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Low-Quality Water and Water Movement in Flooded Rice Soil

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ABSTRACT

A field experiment was conducted in the experimental station, Fac. Agric., Mansoura Univ., Egypt, on rice crop *(Oryza sativa L.)* to evaluate the ability of soil degradation resist as a result of low water quality and farmyard manure application. The experiment involved nine treatments, three irrigation waters quality (tap water, saline sodic water and saline water) and three rates of farmyard manure (0, 5 and 10 ton fed^{-1}). The experiment was designed in split plot design. The results illustrated that the highest fresh and dry weight was recorded with the soil irrigated by tap water followed by saline water and amended with FYM rates 10 and 5 ton fed^{-1}. These results may be attributed to the increase in soil physical properties i.e. saturated hydraulic conductivity (Ks), mean pore diameter (MPD), bulk density (BD) and pore size distribution (PSD). Furthermore, the addition of FYM increased the soil content of organic carbon (SOC) which considered the main reason in improving the soil physical properties in combination with the good chemical composition of irrigation water (Ca^{+2} more than Na^{+}).

Keywords: Low-quality water, saturated hydraulic conductivity, pore size distribution, and rice crop.

INTRODUCTION

In irrigation areas of Egypt, inadequate rainfall and limited surface water supply have led to use the low water quality i.e. agriculture drainage water for irrigation to sustain crop production and control the increasing salinity in deep soils (Joseph *et al.*, 2010). However, soil salinization is one of the major threats to land desertification that frequently appears in regions with drought climate that adversely affects crop production and environmental health (Shokri-kuehni *et al.*, 2017 and Nachshon *et al.*, 2018).

Soil porosity and hydraulic conductivity were the two most important characters regulating water flow, deep percolation (Walker, 1999) which affects the storage of water and air available to plants. However, application of organic matter is often recommended as an applicable choice to maintain good soil structure by increasing soil organic carbon and encourage soil flocculation and aggregation (Tisdall and Oades 1982), which increases the macro porosity and then improves water movement (Martens and Frankenberger, 1992).

On the other hand, rice is the essential source of food for more than one third of the world's population (Joseph *et al.*, 2010). Water is the major factor in rice production. Most rice is grown where the soil is flooded during part or all of the growing season. Several studies dealing with water in flooded rice fields have focused on the different sides of water use and little attention has been paid to the behavior of water in the soil.

The objective of this study was to evaluate the soil degradation resistant as affected by different water quality and FYM applications under rice cultivation.

MATERIALS AND METHODS

1. Site description

A field experiment was conducted at the experimental station, Fac. Agric., Mansoura Univ., Egypt (31°04̄N, 31° 35̄E), on rice crop *(Oryza sativa L.)*.The initial physical and chemical properties of the soil sample (0-20) cm were represented in Table (1).

The standard methods for soil and water analysis were described by Piper (1950), U.S.S.L.S (1954), Black *et al.*, (1965), Hesse (1971), Hillel (1980) and Singh (1980). The micronutrients and heavy metals in water samples were estimated using Qtegra ISDS Data Processing Algorithms for ICAP 7000 Series ICP-OES (Ammann, 2007).

Table 1. Initial values of some physical and chemical properties of the experimental soil.

Physical properties	Value	Chemical properties	Value
Particles size distribution:		pH (in soil paste)	8.54
Coarse sand %	3.45	EC_e dSm^{-1} (in soil paste extract)	2.64
Fine sand %	7.74	$CaCO_3$ %	1.28
Silt %	38.07	Organic matter %	0.79
Clay %	50.74	Soluble cations* ($cmol_{(p+)}$ kg^{-1})	
Texture class	Clayey	Na^+	0.79
Soil order	Entisols	K^+	0.05
Saturation percent %	66.58	Ca^{+2}	0.52
Field capacity %	34.00	Mg^{+2}	0.32
Wilting point %	16.25	Soluble anions* ($cmol_{(p+)}$ kg^{-1})	
Available water %	17.00	CO_3^{-2}	0.00
Hydraulic conductivity ($mday^{-1}$)	0.04	HCO_3^-	0.42
Bulk density ($Mg\ m^{-3}$)	1.12	Cl^-	0.70
Real density ($Mg\ m^{-3}$)	2.27	SO_4^{-2}	0.53
Total porosity %	50.66	Available macro nutrients ($mg\ Kg^{-1}$)	
Void ratio	1.03	N	59.83
		P	11.59
		K	235.00

