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Saline Drainage Water, Irrigation Frequency and Crop Species Effects on Some Physical Properties of Soils

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With 4 tables

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Abstract

This field study evaluated the effects of water quality, irrigation frequency and crop species on some physical properties of soils. The experiment had a split-split-plot design, with three irrigation water qualities (normal water, drainage water and a 1 : 1 mixture of freshwater and drainage water) as the main treatments, two irrigation frequencies (at 7- and 14-day intervals) as the subtreatments and two crops (barley and alfalfa) as the subsubtreatments. The soil infiltration rate was highest in the barley plot receiving freshwater irrigation at weekly intervals. The lowest soil infiltration rate was found in alfalfa plots receiving saline irrigation water at 14-day intervals. Bulk density and proportions of micropores [pore radius (r) $< 1.4\,\mu$m] were higher and the proportion of macropores (r $> 14.4\,\mu$m) was lower in barley than in alfalfa. Saline irrigation caused the greatest decrease in total porosity. The soil infiltration rate was higher with more frequent irrigation, and was highest in alfalfa plots receiving freshwater irrigation. The decrease in soil bulk density and infiltration rate was greater with saline drainage water, irrespective of the crop grown and the irrigation frequency.

Key words: alfalfa — barley — bulk density — infiltration rate — irrigation — irrigation frequency — saline water

Introduction

Soil salinization, under the influence of saline irrigation, is a serious problem for enhanced crop production. Development of soil salinity has increased significantly in the Eastern Region of the Kingdom of Saudi Arabia. Poor physical conditions and chemical properties characterize most of the agricultural soils. Reclamation of salt-affected soils requires measures such as removal of excess soluble salts beyond the root zone by leaching, application of organic or chemical amendments, use of crop rotation and freshwater irrigation. Various crops were reported to improve soil permeability and promote removal of sodium (Na) and salts from the soil (Robbins 1986). As well as suitable crop cultivars, correct crop rotations are essential for achieving continuous improvement of saline and sodic soils (Yadav 1975). Gibbs and Reid (1988) reported that the crop species had a significant effect on soil structure. Deterioration of soil structure was reported to occur under arable crops such as wheat (*Triticum aestivum* L.) and barley (*Hordeum vulgare* L.) (Low 1972). Ojeniyi (1978) found that cultivation of barley resulted in lower soil macroporosity and smaller aggregates. Reid and Goss (1981) postulated that differences in aggregate stability caused by different crop species resulted from contrasting root patterns, especially the proportion of lateral roots, as the release of organic materials occurred mainly near the root tips.

Very little work has been carried out to date on the interactive effects of water quality, crop species and irrigation frequency on soil properties. This paper evaluates the effects of water quality, crop species and irrigation frequency on some specific soil physical properties.

Materials and Methods

The experiment was carried out at the Al-Hassa Irrigation and Drainage Authority Experimental Station, Eastern Region, Kingdom of Saudi Arabia. The climate of the region is arid with a mean annual rainfall of 94 mm, a mean annual temperature of 28.1 °C and relative humidity of 49.7 %. The soil texture of the experimental plots was sandy loam with a bulk density of 1.45 g cm^{-3}. The volumetric water contents were 28 % at field capacity and the −1.5 MPa volumetric water contents were 13.9 %.

The experimental site was ploughed with a moldboard plough in summer followed by two tillage operations with a field cultivar prior to planting. The plot size was 2 m × 2 m, and the walkway between plots was 1 m wide with vertical drains isolating the different treatment plots. Barley (*Hordeum vulgare* L. cv. Gusto) was planted on 8 November 1992 using a seeding rate of 130 kg ha^{-1} and alfalfa (*Medicago sativa* L. cv. Higazi) was planted on 12 October 1992 using a seeding rate of 50 kg ha^{-1}. In the following year, barley was sown on 11 November 1993. A conventional grain seeding drill with a row spacing of 0.2 m was used for planting both the crops. The experimental design was a split-split-plot design. There were three irrigation water qualities [normal water (SI), drainage water (S2) and 1 : 1 mixture of freshwater and drainage water (S3)] as the main treatments, two irrigation frequencies (I1, 7-day irrigation interval, and I2, 14-day irrigation interval) as the subtreatments and two crops (C1, barley and C2, alfalfa) as the sub-subtreatments. Each treatment was replicated three times.

