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Effect of Reuse Drainage Water Management on Rice Growth, Yield and Water Use Efficiency under Saline Soils of Egypt

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Abstract: Current study was designed to explore the effect of poor quality water on rice growth and yield under saline paddy soil of Egypt. Two field experiments were conducted at agriculture research station of El-Sirw, Damitta province, Egypt during the years 2003 and 2004. The water quality treatments were; Mixed water (MW) with salinity level of 1.9-1.92 dS m^{-1} used from seedling to harvesting (T1), drainage water (DW) with 4.69-5.2 dS m^{-1} up to harvesting (T2), MW up to panicle initiation (PI)+DW up to harvesting (T3) and DW up to PI + MW up to harvesting (T4). The ponded water depth treatments were saturation (0 cm), 3 and 6 cm water depth and watering was done after every 4 days. Rice growth and yield was significantly affected by both water quality treatments and pond depths. The Leaf Area Index (LAI), Dry Matter (DM) and number of tillers increased as flooding depths were increased and submergence level of 6 cm depth gave greater LAI, DM and number of tillers. While, crop growth under mixed water treatment was better regarding LAI, DM, number of tillers m^{-2} and days to flowering. Yield components were increased with increasing the ponding depth up to 6 cm except sterility%. Mixed water treatment had favorable affect on yield components, while number of panicle reduced by 14.1, 5.8 and 6.3% and filled grains reduced by 29.7, 7.7 and 24.1% in T2, T3 and T4, respectively. It was observed that Ca^{2+} and K^{+} contents in rice leaves increased with ponding depth but Na^{+} contents reduced. While Na^{+} uptake was lower in MW treatment (T1) than Ca^{2+} and K^{+} uptake as compared to other treatments. Current study suggests the use of MW at early growth stage and its substation by DW at late growth stage for rice growth under saline soil condition. Analogously, flooding depth with 6 cm is recommended to apply when poor quality water has to be used in the irrigation under saline soil.

Key words: Water quality, ponding depth, mixed water, drainage water, Egypt

INTRODUCTION

Out of about 1500 million ha cultivated area in the world, approximately 270 million ha, i.e., 18% of the world's arable land, has been equipped with irrigation (Schultz, 2001). It is estimated that land degradation due to secondary salinization is of the order of 15~30% of the irrigated areas (Ghassemi *et al.*, 1995). In the arid zones, for example Egypt, there are parts which have limited supplies of good quality waters, so it is desirable to irrigate with waters that contain higher salt concentrations. Furthermore, unavailability of fresh water, while rice crop is grown under salt-affected soils results in using poor quality irrigation such as drainage or mixed waters leading to secondary salinization. Obviously, the poor quality and inadequate drainage facilities contribute largely to salinity problem in rice paddies. Under salt-affected soil, using poor quality water wills double the stress problem. Soil salinity is a major environmental stress that adversely affects plant growth and yield of rice crop in growing rice area in Egypt and wide spread areas over the world.

Biswas (1987) stated that plant height, panicles number, 1000-grain weight and grain yield significantly increased with increasing submergence level up to 10 cm. Also, he found that EC values and sterility decreased with

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increasing the submergence levels increased. Also, the EC values at all growth stages were reduced as irrigation intervals were narrowed with an irrigation depth of 7 cm (Zayed, 1997; Didek, 1998). Continuous irrigation with saline water resulted in a decrease in growth, grain yield and yield attributing traits of rice; and chemical contents such as: Ca^{2+}, K^{+} and Na^{+} (Soliman *et al.*, 1993; Mohaiudden *et al.*, 1997, 1998; Sultana, 2001; Shehata, 2004). Na^{+} content of soil were significantly increased when poor quality water was continuously used; while K^{+} and Ca^{2+} contents of soil were in controversial situation under such circumstances (Abd-alla, 1995, Al-Nabulsi, 1998; Atwa, 1999). Use of mixed water instead of the poor quality or saline water was found to be satisfied, alleviate the hazard effect of salt accumulation and produce considerable grain yield for some extent under salt-affected soils. From the point view of variation among the different growth stages of rice regarding salinity tolerance, it was found that the effect of saline water or poor quality water was more pronounced on rice growth when saline irrigation was started at early growth stages (Leland, 1994; Atwa, 1999). The effect was less hazardous at late growth stages, as the plants become more tolerant (Mohaiudden *et al.*, 1998). However, the information on the benefits of alternative forms of poor quality water for paddy irrigation in the salty clay soils of Nile Delta is scanty and not well documented. The objectives of this study were to (a) find out the best alternative forms of poor quality water to reduce the hazardous effect on soil and rice crop in order to increase the efficiency of irrigation system and (b) provide technical information to the farmers for better management of poor water on the farm level.