*** Soluble cations and anions were measured in soil paste extract.**

2. Experimental design

A spilt plot design involved nine treatments and three replicates on a low saline sodic soil. The soil was irrigated with three irrigation waters quality i.e. tap water (EC_{tw} = 0.47 dSm^{-1} & SAR_{adj} = 1.69), saline sodic water (EC_{ssw} = 3.17 dSm^{-1} & SAR_{adj} = 20.82) and saline water

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(EC_{sw} = 4.61 dSm^{-1} & SAR_{adj} = 5.77) and three rates of FYM (0, 5 and 10 ton fed^{-1}) were applied in (5.0×2.0 m^2) plot. The quantity of FYM per plot was 0, 12, 24 Kg.

Rice variety Sakha 104 was cultivated after adding the FYM rates, calcium super phosphate (15% P_2O_5) at 100 Kg fed^{-1}, one third quantity of N dose and the traditional field preparation. Dry seeds were cultivated by broadcast method on the soil surface at 50 Kg fed^{-1} on May 6th in 2017, and then incorporated either by ploughing while the soil is still dry. After planting, the plots were irrigated until the surface soil was saturated (without flooding). The harvest dates were on October 2nd in 2017. The total growing period was 146 days.

The quantity of irrigation water was measured using mechanical water meter at inlets, and during the cultivation season, 16 irrigations (each 5-7 cm) were applied, resulting in total water depths of 40 cm. The quantity of irrigation water was approximately 63 m^3 for the studied area for each once. The rice fields were dried for about 10 days during the season to control rice weeds and insects as a result of long flooding and anaerobic conditions. At each growth stage, the rice plant has received chemical fertilizers as the recommended doses given by Ministry of Agriculture 150 Kg fed^{-1} $(NH_4)_2SO_4$ (75% from RD) and 50 Kg fed^{-1} K_2SO_4 (100% from RD).

The initial analysis of FYM showed that $EC_{1:5}$, $pH_{1:5}$, organic carbon, total N, P, K were 2.82, 7.38, 26.5%, 1.16%, 0.78% and 0.43%, respectively.

The two agricultural drainage waters were collected every five days from drainage near Mit Khames Village Mansoura District. The analysis of water samples were listed in Table (2).

Table 2. Analysis of irrigation water types.

Parameter		Mean Values of irrigation water*			Recommended
		Tap	Saline	Saline Sodic	Max. Conc.**
pH		7.14	7.34	9.48	6.5-8.4
EC (dSm^{-1})		0.47	4.61	3.17	0-3
RSC		-1.60	-23.83	2.52	1.25-2.50
$SAR_{Adj.}$		1.69	5.77	20.82	6-24
SO_4^{-2} (mmol L^{-1})		0.40	14.44	8.49	0-20
Cl^-(mmol L^{-1})		2.50	7.31	13.96	4-10
NH_4^+		0.00	6.61	2.91	0-5
NO_3^-		0.00	11.00	3.47	0-30
B		0.00	0.53	0.46	0.7-3
Fe		0.02	4.53	1.23	5.00
Cu	mg L^{-1}	0.00	0.18	0.07	0.20
Zn		0.01	1.34	0.82	2.0
Mn		0.01	0.17	0.09	0.20
Cd		0.00	0.01	0.00	0.01
Pb		0.01	2.16	1.57	5.00
Ni		0.00	0.06	0.10	0.20
Water Class***		Normal	Severe salty	Severe salty and sodic	

*** The mean values of the number of irrigation during the season.**
**** Adapted from National Academy of Sciences (1972) and Pratt (1972).**
***** According to Ayers and Westcot (1985).**

3. Experimental Measurements

The depth of flooding water was recorded every two days at several points in the field. The surface soil and plant samples were collected at vegetative (65th DAT), tillering (95th DAT) and harvest (146th DAT).

The soil saturated hydraulic conductivity was measured according to Singh, (1980) by irrigation water types. The desorption curve was determined by soil water-vapor pressure relationships according to (Danielson, 1980 and Schofield and Dacosta, 1935). Also, soil mean pores diameter (μm) was calculated by Dielman and De Ridder, (1972).