The crops were established by applying freshwater (EC = 2.1 dS m^{-1}) at a uniform rate of 2157 m^3 ha^{-1} $month^{-1}$ for the initial period of 1 month. After that time, the plants had achieved the desired ground cover and could bear saline water irrigation. At this crop stage, different frequencies of irrigation treatment were used. The mean chemical composition of the different irrigation waters is given in Table 1. Irrigation water was applied through the basin system of irrigation at two irrigation frequencies to replenish the soil water deficit up to a 0–90 cm depth of soil. The soil moisture deficit was measured using a neutron probe at each 30-cm depth of soil before each irrigation. Two access tubes were placed between two plant rows in each plot. The amount of irrigation water applied was based on the crop consumptive use of water in the area.

Undisturbed soil cores were taken from 0–10, 10–20 and 20–30 cm depths at three locations, both within and between plant rows, in June 1993. The soil cores were used to determine soil bulk density and soil moisture retention using a pressure membrane apparatus (Klute 1986). The soil cores were saturated by capillary. Apparent pore size distribution was inferred from soil water retention characteristics using the surface tension relationship at 20 °C, $d = 0.298\,h^{-1}$, where h is soil water potential and d is pore diameter (Marshall 1959). Composite soil samples were taken from 0–10, 10–20 and 20–30 cm depths at five locations in each subplot in June 1993. The soil cores were air-dried, ground, passed through a 2-mm sieve and analysed for particle distribution by the hydrometer method (Klute 1986). The infiltration rate of the soil was measured with double-ring infiltrometers at two locations in each subplot.

Data were analysed statistically by three-way analysis of variance using SAS (SAS Institute 1987).

Results and Discussion

The effect of the crop on bulk density was significantly greater than that of irrigation frequency or water quality, the effect of water quality not being significant (Table 2). However, bulk density tended to be lower with saline water than with freshwater irrigation. Deoring and Reeve (1965) and Misopolinos (1985) reported similar results. The bulk density was higher in the surface than the subsurface soil layers in barley than cropped area, which received freshwater irrigation. The bulk density of the soil was significantly higher in the 0–10 cm soil layer under the barley crop than under the cropped area. The bulk density was 1.59 g cm^{-3} after two croppings of barley than alfalfa crop where it was 1.54 g cm^{-3} under continuous cropping as compared to a post cropping bulk density of 1.18 g cm^{-3}. The soil was relatively well aggregated, dried uniformly and was loosely packed at the start of the experiment, as indicated by the initial low bulk density of the soil.

Table 1: Chemical composition of irrigation water

Water type	EC	pH (dS m^{-1})	Concentration (meq l^{-1}) Na	Cl	Ca	K	Mg	HCO_3	SO_4	Adj. SAR[1]	Water class
1992–93											
Normal	3.5e	7.6a	27.9cd	23.3d	7.1d	1.2d	6.1d	1.5c	4.1c	18.6d	C3S4
Mixed (1 : 1)	7.9d	7.6a	48.2b	35.8cd	14.2c	4.1b	11.5cd	1.9c	6.2c	31.6c	C4S2
Drainage	11.2b	7.5a	68.5b	48.4c	23.7ab	6.1a	19.4ab	2.3c	8.1c	42.1b	C4S4
1993–94											
Normal	3.2e	7.3a	10.4d	22.3d	7.0d	0.6d	5.6d	3.3b	5.7c	16.6d	C3S1
Mixed (1 : 1)	9.5c	7.2a	72.8b	73.8b	18.4bc	3.4c	16.9bc	3.9b	33.8b	49.7	C4S3
Drainage	16.1a	7.1a	126.4a	125.3a	29.7a	5.6a	28.0a	5.2a	59.9a	79.3a	C4S4

[1]SAR: adjusted sodium adsorption ration.
Means followed by the same letter in each column are not significantly different according to the Duncan's multiple range test ($P < 0.05$).

