	45.3	31.7	32.2	41	31.1	32	34.5
P (gkg^{-1})									
Control	10.5	11.9	15	13.5	14.1	15.1	8.8	13.3	14.4
2000	9	9.5	11.3	7.7	8	9.7	6.2	8.2	10
3000	5.9	6	10.4	5.2	6.6	7	4.3	5.4	6.2
4000	5.5	5.5	8.4	4.7	5.5	6.2	3.6	3.6	5.2
K (gkg^{-1})									
Control	3.2	4.9	6	4.4	5.1	5.7	5.1	5.5	8
2000	2.9	3.8	4.9	4	4.1	4.4	3.7	4.7	5.4
3000	2.8	2.8	4.8	2.5	3.2	3.9	2.5	3.2	4.7
4000	2.4	2.5	4.4	2.4	3	3.8	1.8	3	3.5

	LSD $_{0.05}$				
	Soil (S)	**Salinity (L)**	**Sulfur (E)**	**L × E**	**S × L × E**
N content (Shoot)	0.5	0.5	0.5	0.9	1.6
P content (Shoot)	0.1	0.11	0.1	0.19	0.33
K content (Shoot)	0.5	0.5	0.5	0.9	Ns
N content (Grain)	1.6	1.8	1.6	3.1	5.4
P content (Grain)	0.5	0.5	0.5	0.9	1.6
K content (Grain)	0.3	0.3	0.3	0.6	1.0

decreased with increasing salinity levels in the irrigation water in all soils under investigation, and the highest P content was found under 3000 mgl^{-1} salinity level. Potassium content of the wheat grain cultivated in sandy soil behave in similar trend as found in calcareous and alluvial soils.

Data in Table 5 showed the effect of different salinity levels in the irrigation water on the total uptake of N, P and K for calcareous, alluvial and sandy soils. The data showed clearly that saline irrigation water decreased the uptake of N, P and K gradually with increasing salinity up to 4000 mgl^{-1} for all soils under study. The decrements in

Table 5. Effect of irrigation water salinity and sulfur applications on NPK uptake of wheat.

Water salinity level ppm	Calcareous soil			Alluvial soil			Sandy soil		
	Sulfur (kg/ha)			Sulfur (kg/ha)			Sulfur (kg/ha)		
	0	475	950	0	475	950	0	475	950
Shoot uptake									
N (kg/ha)									
Control	307	418	806	407	538	631	229	339	526
2000	261	358	457	305	347	472	188	224	367
3000	183	236	296	255	292	355	137	200	235
4000	133	171	216	162	239	287	106	157	188
P (kg/ha)									
Control	60	111	168	62	89	121	36	64	85
2000	38	42	62	42	48	84	33	35	53
3000	27	33	40	35	41	67	28	31	37
4000	12	22	32	26	27	39	23	26	30
K (kg/ha)									
Control	238	298	419	304	354	421	202	273	357
2000	212	248	288	240	285	314	181	196	339
3000	169	207	230	219	261	265	157	165	204
4000	138	173	178	169	182	229	127	135	148
Grain uptake									
N (kg/ha)									
Control	442	729	999	382	478	913	374	448	653
2000	244	391	509	321	440	617	211	285	357
3000	195	247	397	279	322	372	144	176	197
4000	136	201	260	165	185	229	116	126	157
P (kg/ha)									
Control	87	146	233	105	119	204	73	113	166
2000	51	66	135	62	80	123	41	55	82
3000	41	46	95	39	57	62	27	35	43
4000	27	31	50	26	33	38	17	19	29
K (kg/ha)									
Control	154	260	381	167	197	309	159	190	317
2000	143	164	220	145	165	235	112	127	152
3000	121	131	174	115	134	142	90	99	120
4000	91	106	129	86	94	109	73	84	94

	LSD $_{0.05}$				
	Soil (S)	**Salinity (L)**	**Sulfur (E)**	**L × E**	**S × L × E**
N uptake (shoot)	11.88	13.73	11.88	23.78	41.17
P uptake (shoot)	2.45	2.83	2.45	4.90	8.50
K uptake (shoot)	9.95	11.47	9.95	19.87	34.44
N uptake (grain)	14.40	16.61	14.40	28.77	49.86
P uptake (grain)	4.14	4.78	4.14	8.26	14.33
K uptake (grain)	5.14	5.95	5.14	10.31	17.83

N-uptake of wheat plant for calcareous soil were 45, 56 and 69% relative to the control treatment, under saline irrigation water of 2000, 3000 and 4000 mgl^{-1}, respectively. While these figures for alluvial soil was 16, 27 and 57%, respectively. The highest reduction on total N-uptake was obtained from wheat plant cultivated in sandy soil which reached 44, 62 and 69%, respectively.