MATERIALS AND METHODS

Two field experiments were conducted during 2003 and 2004 with salt-tolerant rice cultivar (*Oryza sativa* L.) namely; Giza 178 in the farm of agriculture research station, El-sirw, Damitta province, Egypt (Fig. 1). The station is located at the 31° 33' N latitude and 31° 72' E longitudes. The soil was clayey with salinity level of 9.0 and 8.0 dS m^{-1} in 2003 and 2004, respectively. The experiments were arranged in split-plot design with four replications. The main treatments (ponded water depth) are: irrigation with continuous flooding with saturation (0 cm depth), irrigation with 3 cm water depth and irrigation with 6 cm water depth and the watering was done after every four days.

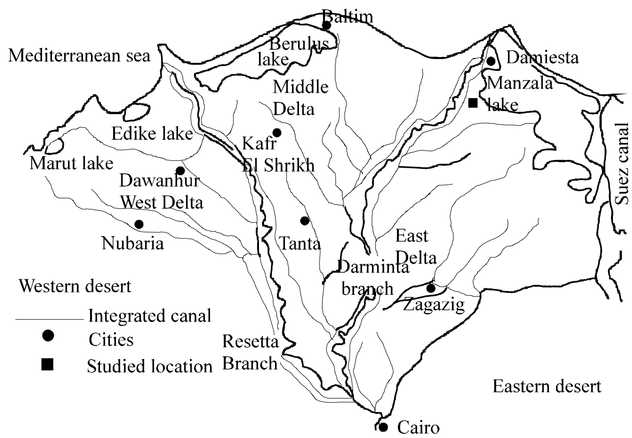

Fig. 1: Map of Nile Delta showing the location of the study area

The treatments related to water quality practices were arranged as sub-treatments are; mixture water (MW) with salinity levels ranged from 1.9 ~1.92 dS m^{-1} used over all season (T1), drainage water (DW) with 4.69 ~ 5.2 dS m^{-1} up to the end of seasons (T2), MW up to panicle initiation (PI)+DW up to the end of seasons (T3) and DW up to PI+MW up to the end of the season (T4). The soil physico-chemical properties and meteorological data of the studied site during the growing seasons are shown in Table 1 and 2. The chemical analysis for the irrigation water is presented in Table 3. Standard agricultural operations such as land preparation, fertilizer application, weeding and planting date were adopted for all treatments. Nitrogen was applied at the rate of 150 kg ha^{-1} as urea in splits doses; phosphorus was applied at the rate of 36 kg ha^{-1} as calcium mono-phosphate. Zinc sulphate was applied at the rate of 50 kg Zn ha^{-1} before transplanting. Young rice plants were grown in a nursery for one month and thereafter transplanted at 20×20 cm spacing in each treatment. Crop was harvested at maturity. It is worth to mention that each plot was completely isolated from each other using wide border and plastic sheet to prevent lateral movement of water. The obtained data were statically analyzed using the MSTAT software (1989) and the mean differences were compared using LSD test according to Gomez and Gomez (1984).

For measuring the leaf area index (LAI) and dry matter accumulation (DM), five plants were cut randomly just at the soil surface at 85 days after transplanting (DAT). Plants were carefully washed with deionized water and DM of leaves and stem were measured. Leaf Area (LA)

Table 1: Physio-chemical properties of the soil at El-Sirw during the growing seasons

	Physical properties							
	Particle size distribution (%)							
Depth (cm)	Clay	Silt	Sand	Texture class	Dry bulk density (g cm^{-3})	Wilting point (%)	Field capacity (%)	Saturation capacity (%)
0-20	44.1	28.6	27.3	Clayey	1.28	26.7	40.3	51.7
20-40	40.0	30.0	30.3	Clayey	1.34	24.3	37.8	49.6
40-60	40.0	31.0	29.0	Clayey	1.35	24.2	37.8	49.0

Chemical properties*			Cation (meq L^{-1})			Anion (meq L^{-1})				
Depth (cm)	$pH_{1:5}$	$EC_{1:5}$ (dS m^{-1})	Na^+	K^+	Ca^{2+}	Mg^{2+}	HCO_3^-	Cl^-	SO_4^{2-}	$SAR_{1:5}$
0-20	8.2	9.7	77	0.46	7.3	12.5	8.5	58	30.8	24.47
20-40	8.0	8.1	65	0.42	4.5	11.5	7.1	44	30.2	22.98
40-60	8.2	8.0	62	0.41	4.3	10.5	7.0	40	30.1	22.79

*Extraction for ions was carried out in a soil-water ratio of 1:5

Table 2: Metrological data, ETa, ETp (mm d^{-1}) and crop coefficient (Kc) at El-Sirw during the study period