RESULTS AND DISCUSSION

1. Fresh, Dry weight of rice

The low irrigation waters quality and FYM applications significantly affected the most fresh and dry weight of rice crop during the season (Table 3).

Table 3. Analysis of variance for fresh, dry weight of rice crop as affected by applying FYM and different water qualities.

Treat.	1st Stage		2nd Stage		3rd Stage	
	F_W	D_W	F_W	D_W	F_W	D_W
Irrigation (I)	NS	23.5*	NS	29.9*	NS	34.3*
FYM (F)	30.2*	NS	31.4*	NS	NS	30.7*
I ×F	29.1**	21.8*	NS	32.2**	NS	28.4*

***, ** = Significant at P<0.05 and 0.01, respectively and NS= Not-Significant**

The irrigation with saline sodic and saline waters (I_2 and I_3) resulted an increase in rice fresh weight at most growth stages (Fig. 1) especially when adding any rate of FYM. On the other hand, tap water (I_1) was the most effective water in increasing rice fresh and dry weight with or without adding FYM followed by saline water (I_3) only with FYM. Rao, (1998) and Choudhary *et al.,* (2010) reported that organic materials particularly FYM can help in restoring soil physical quality and increased nutrient availability of the degraded soils i.e. sodic soil.

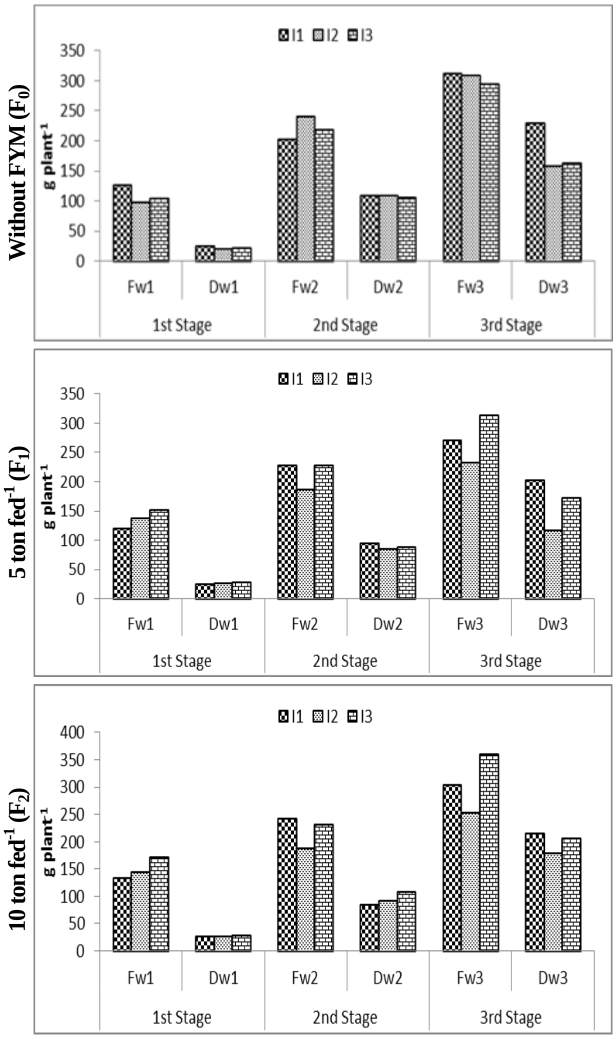

Fig. 1. Effect of irrigation water qualities and FYM application on fresh and dry weight of rice crop at different growth stages.

2. Soil properties

The irrigation water qualities and FYM rates have a significant effect on soil by improving the most estimated parameters i.e. saturated hydraulic conductivity (Ks), bulk density (BD), mean pore diameter (MPD) and porosity as shown in Table (4).

Table 4. Analysis of variance for some soil properties as affected by applying FYM and different water qualities.