Table 2: Effect of crop species, water quality and irrigation frequency on post-trial soil bulk density (g cm^{-3})

Treatment	Bulk density depth increment (cm)			
	0–10	10–20	20–30	Mean
Crop species				
Barley	1.59	1.54	1.52	1.55
Alfalfa	1.54	1.50	1.50	1.51
$LSD_{0.05}$	0.02	ns	ns	ns
Water quality				
S_1	1.57	1.53	1.54	1.55
S_2	1.54	1.50	1.48	1.51
S_3	1.56	1.52	1.51	1.53
$LSD_{0.05}$	ns	ns	ns	ns
Irrigation frequency				
I_1	1.57	1.52	1.50	1.53
I_2	1.54	1.49	1.47	1.49
$LSD_{0.05}$	0.02	0.02	0.01	0.03

The bulk density of soil in the 0–10 and 10–20 cm layers was not affected significantly by crop species or water quality. Mean bulk density was 1.52 g cm^{-3} at 0–10 cm and 1.51 g cm^{-3} at 10–20 cm soil depth.

The effect of irrigation frequency on bulk density varied significantly between the barley and alfalfa cropped plots. Application of irrigation water at 7-day intervals resulted in significantly higher bulk density than application at 14-day intervals. In general, the bulk density of soil at all depths showed increases over the entire experimental period.

Soil characteristics such as sorptivity, transmissivity and infiltration rate measured at 1-min and 2-h intervals were affected significantly by crop species, water quality and irrigation frequency (Table 3). The values of these soil characteristics were highest in the barley plot receiving freshwater at 7-day intervals and lowest in alfalfa cropped plots receiving saline water at 14-day intervals. The beneficial effect of barley on the infiltration rate of soil could be primarily due to more tillage during land preparation, preventing crust formation at the soil surface (IITA 1984).

Table 3: Effect of crop species, water quality and irrigation frequency on infiltration characteristics

Treatment	Sorptivity (mm min^{-1})	Transmissivity (mm min^{-1})	Infiltration rate (mm min^{-1})		Infiltration (cumulative at 2 h)
			1 min	2 h	
Crop species					
Barely	90	7.53	58.3	16.1	1962
Alfalfa	73	−0.87	28.4	6.5	1189
$LSD_{0.05}$	14.4	4.12	11.9	5.6	539
Water quality					
S_1	89	3.63	59.3	15.3	1754
S_2	81	1.71	41.6	10.9	1551
S_3	76	−0.35	29.2	7.7	1422
$LSD_{0.05}$	3.2	0.74	9.7	1.4	129
Irrigation frequency					
I_1	86	3.43	46.3	15.8	2086
I_2	77	−0.10	40.4	6.8	1065
$LSD_{0.05}$	2.6	1.58	3.8	3.0	608

Table 4: Effect of crop species, water quality and irrigation frequency on post-trail soil water content and pore size distribution at different soil depths

	Saturation percentage ($m^3 m^{-3} \times 100$)				Pore size distribution											
					I < 1.4 μm				r = 1.4 –14.4 μm				r = 14.4 μm			
	Soil depth (cm)				Soil depth (cm)				Soil depth (cm)				Soil depth (cm)			
Treatment	0–10	10–20	20–30	Mean	0–10	10–20	20–30	Mean	0–10	10–20	20–30	Mean	0–10	10–20	20–30	Mean
Crop species																
Barley	49.3	43.8	40.9	44.7	53.6	47.5	45.1	48.7	28.5	32.2	35.3	32.3	19.7	19.3	20.6	19.3
Alfalfa	45.2	40.7	36.4	40.8	29.5	25.5	21.4	25.5	22.9	30.2	34.2	34.5	47.6	44.3	43.1	45.0
$LDS_{0.05}$	3.2	2.5	3.3	3.2	12.9	13.3	14.7	13.8	4.3	1.9	0.6	2.5	14.7	10.6	17.9	12.9
Water quality																
S_1	52.6	47.5	43.3	47.8	47.5	43.8	41.6	44.3	28.4	34.2	36.8	33.1	24.1	22.0	21.6	22.6
S_2	45.1	42.7	39.9	42.6	45.6	40.9	37.8	41.4	26.9	31.1	35.6	31.2	27.5	28.0	26.6	27.4
S_3	44.1	36.6	32.8	37.8	31.6	24.8	20.4	27.1	21.8	29.8	32.3	28.0	46.6	45.4	47.3	46.4
$LSD_{0.05}$	0.4	4.7	2.5	1.9	7.5	5.1	3.9	1.2	2.6	3.6	2.0	1.4	4.9	9.7	7.8	3.3
Irrigation frequency																
I_1	54.6	49.1	44.5	49.4	55.2	48.9	43.8	49.3	30.0	33.0	36.6	33.2	14.8	18.1	20.4	17.8
I_2	39.9	35.4	32.8	36.0	27.9	24.1	22.7	24.9	21.4	30.4	33.2	28.3	50.7	45.5	43.3	46.5
$LSD_{0.05}$	12.5	11.9	9.3	4.7	11.9	11.5	18.3	17.3	5.9	1.5	2.8	3.3	26.7	11.1	17.3	14.7

r = radius.