Season	May 17-Sept. 30, 2003							
Month	Ave. temp. (°C)	Ave. humidity (%)	Wind velocity (km d^{-1})	Sunshine hours	Duration (Day)	ETa[(1)] (mm d^{-1})	ETp[(2)] (mm d^{-1})	Kc
May	23.6	60.45	106.7	12.0	14	7.60	5.49	1.384
June	26.1	64.95	89.3	12.1	30	8.20	5.75	1.426
July	26.3	68.50	100.0	12.3	31	8.40	5.77	1.456
Aug.	26.8	73.15	85.3	11.6	31	7.50	5.38	1.394
Sept.	25.5	68.60	99.0	10.5	30	6.50	4.70	1.383
Average	25.7	67.1	96.1	11.7	27.2	7.6	5.4	1.407
Season	May 16-Sept. 30, 2004							
May	20.5	58.0	108.0	12.0	15	7.01	5.03	1.394
June	24.3	65.3	119.0	12.0	30	7.80	5.61	1.390
July	25.8	67.0	103.0	12.4	31	8.10	5.74	1.411
Aug.	26.8	67.7	86.3	10.5	31	7.20	5.13	1.404
Sept.	25.1	67.8	99.6	9.5	30	6.40	4.70	1.362
Average	24.5	65.2	103.2	11.3	27.4	7.3	5.2	1.404

[(1)]ETa: Actual evapotranspiration, [(2)]ETp: Potential evapotranspiration using Penman-Monteith method

Table 3: Chemical analysis of mixed and drainage water as an average over two seasons

			Cation (meq L^{-1})				Anion (meq L^{-1})			
Water status	$pH_{1:5}$	$EC_{1:5}$ (dS m^{-1})	N^{a+}	K^+	Ca^{2+}	Mg^{2+}	HCO_3^-	Cl^-	SO_4^{2-}	$SAR_{1:5}$
Mixed water	8.1	1.90	9.0	0.50	4.0	6.0	4.0	7.63	9.26	4.03
Drainage water	8.0	5.52	36.0	0.33	11.3	12.6	7.3	16.9	36.0	10.41

was measured with a leaf area meter. The flowering date was estimated by the period from sowing to 75% heading.

For estimation of mineral concentration, oven dry samples of 85 days old plants were digested by HNO_3^- $HClO_4$ and Na^+, Ca^{2+}, K^+ were precisely analyzed by atomic absorption spectrometry (Mitusui *et al*., 1999).

Fifteen plants were randomly selected from each plot at harvesting time to determine the plant height (cm), tillers number, panicle number per hill, panicle length (cm), filled grains per panicle, sterility% and 100 grains weight (g). Rice grain yield was determined from a 25 m^2 area in each plot, after harvesting. The plants were air-dried for about 3 days, threshed and the weight of grains were recorded (kg ha^{-1}) at 14% moisture content basis as described by Wang *et al.* (1997).

EC was determined in the field using portable EC-meter. The analytical methods employed for chemical analyses were as follows: a) determination of Na^+ and K^+ in a 1:5 soil-water solution by flame photometer; b) determination of Ca^{2+} and Mg^{2+} using atomic absorption spectrophotometer; c) determination of SO_4^{2-} using visible spectrophotometer and Cl^- using titration method (Jackson, 1967).

Amounts of water applied (mm) were measured and recorded by parshall flume (20×90 cm). After measuring the water discharge and the required time, the amount of water applied per unit area was calculated. Water Use Efficiency (WUE) was determined by the method described by Michael (1978) as the grain yield weight (kg) produced per unit volume of applied water (m^3).

The consumptive use of water for rice crop was determined using tank with 60 cm diameter and 110 cm length. The tank was placed in the center of experimental field in order to be surrounded by buffer area of paddy, representing the actual microclimate. Three tanks were used for the measurement of consumptive use of water for each treatment. First tank has a bottom wall and rice plants were grown on soils in the tank to measure the evapotranspiration. Second tank has also a bottom wall but no plants were grown to measure evaporation from water surface. Third one has no bottom and rice plants were grown in it to measure both evapotranspiration and water percolation. At the start of experiment, the water level in each tank was set at 10 cm above the soil surface. Water level in each tank was measured daily to determine water losses, which was being compensated to maintain the desired level. Rice plants were transplanted from the nursery bed to the two tanks on the same day of transplanting in the field, (Abou El Hassan *et al*., 2005).