Treat.	1st Stage					2nd Stage					3rd Stage				
	Ks	BD	E	MPD	SOC	Ks	BD	E	SOC	MPD	Ks	BD	E	SOC	MPD
Irri. (I)	0.10*	0.04*	1.54*	0.32*	0.04**	0.12**	NS	NS	0.11*	0.48**	0.20**	0.08*	3.15*	0.09**	0.83*
FYM (F)	0.14**	0.01**	0.21**	0.45**	0.06*	0.08**	NS	NS	NS	0.39**	0.08**	0.05**	2.22**	0.06**	0.24**
I ×F	0.09*	0.02**	0.5**	0.47*	NS	0.17*	NS	NS	0.14**	0.51*	0.13**	0.11*	2.5*	NS	0.57**

***, ** = Significant at P<0.05 and 0.01, respectively and NS= Not-Significant**

Water flow and mean pore diameter

The saline irrigation water with a high rate of FYM (10 ton fed^{-1}), increased the saturated hydraulic conductivity (Ks) as a result of increase the mean pore diameter (MPD) compared with the other irrigation water (Fig. 2). The I_1F_2 was the most perfect treatment in increasing the rate of water flow by 160, 131% at 2nd and 3rd growth stage, respectively compared with control (I_1F_0). At 2nd growth stage, I_3F_2 treatment increased the rate of water flow by 69% comparing with (I_1F_2) treatment.

On the contrary, using of saline-sodic water recorded the lowest mean values for water flow. In general, the water flow and MPD at the 2nd growth stage (tillering) of rice growth take a decreasing trend for all the treatments. A number of researchers reported that irrigation with sodic water high in HCO_3^- leads to increase soil pH and exchangeable Na^+, decrease soil permeability and aeration due to crusting, clay dispersion and migration leading to clogging of pores (Grattan and Oster, 2003 and Oster, 2004) thereby adversely affecting crop productivity (Choudhary *et al.*, 2006 and Minhas *et al.*, 2007).

Bulk density and porosity

Soil bulk density and porosity were significantly affected by water qualities and FYM applications especially at the vegetative and harvest stages of rice growth (Table 4 and Fig. 2). The I_1F_2 treatment was recorded as the meanest values of bulk density by a rate of 20%, meanwhile the soil porosity was decreased by 22% compared with control (I_1F_0). These results agree with Enas, (2018) who reported that the poor quality water had a harmful effect on soil porosity and structure.

