Interaction between the Effects of Deficit Irrigation and Water Salinity on Yield and Yield Components of Rice in Pot Experiment

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Abstract : Water scarcity and salinity are important limitations for agricultural production in semi-arid region. The purpose of this research is to study the interaction between the effects of water salinity and deficit irrigation on yield as grain per pot and yield components in greenhouse conditions. The irrigation treatments were continuous flooding (control), intermittent flooding (intervals of 1 or 2 d); W_o, W_1, and W_2, respectively. The salinity levels of irrigation water were 0.6 (control), 1.5, 3.0, 4.5 and 6 dS m^{-1} in year of 2005 and 0.6 (control), 1.5, 2.5, 3.5 and 4.5 dS m^{-1} in the year of 2006, which are referred to as S_o, S_1, S_2, S_3 and S_4, respectively. A local cultivar (Kamphiroozi) was planted in pots in a greenhouse in 2005 and 2006. The results indicated that grain weight per pot was not significantly different between continuous flooding and intermittent flooding at 1-d intervals. The volumetric water contents of soil before each irrigation in the intermittent flooding at 1- and 2-d intervals were 0.36 and 0.34 cm^3 cm^{-3} with a corresponding matric head of -431 cm and -594 cm, respectively. The grain weight per pot was not reduced significantly by salinity level of 1.5 dS m^{-1} in W_o and W_1, while it decreased significantly at salinity levels higher than 2.5 dS m^{-1} in W_2. With increasing irrigation water salinity levels from S_o to S_1, the straw weight per pot increased significantly. Generally, increased irrigation water salinity reduced 1000-grain weight, but water stress mitigated the reduction of 1000-grain weight by salinity. With increasing irrigation salinity beyond threshold (1.5 dS m^{-1}), deficit irrigation resulted in significantly higher number of spikelets per panicle compared with flooding irrigation. Increased salinity with deficit irrigation resulted in a higher percent of unfilled grain. With increasing salinity level of irrigation water beyond the threshold values (1.5 dS m^{-1}) the deficit irrigation resulted in a lower percent of unfilled grain. respectively. The reduction of average grain weight per pot per unit increase of salinity of saturation extract was 14.5% per dS m^{-1} in continuous flooding, and 11.0% per dS m^{-1} in intermittent flooding (1-d and 2-d intervals) in the two years of study. The average reduction of grain weight per pot per unit increase in irrigation water salinity was 38.0% per dS m^{-1} in continuous flooding, 17.0% per dS m^{-1} in intermittent flooding (1-d and 2-d interval) during the two years of study. Finally, it is concluded that with saline water at 2.5–3.0 dS m^{-1}, intermittent irrigation is preferable for rice production and with saline water at 3.5 dS m^{-1} or higher continuous flood irrigation failed to produce grains, but intermittent irrigation produced some grains whose weight per pot was about 50% of that in non-saline irrigation water.

Key words : Matric and osmotic head, Saline water, Water saving irrigation.

Introduction

Rice (*Oryza sativa* L.) is one of the most important food crops in the world. It is a major food grain for more than half of the world population. Rice is a grain that provides more than 80% of the daily calories for the consumers (Gallagher, 1984). The world population is continuously increasing, while the world renewable fresh water resources are limited. Increasing world population requires more water for domestic, industrial, environmental, recreational and agricultural needs. Although water is abundant in global scale, 97% is saline, 2.25% is glacier and just 0.75% is available as freshwater in watersheds, rivers and lakes (FAO, 2003). Because of the scarcity of water resources, their effective use has been emphasized (FAO, 2003).

Therefore, wastewater and saline water must be used in food production.

According to FAO statistics, paddy production in I.R. of Iran is about 2.3 million tons from 578,000 ha in Mazandaran, Guilan, Fars, Khuzestan and Isfahan provinces (Anonymous, 2006). In these provinces, the irrigation water is supplied from surface and groundwater sources. The quality of surface water is declining due to mixing of drainage water in river water in the upstream regions. The groundwater quality deteriorated by over pumping and salt water intrusion. Furthermore, higher cultivated land and municipal and industrial water uses enhanced the scarcity of irrigation water. Therefore, irrigation water scarcity and low water quality are challenging issues in these regions especially for rice production that is the

Table 1. Physico-chemical properties of the soil used in the experiment.