While total P uptake was decreased with 42, 53 and 69% for wheat plant cultivated in calcareous soil irrigated with 2000, 3000 and 4000 mgl^{-1} saline irrigation water, respectively. These figures for wheat plant cultivated in alluvial soil were 41, 63 and 75% and for sandy soil they were 43, 63 and 77%, respectively. With regard to the total uptake of K of wheat plant, it also reduced with 7, 21 and 41% for wheat plant cultivated in calcareous soil and irrigated with salinity levels 2000, 3000 and 4000 mgl^{-1}, respectively. These percentage of reductions for alluvial soil were 13, 31 and 48%; and these figures for sandy soil they were 30, 43 and 54%, respectively. In this respect Similar conclusion was reported by Abdallah et al. (2010), Rahman et al. (2011), Abdelhamid et al. (2013) and El-Kholy et al. (2013) studied the use of diluted sea water for irrigation and its effect on plant growth and nutrients uptake stated that increasing salinity levels in the irrigation water inversely affected the total uptake of macronutrients in both shoot and grain yield of wheat.

The total uptake of N, P and K wheat plant progressively and significantly increased with increasing sulfur application rates in different studied soils as shown in Table 5. Wheat plant cultivated in calcareous soil recorded the highest N, P and K uptake under fresh irrigation water treatment (control) treated with 950 kg Sha-1 and it could be arranged as total N,P and K uptake of the control treatment of wheat plant cultivated in different soils as follows: Wheat plant cultivated in calcareous > alluvial > sandy soils. Similar conclusion was reported by Mohamed (2000, 2006) and Mohamed et al. (2007). Under the salinity irrigation water and sulfur applications data in Table 5 showed clearly that increasing salinity levels in the irrigation water up to 4000 mgl^{-1} progressively and significantly decreased the total uptake of N, P and K of wheat plant in different soils under study. At the same time, sulfur application up to 950 kg Sha-1 increased the total uptake of N, P and K for wheat plant under different salinity levels in the irrigation water, relative to the control treatment. These increments of total uptake of N, P and K for wheat cultivated in calcareous soil were more than that found in wheat cultivated in the alluvial and sandy soils. The increments of N uptake of wheat cultivated in calcareous soil were 109, 104 and 91% under salinity levels 2000, 3000 and 4000 mgl^{-1} in the irrigation water, respectively. While these figures were 92, 34 and 39% for wheat cultivated in alluvial soil and 69, 37 and 35% for wheat cultivated in sandy soil. Similar trend was found for total uptake of P of wheat treated with sulfur up to 950 kg Sha-1, while wheat cultivated in calcareous soil recorded the highest values of increment which reached 168, 133 and 88% relative to control treatment (without sulfur application) under salinity levels 2000, 3000 and 4000 mgl^{-1} in the irrigation water respectively.

In this respect, Mohamed et al. (2007), Abdalla et al. (2013) and El-Kholy et al. (2013) studied the P uptake of wheat plant cultivated in saline sodic calcareous soil and found that P uptake increased progressively with increasing sulfur application up to 1 ton S fed^{-1}. The percentage of increments relative to the control treatments of total P uptake of wheat cultivated in alluvial and sandy soil resulting from sulfur treatments were almost equal under different levels of salinity in the irrigation water. With regard to total uptake of K of wheat, the data in Table 5 showed that sulfur treatments significantly increased K uptake under different salinity levels in the irrigation water. Under low salinity level (2000 mgl^{-1}),the percentage of increments of K uptake relative to the control treatment were 53, 62 and 36% for wheat plant cultivated in calcareous, alluvial and sandy soils, respectively. While under moderate and high salinity levels in the irrigation water (3000 and 4000 mgl^{-1}) these values of increments were not more than 44, 26 and 32% for wheat cultivated in calcareous, alluvial and sandy soils, respectively.

These results indicated the K uptake of wheat decreased with increasing salinity level in the irrigation water. Mohamed et al. (2007), Abdalla et al. (2013), Churka et al. (2013) and El-Kholy et al. (2013) studied the effect of using diluted sea water for irrigation wheat plant on the K uptake reported that the total uptake of K markedly decreased with increasing salinity level in the irrigation water. They added that this may be due to the reduction in dry weight of wheat plant resulting from increasing salinity level in the irrigation water.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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