RESULTS AND DISCUSSION

Effect of ponded water depth and water quality treatments on growth characters: Leaf Area Index (LAI), Dry Matter production (DM), number of tiller m^{-2} and days to heading showed significant variation when rice plants were irrigated by different quality water and ponded water depths (Table 4). The LAI, DM and number of tillers increased as flooding depths were increased. The submergence level of 6 cm depth had the highest values of LAI, DM and tillers number. This could be explained that the saline soil needs more irrigation water to remove harmful salts such as NaCl from root growth zone to lower layers. Thereby, under such condition, increase in submergence level is more needed. Under low water input, the salinity hazard and water stress might have reduced the photosynthesis and inhibited the growth regulators leading to small leaf area and less dry matter formation (Kashem *et al*., 2000). Regarding plant phonology, it was found that the submergence level of 6 cm gave the shortest period from transplanting to heading date. Stress induced by salinity and drought inhibited the plant phonology particularly maximum tillering and panicle initiation stages which leaded to delay in flowering (Zayed, 2002).

Concerning the effect of poor quality water used for irrigation, data showed that different water quality treatments varied in their effect on rice growth (Table 4). Generally, crop growth under mixed water (MW) treatment (1.9~1.92 dS m^{-1}) T1 was better regarding LAI, DM, number of tillers m^{-2} and days to flowering. On contrary, rice growth and dry matter accumulation reduce and number of tillers m^{-2} and days to flowering delayed significantly with drainage water (DW) applied through out the season T2. Leaf area index, DM and number of tillers m^{-2} reduced 16.6, 18.1 and 32.7%, respectively, by DW used over whole the season T2 as compared to T1. Mixed water up to PI + DW till maturity T3 showed a little decrease in rice growth and dry matter production, followed by DW up to PI + MW up to the season off T4 treatment. That may be due to high salinity level and Na^+ content at beginning of the season in soil and drainage water as well as high temperature. The interaction between ponded water depths and poor quality water treatments had significant effect on dry matter accumulation during the year 2003. The maximum dry matter of 588.3 and 596.9 g m^{-2} was produced with MW T1 during 2003 and 2004 seasons, respectively. At the

Table 4: Leaf Area Index (LAI), Dry Matter production (DM), tiller number and heading date as affected by water depth and quality treatments under salt-affected soil

	LAI		DM (g m^{-2})		Tillers number per m^2		Days to heading	
Treatments	2003	2004	2003	2004	2003	2004	2003	2004
Water depth (R)								
0 cm	3.73	4.19	496.3	505.6	382.8	329.0	91.9	92.3
3 cm	4.18	4.58	527.8	525.6	409.5	359.4	91.8	92.5
6 cm	4.94	5.17	595.1	599.9	448.5	451.5	90.3	90.2
LSD (0.05)	0.19	0.17	13.8	16.7	17.0	33.0	1.0	1.2
Water quality (T*)								
T1	4.73	5.04	588.3	596.9	481.3	481.0	89.8	90.3
T2	3.88	4.27	481.7	489.3	362.5	285.5	93.3	92.6
T3	4.53	4.79	563.6	565.0	431.3	410.4	90.0	91.4
T4	3.99	4.49	525.4	523.7	379.3	343.8	92.3	92.5
LSD (0.05)	0.17	0.16	13.3	17.1	41.5	37.5	1.2	1.0
R×T	ns	ns	**	ns	ns	ns	ns	ns

*T1 = Mixed water overall season (MW), T2 = Drainage water overall season (DW), T3 = MW to panicle initiation + DW to harvest and T4 = DW to panicle initiation + MW to harvest

Table 5: Yield components as affected by water depth and quality treatments under salt-affected soil

	Plant height (cm)		Panicles number m^{-2}		Panicle length (cm)		Filled grains/panicle		Sterility (%)		100-grain weight (g)	
Treatments	2003	2004	2003	2004	2003	2004	2003	2004	2003	2004	2003	2004
Water depth (R)												
0 cm	82.6	76.4	339	283	17.0	18.8	79.3	81.3	18.4	19.3	18.1	18.2
3 cm	86.2	80.8	364	339	18.0	19.1	89.1	93.7	16.8	18.1	18.8	18.8
6 cm	90.5	84.5	406	419	20.0	19.2	115.9	119.3	12.2	14.0	20.1	19.9
LSD (0.05)	2.54	2.45	28.8	49.3	1.0	1.0	4.95	3.87	1.56	1.15	0.40	0.7
Water quality (T*)												
T1	90.5	83.5	440	458	20.0	19.8	114.7	110.8	12.8	13.3	19.9	20.1
T2	81.6	77.5	310	260	16.0	18.2	76.8	81.7	21.6	22.9	18.1	18.0
T3	90.4	80.3	394	377	18.0	19.5	104.8	103.4	12.8	13.7	19.2	19.1
T4	83.2	81.0	335	292	18.0	19.3	82.8	88.3	15.9	18.6	18.8	18.7
LSD (0.05)	2.44	2.29	31.9	40.0	1.0	0.7	6.59	3.32	1.07	1.08	0.62	0.6
R×T	ns	ns	ns	ns	ns	ns	**	ns	**	**	ns	ns

*T1 = Mixed water overall season (MW), T2 = Drainage water overall season (DW), T3 = MW to panicle initiation + DW to harvest and T4 = DW to panicle initiation + MW to harvest

same time, the highest values of DM 595.1 and 599.9 g m^{-2} were recorded when 6 cm flooding depth was used in 2003 and 2004 seasons, respectively.