Physical property		Chemical property	
Sand (%)	5	Ca (mg L^{-1})	176.3
Silt (%)	49	Cl (mg L^{-1})	35.5
Clay (%)	46	Na (mg L^{-1})	5.57
Field capacity (cm^3 cm^{-3})	0.35	K (mg L^{-1})	0.6
Permanent wilting point (cm^3 cm^{-3})	0.21	CaCO$_3$ (mg L^{-1})	326.9
Bulk density (g cm^{-3})	1.26	pH	6.82
		EC (dS m^{-1})	0.5
		P (mg kg^{-1})	20.0

main crop in Mazandaran and Guilan provinces.

Water scarcity resulted in water stress in plants, which affects the physiological processes regulating plant growth. The effect of water stress on plant growth varies with the type of cultivar, degree and duration of water stress and stage of plant growth (Anonymous, 2004). Dry matter accumulation at flowering and maturity was significantly reduced in deficit irrigation conditions, but at the reproductive stage drought significantly increased the dry matter partitioning from leaves to stems (Kumar et al., 2006; Boonjung and Fukai, 1996). Intermittent flooding was not significantly different from continuous flooding irrigation for rice yield (Pirmoradian et al., 2004a). Furthermore, intermittent flooding increased water-use efficiency by 20 to 60% compared with continuous flood irrigation (Pirmoradian et al., 2004a). Optimum water supply was achieved by intermittent flooding (2-d interval) and reduction in nitrogen uptake in continuous flood irrigation due to the nitrate leaching from the root zone was reported (Pirmoradian et al., 2004b).

With increasing water salinity beyond 3.4 dS m^{-1}, grain weight per plant, grain weight per panicle, spikelet number per panicle and tiller number per plant decreased (Zeng and Shannon, 2001; Asch and Wopereis, 2001). Although the separate effects of water saving irrigation and water salinity on rice yield have been reported by many investigators, there is little information on their interaction.

The objective of the present study was to determine the interaction between the effects of water salinity and deficit irrigation on yield and yield components of rice in pot experiments.

Materials and Methods

This research was conducted in a greenhouse at the College of Agriculture, Shiraz University in 2005 and 2006. The soil was a silty clay from rice planting area (Kooshkak, Fars province). It was collected from the top 20 cm layer and some of the physico-chemical properties of this soil are shown in Table 1. The soil was air-dried, crushed to pass through a 2-mm sieve.

Plastic pots with 23.5 cm in height and 23 cm in diameter filled with 8.25 kg of air dried soil. Twenty five seeds (local low tiller cultivar of Kamphiroozi) were planted in each pot on 18 and 27 April, 2005 and 2006, respectively and each pot irrigated with tap water to field capacity.

Nitrogen (N) and phosphate (P) were applied uniformly to all pots at the rate of 163 mg kg^{-1} soil of ammonium nitrate (equivalent to 120 kg ha^{-1} N) and 51.6 mg kg^{-1} soil of triple superphosphate, Ca(H$_2$PO$_4$)$_2$ (equivalent to 50 kg ha^{-1} P), respectively. After 2 wks, seedlings were thinned to 15 plants per pot and after 4 wks, they were thinned to 10 plants per pot. The planting scenario in pot was in accordance to that in the field condition, where seedlings transplanted with a spacing of 20×20 cm in hills each with 3–4 seedlings. Therefore, on a unit area basis, the number of plants in pot was similar to that planted in fields. At this stage, the irrigation and salinity treatments were started. Three irrigation treatments consisted of continuous flooding, intermittent flooding at 1-d intervals and intermittent flooding at 2-d intervals. A flexible drain tube was connected to the bottom end of the pot wall for water drainage for intermittent irrigation treatments. These tubes were closed for continuous flood irrigation treatment. A standing water depth of 3.0 cm on the soil surface of the continuous flood irrigation was kept by daily water application. In intermittent irrigation treatments, water was applied 1- and 2-d after the standing water disappeared. The amount of applied water in these treatments was the sum of water required to raise the soil water to saturation and a standing water depth of 3.0 cm.