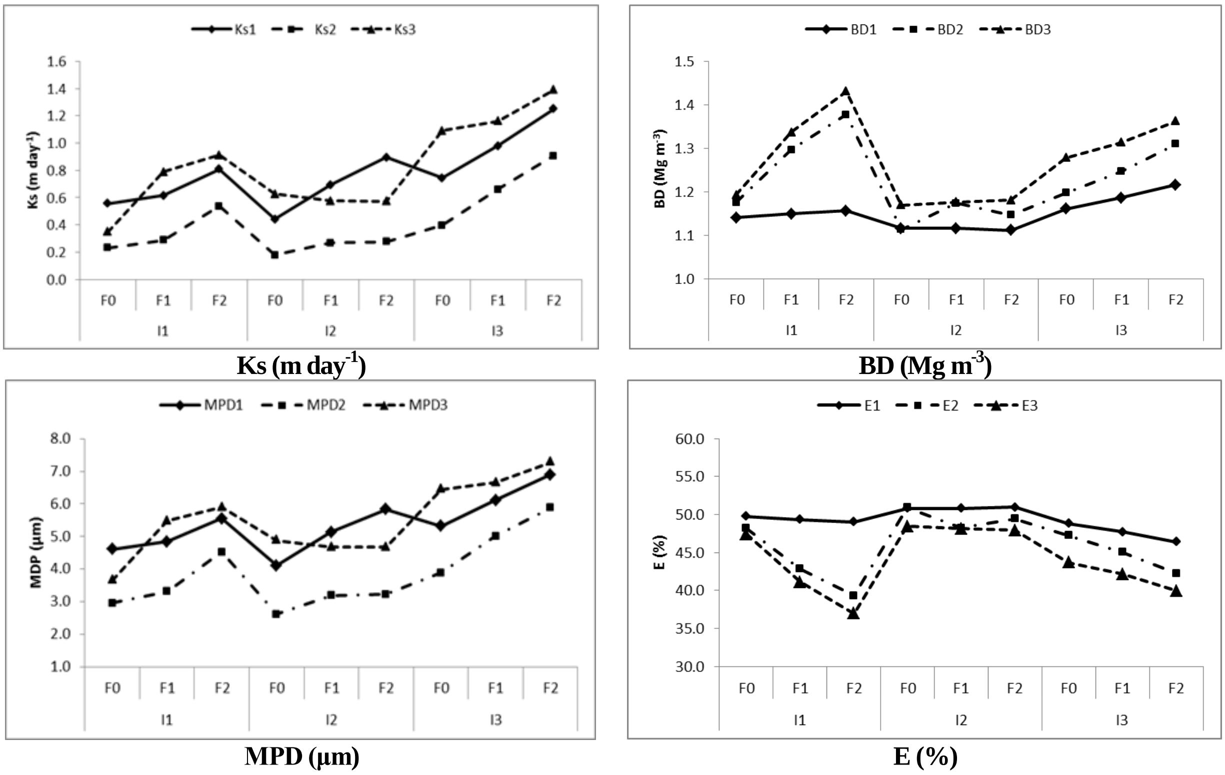

Fig. 2. Effect of irrigation water qualities and FYM applications on some physical properties of the studied soil.

Pore size distribution

Description of the pore system provides a realistic foundation for understanding the retention and flow of water in the soil. Furthermore, knowing how pores participate in the overall fabric of the soil and its capability to transmit solutes. The combination effect of water quality and FYM was very obvious in changing the pore size distribution. Table (5) shows that irrigation by tap and saline water increased the pore size as increasing the FYM rates at most moisture degrees. Whereas the larger pore more than 500 µm decreased by applying FYM with tap water as compared with control (I_0F_0). The impact of FYM (with tap water) in increasing the pore size was found at bonding pore (less than 0.005 µm), on the other hand the effect of FYM (with saline water) was more effectiveness at pore more than 0.5 µm as compared with tap water. These results are agree with Greenland, (1981), who reported that the storage pores (0.5-50 µm), as well as transmission pores (50-500 µm), are necessary for soil water movement and plant growth. Pores larger than 500 µm can have some useful effects on water movement (drainage) and root penetration, especially in clayey soils.

On the contrary, the irrigation by saline-sodic water with addition of FYM at 5 ton fed^{-1} (F_1) was better than 10 ton fed^{-1} (F_2), generally, the additions of FYM had a reverse effect on pore size as a result of increasing the sodium content in water consequently in soil. The pore size decreased with FYM additions; moreover, the problem of water flow will increase especially at high moisture degree as compared with control (I_2F_0).

In addition, negative high correlations -(0.96-0.91) have been found between pore size distribution and soil porosity until moisture degree 50% and pore size less than 8 µm which responsible for holding and storage water and there are negative moderate correlations -(0.70-0.67) between pore size distribution and hydraulic conductivity at the same moisture degree and pore diameter.

Table 5. Effect of irrigation water qualities and FYM applications on pore size distribution of the studied soil after harvest stage.

Treat.	r (µm) at different water moisture degrees (θ_m)%							
	10	20	30	40	50	60	70	80
Tap Water (I_1)								
F_0	0.00032	0.0036	0.0405	0.453	5.06	56	631	7042
F_1	0.00057	0.0057	0.0574	0.576	5.79	58	585	5872
F_2	0.00099	0.0091	0.0833	0.765	7.03	65	593	5442
Saline Sodic water (I_2)								
F_0	0.00023	0.0025	0.0271	0.297	3.25	36	389	4251
F_1	0.00031	0.0030	0.0302	0.299	2.97	29	291	2885
F_2	0.00030	0.0027	0.0238	0.214	1.92	17	155	1387
Saline water (I_3)								
F_0	0.00035	0.0037	0.0392	0.415	4.40	47	493	5226
F_1	0.00048	0.0049	0.0512	0.530	5.48	57	587	6080
F_2	0.00087	0.0086	0.0840	0.825	8.10	79	780	7659

It is concluded that the organic matter applications can improve most soil physical properties through increased soil aggregation (Zhang and Fang, 2007), increase in the volume of macro-pores while decreasing micro-pores (Hati *et al.,* 2006) increased saturated hydraulic conductivity (Ndiaye *et al.,*2007), consequently improved soil water-holding capacity at both field capacity and wilting point (Rasool *et al.,*2007).