Effect of ponded water depth and water quality treatments on yield components: It can be noticed that all yield components were significantly affected by ponded water depths except panicle length during 2004 season (Table 5). All yield components increased with increasing the ponded water depth up to 6 cm except sterility%. As it is mentioned earlier that submergence level of 6 cm improved the soil condition and enhanced the rice growth which led to increase in rice yield parameters. Also, the poor yield components resulted from saturation (0 cm) treatment failed to remove more harmful salts from the root zone and could not relief the salinity stress which ultimately affected the crop yield. The data are in an agreement with those reported by Biswas (1987).

With respect to the impact of water quality treatments, the data presented here showed a significant effect on yield characters. Highest mean values of yield components were recorded in MW T1 followed by MW till PI+DW up to the end of season T3 and DW till PI+ MW up to the end of season T4. However, using DW overall the season T2 sharply decreased all the yield components. For example, the average reduction (%) in number of panicles was 36.5, 14.1 and 30.2%, while for filled grains reduction was 29.71, 7.67 and 24.12% for T2, T3 and T4, respectively. Subsequently the number of panicles reduced severely under poor quality water followed by number of filled grains.

Finally, the yield components were restricted under poor quality water so it can be inferred that irrigation with drainage water accumulate more Na^+ and increase EC level resulting in unfavorable conditions for optimum rice growth. In addition, the saline irrigation inhabits reduces dry matter accumulation, lowers assimilation production and its transformation from stem or sheath to grains, restrict panicle formation and grain filling; and promote the early aging particularly during the grain filling period leading to decrease in rice grain yield (Zayed, 2002). It implies that use of poor quality water at early growth stages of rice is unfavorable. However, it is possible to use poor quality water at late growth stage with little yield reduction. The interaction between ponded water depth and water quality treatments had no significant effect on the studied yield components except number of filled grains per panicle in 2003 season, sterility% in 2003 and 2004 seasons and grain yield in 2004.

Effect of ponded water depth and water quality treatments on Na^+, Ca^{2+} and K^+ content in rice leaves: Data presented in Table 6 and 7 showed that Na^+, Ca^{2+} and K^+ in rice leaves were significantly affected by ponded water depths in both seasons. Increasing submergence level significantly increased Ca^{2+} and K^+ contents in rice leaves but Na^+ contents reduced. The maximum values recorded under flooding depth of 6 cm for K^+ were 6.57 and 6.72 mg g^{-1} and for Na^+ and Ca^{2+} were 1.36 and 1.63 mg g^{-1}, respectively in both seasons. While the lowest values of Na^+ contents in rice leaves were 2.42 and 2.87 mg g^{-1} resulted from flooding depth (6 cm). It seems that submergence level of saturation allowed more Na^+ accumulation in soil and resulted in high external Na^+, against Ca^{2+} and K^+ leading to more Na^+ uptake but less Ca^{2+} and K^+ uptake. Mohamed *et al.* (1987) stated that high external Na^+ in soil reduced Ca^{2+} uptake in which more Ca^{2+} and K^+ content in rice leaves enhanced salinity tolerance of rice.

Table 6: Na^+, K^+ and Ca^{2+} in leaves of rice crop as affected by water depth and quality treatments under salt-affected soil

	Na^+ (mg g^{-1})		K^+ (mg g^{-1})		Ca^{2+} (mg g^{-1})		$EC_{1:5}$ (dS m^{-1})	
Treatments	2003	2004	2003	2004	2003	2004	2003	2004
Water depth (R)								
0 cm	57.2	57.0	0.61	0.44	7.53	7.03	6.6	6.0
3 cm	49.0	49.4	0.67	0.50	7.93	7.59	5.9	5.5
6 cm	37.9	39.7	0.74	0.56	10.3	9.16	4.9	4.9
LSD (0.05)	4.90	3.27	0.03	0.03	0.39	0.32	0.27	0.30
Water quality (T*)								
T1	34.1	33.7	0.76	0.62	9.97	9.50	4.2	4.1
T2	68.6	67.8	0.57	0.42	7.34	6.23	7.4	7.3
T3	38.4	41.1	0.70	0.49	8.99	8.54	5.0	4.6
T4	51.1	52.5	0.64	0.47	7.98	7.43	6.6	5.9
LSD (0.05)	3.45	6.60	0.03	0.03	0.54	0.32	0.41	0.5
R×T	ns	ns	ns	ns	ns	ns	ns	ns