The infiltration rate of soil was higher under more frequent irrigation (Table 3). The initial infiltration rate of soil was 18.3 mm min^{-1} and the maximum infiltration rate measured after 2 h was obtained under the barley crop receiving freshwater irrigation at 7-day intervals. This could be attributed to the combined effect of higher soil porosity and the non-formation of soil crust in barley plots. Oster and Schroer (1979) and Sharma (1986) reported similar increases in the infiltration rate of soil. However, the increase in the infiltration rate of soil reported by Reeve and Bower (1960), Mohite and Shingte (1981) and Misopolinos (1985) is in contradiction to the present findings.

The saturation percentage of soil at a depth of 10–20 cm was lowest in alfalfa plots irrigated with saline water at 14-day intervals (Table 4). There were no significant differences among other treatments. The soil water retention characteristics in the 0–10 cm soil layer reflected the pore size distribution at that particular soil depth.

Crop species and water quality significantly affected pore size distribution, but this was not affected by irrigation frequency at any soil depth. The volume of macropores differed to a greater extent than the volume of micropores among the various crop species treatments. This suggests that the changes in soil bulk density and total porosity due to crop species could be the result of a collapse of macropores with a subsequent increase in the volume of micropores (Bauder and Brock 1992). However, the alfalfa crop resulted in a higher proportion of macropores (pore radius, $r > 14.4\,\mu m$) and lower proportion of micropores (pore radius, $r < 1.4\,\mu m$) at 0–10 cm soil depth than the barley crop. The proportion of mesopores ($r = 1.4$–14.4) was not affected significantly by crop species, water quality or irrigation frequency. The changes in pore size distribution reflect the degree of compaction, which was highest at a soil depth of 0–10 cm under the alfalfa crop.

Previous studies (Gish and Jury 1982) indicated that the presence of a growing crop could decrease the macroporosity and hydraulic conductivity of the soil. This was attributed to root activity. Plant roots enlarge pores, create new pores and compact the soil around plant roots, thus decreasing the size and percentage of macropores. Root decomposition frees channels for water movement thus increasing the hydraulic conductivity of the soil (Gish and Jury 1982). Soil water retention and pore size distribution beyond a soil depth of 0–10 cm were not affected significantly by any of the experimental treatments except crop species.

Zusammenfassung

Salzhaltiges Drainagewasser, Bewässerungshäufigkeit und Kulturpflanzenarten mit Wirkung auf einige physikalische Eigenschaften des Bodens

Eine Felduntersuchung wurde vorgenommen, um dem Einfluss der Wasserqualität, der Bewässerungshäufigkeit und Kulturpflanzenarten auf einige physikalische Eigenschaften von Böden zu untersuchen. Die Infiltrationrate mit Frischwasser in wöchentlichen Abständen unter Gerste war hoch. Eine Behandlung mit Salzwasser in 14 tägigen Abständen unter Luzerne zeigte eine geringere Infiltrationsrate des Bodens. Bodendichte und der Anteil der Mikroporen (Poren mit einem Radius von $r < 1{,}4$ mm) waren größer und der Anteil der Makroporen ($r > 14{,}4$ mm) war unter Gerste geringer. Bewässerung mit Salzwasser verursachte die stärkste Abnahme in der Gesamtporosität. Die Infiltrationsrate des Bodens nahm mit der Häufigkeit der Bewässerung zu und zeigte den höchsten Wert bei Luzerne und einer Frischwasserbewässerung. Die Abnahme in der Bodendichte und der Infiltrationseigenschaften waren bei Salzwasserdrainage unabhängig von der Kulturpflanzenart und der Bewässerungshäufigkeit höher.

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