Soil organic carbon (SOC)

The amendment of soil by FYM resulted in higher soil organic carbon (SOC) at all the treatments during the plant season compared with control (Fig. 3). Also, it is found that SOC increased at harvest stage. The highest mean value was recorded after harvest especially when soils irrigated by saline (1.32%) then tap water (1.30%). These increases may be attributed to the following reasons: (1) many of nano-sized pores connected and could receive quantities of SOC from micro and meso-pores in both micro and macro-aggregates as suggested by Marschner and Kalbitz, (2003), (2) formation of stable aggregates (particularly in soil irrigated by saline and tap water) enhanced physical protection of SOC against microbial decomposition (Six *et al.,* 1998). Moreover, Mansour, (2012) showed that SOC content was found to increase with increasing stages of plant growth at FYM rate of 12 ton fed^{-1}.

Increasing of pore size considers an indicator to forming new aggregates. These results confirmed by Kaiser and Guggenberger, (2003), they found that the majority of soil sorptive surfaces are located among the meso and micro-pores of aggregate interiors. Also, the expanding of intra-aggregate pore connectivities and associated pore networks will help the greater quantities of carbon to be retained by the best managed soils. Besides, greater SOC within aggregates also stabilizes aggregate pore structures, hydraulic conductivity and improving internal porosity (Park and Smucker, 2005). Therefore, the high content of organic matter increases resistance of the soil to degradation by using poor quality water through improving soil physical and hydraulic properties.

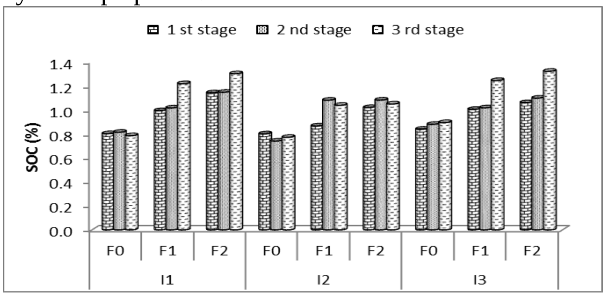

Fig. 3. Effect of irrigation water qualities and FYM applications on soil organic carbon in the studied soil.

CONCLUSION

The results indicate that the incorporation of organic manure with low-quality water had a beneficial effects on soil physical properties. Hence, it increased soil organic carbon content, helped regenerate soil structure and improved soil physical and hydraulic properties. These are important for sustaining production in rice crop irrigated by poor quality water. Thus, the use of these poor quality waters for irrigation without proper amendments should be discouraged and special management.

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المياه منخفضة الجودة وحركة الماء بأراضي الأرز المغمورة

إيناس مصطفى سليمان و مصطفى محمود منصور
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أجريت تجربة حقلية في مزرعة كلية الزراعة ـ جامعة المنصورة ـ المنصورة، علي نبات الأرز لتقييم قدرة التربة علي مقاومة التدهور الناتج عن استخدام مياه ري منخفضة الجودة مع إضافة السماد البلدي. اشتملت التجربة علي تسع معاملات هي: ثلاث أنواع من مياه الري (الماء العادي، ومياه ملحية صودية، ومياه ملحية) وثلاث معدلات من السماد البلدي (صفر, و5, و10 طن ف$^{-1}$) في تصميم قطع منشقة. أوضحت النتائج أن التربة المروية بالماء العادي يليه الماء المالح والمضاف لها سماد بلدي بالمعدلين 10، و5 طن ف$^{-1}$ علي الترتيب. ويرجع سبب هذه النتائج إلي زيادة قيم الخواص الطبيعية بالتربة كالتوصيل الهيدروليكي المشبع, ومتوسط قطر المسام, والكثافة الظاهرية، والتوزيع الحجمي للمسام. علاوة علي ذلك, أدت إضافة السماد البلدي إلي زيادة محتوي التربة من الكربون العضوي والذي يعتبر السبب الرئيسي في تحسين الخواص الفيزيائية للتربة بالارتباط مع التركيب الكيميائي الجيد لمياه الري (محتوي الكالسيوم أعلي من الصوديوم).