*T1 = Mixed water overall season (MW), T2 = Drainage water overall season (DW), T3 = MW to panicle initiation + DW to harvest and T4 = DW to panicle initiation + MW to harvest

Table 7: K^+ and Ca^{2+} content (mg g^{-1}) as affected by the interaction between water depth and quality treatments in leaves of rice crop in 2003 and 2004 seasons

		K^+ (mg g^{-1})				Ca^{2+} (mg g^{-1})			
Year	Water depth	T1*	T2	T3	T4	T1	T2	T3	T4
2003									
	0 cm	6.50	5.43	6.28	5.59	1.28	0.97	1.13	0.96
	3 cm	6.72	5.55	6.44	5.71	1.73	1.13	1.24	1.40
	6 cm	7.53	8.11	6.79	6.42	2.20	1.29	1.56	1.46
LSD (0.05)		0.198				0.13			
2004									
	0 cm	5.93	5.20	5.74	5.45	1.19	0.89	1.07	0.94
	3 cm	6.66	5.51	6.28	5.75	1.28	0.95	1.16	0.99
	6 cm	7.64	5.73	6.73	6.18	1.72	1.16	1.33	1.24
LSD (0.05)		0.27				0.09			

*T1 = Mixed water overall season (MW), T2 = Drainage water overall season (DW), T3 = MW to panicle initiation + DW to harvest and T4 = DW to panicle initiation + MW to harvest

Analogously, data showed that Na^+, Ca^{2+} and K^+ in rice leaves were markedly affected by the various alternatives of water quality treatments in both seasons. The using of MW overall season T1 treatment was found to restrict Na^+ uptake more, while Ca^{2+} and K^+ uptake increased. Drainage water T2 treatment showed contrary results regarding Na^+, $Ca^{2+}$and K^+ content in rice leaves. Also, the alternative irrigation with DW up to PI + MW up to the end of season did not improve Ca^{2+} and K^+ uptake or content in leaves against Na^+ content. Drainage water has much higher Na^+ than Ca^{2+} and K^+contents under such treatment. High Na^+ content in rice leaves reduced photosynthesis rate, lowered growth and decreased the grain yield. However, reducing Na^+ content or uptake against Ca^{2+} and K^+ uptake is very important way to enhance the rice tolerance for salt hazard (Mohamed *et al*., 1987).

Effect of ponded water depth and water quality treatments on salinity level and some chemical composition of soil: Data listed in Table 8 showed that ponded water depths had significant effect on soil Na^+, Ca^{2+} and K^+ concentrations as well as salinity levels. Increasing flooding depth consistently reduced salinity levels and Na^+ concentration in soil, while Ca^{2+} and K^+ content increased. So, increasing applied water under saline soil had high ability to leach more Na^+ cation from soil which results in decrease in salinity level. Minimum Na^+ contents 37.9 and 39.7 mg g^{-1} soil and EC value 4.9 dS m^{-1} were recorded when 6 cm water depth was used in both seasons. While, 6 cm flooding depth treatment gave the highest value of Ca^{2+} and K^+content in the soil. The current results are in agreement with those obtained by Biswas (1987) and Zayed (1997).

Water quality treatments affected the mean values of Ca^{2+}, K^+, Na^+ contents and EC level in order; T2<T4<T3<T1 irrespective of irrigation treatments. Thereby, MW applied through out the season T1 gave lowest values of Na^+ contents in soil and EC value, while Ca^{2+} and K^+ contents were high. It can be reduce salinity level with intermittent saline irrigation, fresh water or slight saline irrigation which can be applied during season instead of poor water. Drainage water increased Na^+ accumulation and EC values and reduced available Ca^{2+} and K^+ content in soil. High Na^+ contents in soil and high

Table 8: EC, Na^+, K^+ and Ca^{2+} in soil as affected by water depth and quality treatments under salt-affected soil

	Na^+ (mg g^{-1})		K^+ (mg g^{-1})		Ca^{2+} (mg g^{-1})	
Treatments	2003	2004	2003	2004	2003	2004
Water depth (R)						
0 cm	3.41	3.28	5.58	5.95	1.02	1.08
3 cm	2.98	3.22	6.05	6.10	1.09	1.38
6 cm	2.42	2.87	6.57	6.72	1.36	1.63
LSD (0.05)	0.29	0.12	0.23	0.07	0.08	0.06
Water quality (T*)						
T1	1.34	1.98	6.74	6.92	1.04	1.74
T2	4.04	4.19	5.48	5.69	1.00	1.13
T3	2.51	2.61	6.25	6.51	1.19	1.30
T4	3.35	3.75	5.79	5.91	1.06	1.27
LSD (0.05)	0.38	0.14	0.17	0.12	0.04	0.08
R×T	ns	ns	ns	ns	ns	ns

Table 9: Summary of the analysis of variance for the effect of water depth and quality treatments on the affected grain yield, water applied and WUE in 2003 and 2004 seasons

		F-value		
Source of variation		Water applied (mm)	Grain yield (kg ha^{-1})	WUE (g m^{-3})
2003	Water depth (R)	6892.0**	406.0**	24.4**
	Water quality (T)	247.8**	1218.0**	802.0**
	R×T	11.9**	32.9**	20.4**
2004	Water depth (R)	6044.0**	3428.0**	1874.0**
	Water quality (T	204.4**	3164.0**	5821.0**
	R×T	13.9**	65.2**	190.2**

**p<0.01, *p< 0.05 and ns = not significant

EC values produced more Na^+ uptake, less Ca^{2+} and K^+ uptake, less growth and low grain yield. It can be concluded from the data that submergence level of irrigation under salt affected soil has to be increased up to 6 cm and saturation level is not recommended under such circumstances. The substitution of DW to MW at late growth is possible with little yield reduction.

Effect of ponded water depth and water quality treatments on water applied and water use efficiency: Data presented in Table 9 showed that the ponded water depth, quality treatments and their interactions have significant effect on grain yield, water applied and WUE. Results showed that the mean values for amount of applied water (mm) in both seasons increased with increasing ponded water depth (Fig. 2 and 3). The highest mean values of amounts of applied water were 1183 and 1146 mm recorded for 6 cm water depth in 2003 and 2004 seasons, respectively. This might be due to the greater water losses by percolation. As rice is the only crop which can grow in standing water, consequently, high irrigation losses occurred in the rice fields (Abou El Hassan, 2005). Regarding the effect of ponded water depth on rice grain yield, the data showed in Fig. 2 and 3 indicate that increase in ponded water depth led to increase in yield under all water quality treatments during the both seasons. Grain yield of rice crop had the same pattern as of its component under various ponded water depths. This can be attributed to the characteristics of rice crop, which is more sensitive to ponded water. WUE values were higher under 6 cm ponded water depths than those under 0 or 3 cm water depth. That mean grain yield of rice is more effective on WUE than amount of applied water. The treatments under 6 cm water depths recorded the highest mean values of WUE 333 and 310 g m^{-3} during 2003 and 2004 seasons, respectively.

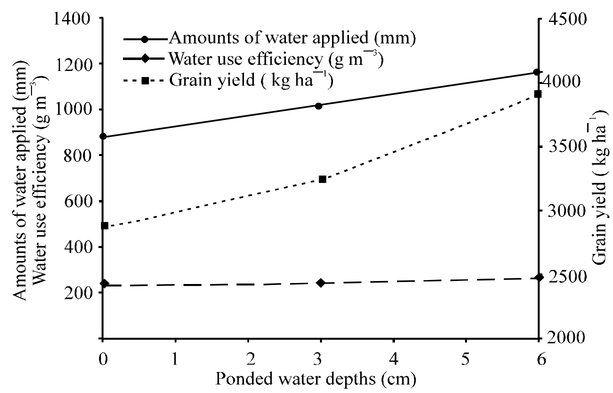

Fig. 2: The effect of ponded water depth on amounts of applied water, water use efficiency and rice yield in 2003 experimental season

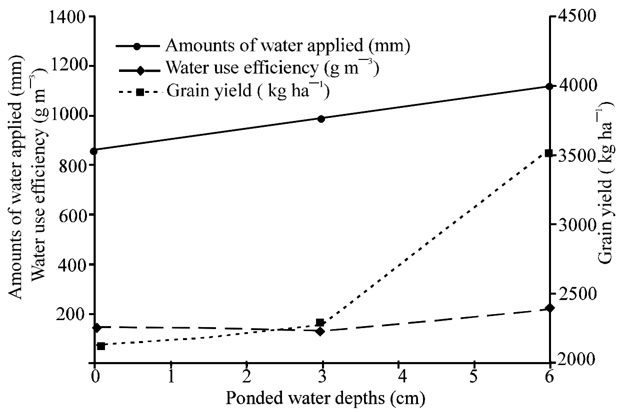

Fig. 3: The effect of ponded water depth on amounts of applied water, water use efficiency and rice yield in 2004 experimental season

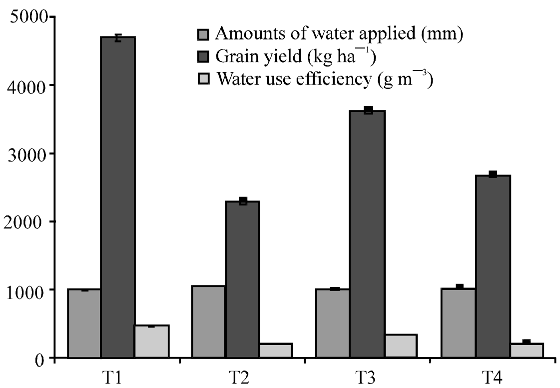

Fig. 4: The effect of water quality treatments on amounts of applied water, water use efficiency and rice yield in 2003 experimental season

Regarding the effect of water quality on amount of water applied to rice crop, the data shown in Fig. 4 and 5 indicate that the lowest mean values of amount of applied water were 1010 and 991 mm recorded for T1, while the highest mean values for amount of applied water were 1080 and 1055 mm recorded for T2 in 2003 and 2004 seasons, respectively. Thus, it is clear that drainage irrigation accumulated more Na^+ and enhanced EC level resulted an unfavorable effect on rice growth under such condition. In case of effect of water quality on grain yield of rice crop, the data illustrated in Fig. 4 and 5 indicate that grain yield varied in order: T1 > T3 > T4 > T2, in both seasons. Also, the highest values of rice grain yield were 4.68 and 3.9 t ha^{-1} obtained when submergence

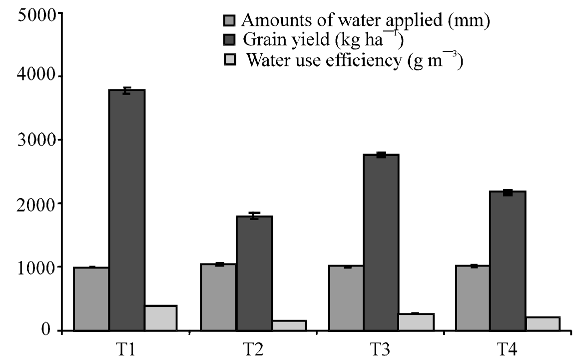

Fig. 5: The effect of water quality treatments on amounts of applied water, water use efficiency and rice yield in 2004 experimental season

level of 6 cm was applied with MW through out the season (T1).The reduction% in grain yield (as an average for both seasons) due to various poor quality water treatments were 51.4, 24.5 and 42.4% for T2, T3 and T4 treatments, respectively. Also, the WUE differed in the order; T1 > T3 > T4 > T2, in both seasons. Mixed water T1 treatment was recorded with maximum WUE values of 462 and 382 g m^{-3} during 2003 and 2004 seasons, respectively. As shown in Table 2, the monthly average values of crop coefficient (Kc) for rice calculated during 2003 seasonal, based on Modified Penman method, were 1.384 (May), 1.426 (June), 1.456 (July), 1.394 (August) and 1.383 (September). While, for 2004 seasonal Kc values were 1.394 (May), 1.390 (June), 1.411 (July), 1.404 (August) and 1.362 (September). These results indicated that the value of Kc was lowest at early stages of growth and increased gradually up to the maximum in mid of season (grain filling stage) and then decreased at maturing stage.

Whole discussion can be concluded as follows:

Use of MW at early growth stage and its substation by DW at late growth stage is preferred for rice growth under saline soil condition. Also, flooding depth with 6 cm is recommended to apply when poor quality water has to be used in the irrigation under salt affected soils, which helps to leach more salts. Maximum grain yield (4.68 and 3.90 t ha^{-1}) was obtained when submergence level of 6 cm was applied with MW over all season.

- High sodium and low Ca^{2+} and K^+ contents in rice leaves negatively affected rice growth, dry matter production and assimilate transformation as well as yield components and grain yield. It is recommended that more water should be added under saline soil or saline water circumstances to improve Ca^{2+} and K^+ contents in rice leaves.

- Maximum mean values of amount of applied water were (1183 and 1146 mm) recorded for 6 cm water depth in 2003 and 2004 seasons. The treatments under 6 cm water depths recorded the highest mean values of WUE of 333 and 310 g m^{-3} during 2003 and 2004 seasons, respectively.
- Regarding the effect of water quality treatments on amounts of water applied to rice crop, maximum amount of water applied was 1080 and 1055 mm recorded for T2 treatment during 2003 and 2004 seasons, respectively. While, the T1 was recorded with maximum mean values of WUE of 462 and 382 g m^{-3} during 2003 and 2004 seasons, respectively.
- Based on WUE results, it is suggested that under saline soils rice crop should be irrigated up to 6 cm ponded water depth with mixed water (MW) of 1.92 dS m^{-1} salinity level.

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