The salinity levels of the irrigation water were 0.6 (tap water), 1.5, 3.0, 4.5 and 6.0 dS m^{-1} in year 2005 and 0.6 (tap water), 1.5, 2.5, 3.5 and 4.5 dS m^{-1} in 2006, which were adjusted by adding NaCl and CaCl$_2$ to the tap water at equal equivalent proportions. Table 2 shows the results of the chemical analysis of the saline irrigation water. The experimental layout was a 3×5 factorial arrangement with four replications and analysis of variance (ANOVA) was performed for this arrangement. The maximum and minimum air

Table 2. Chemical analysis of the saline irrigation water used in the experiment.

EC dS m^{-1}	pH	Cl mg L^{-1}	Na mg L^{-1}	Ca mg L^{-1}	HCO$_3$ mg L^{-1}
0.6	7.95	60.3	19.2	128.0	388.1
1.5	8.01	414.8	96.6	224.0	306.4
2.5	7.70	620.2	110.5	388.4	306.4
3.0	7.91	719.6	136.6	497.0	306.4
3.5	7.30	1505.9	175.7	670.4	294.3
4.5	7.52	1772.5	226.9	882.0	245.1
6.0	7.25	2230.3	359.6	1523.0	265.6

temperatures were 37 ± 7 and 15 ± 5°C, respectively.

Undisturbed samples of soils were used to determine the soil water retention curve using a hanging water column and pressure plate apparatus. The soil water retention is shown by the following equation:

$$\theta = 0.21 + 0.23(1 + |0.015 \times h|^{1.153})^{-0.133} \qquad (1)$$

where θ is the soil volumetric water content in cm^3 cm^{-3}, and h is the soil water matric head in cm.

Soil water content before each irrigation in pots was measured by weighing the pots. Drainage water was collected seven times during the growing season. Electrical conductivity was determined in the drainage water during the growing season. Soil water content before each irrigation converted to matric head of soil water by using Eqn (1).

In field conditions with soil similar to that used in this pot experiment, the deep percolation in continuous flood irrigation is about 2–3 mm d^{-1} while in a pot experiment with continuous free drainage under continuous flood irrigation, the drainage rate should be several folds that in the field conditions. Therefore, under free drainage conditions in pot experiments the salt accumulation would be much lower than that in the field conditions. Therefore, in this experiment, the drain was kept closed in continuous flood irrigation and then, opened bi-weekly (seven times during the growing season) for salt washout to simulate the field conditions in continuous flood irrigation. Furthermore, the amount of irrigation water was about 2300 to 2700 mm in the flood irrigation treatment, which is similar to those used in farmers fields with soil similar to that used in the pot experiment. Leaching fraction in this pot experiment varied from 0.5 to 0.8 for intermittent and flood irrigation. The leaching in the field occurred in the first quarter of the root zone with a leaching fraction of 0.15 for the whole root zone. Thus, the salt leaching condition in the pot experiment is similar to that in field condition.

Before harvest, the number of panicles per plant

Table 3. Grain weight per pot of rice (g pot^{-1}) at different levels of salinity with irrigation at different intervals in 2005 and 2006.

Salinity levels dS m^{-1}	Irrigation intervals		
	Continuous (W$_0$)	1-d (W$_1$)	2-d (W$_2$)
	2005		
0.6 (S$_0$)	19.07 a*	15.65 ab	13.43 bc
1.5 (S$_1$)	17.73 a	13.84 bc	12.30 bcd
3.0 (S$_2$)	8.99 de	10.72 cde	10.94 cde
4.5 (S$_3$)	0.00 f	8.04 e	8.66 e
6.0 (S$_4$)	0.00 f	2.87 f	2.29 f
	2006		
0.6 (S$_0$)	20.30 a	17.54 ab	15.44 bc
1.5 (S$_1$)	18.06 ab	15.38 bc	14.21 c
2.5 (S$_2$)	9.95 de	12.11 cd	11.45 cd
3.5 (S$_3$)	0.91 f	7.88 de	8.50 de
4.5 (S$_4$)	0.00 f	7.07 e	8.10 de

* Means followed by the same letter in each column and rows are not significantly different at 5% level of probability by Duncan multiple range test.

was determined. At harvest, the plants were cut at the soil surface and the roots were also washed free of soil. Plant tops and roots were dried in an oven at 65°C for 48–72 hr. Grains were separated from straw and weighed. The grain weight was corrected to 14% moisture content. Sub samples of grains were used to determine the 1000-grain weight and unfilled grains percentages. Before root separation from soil, soil samples were collected for chemical analysis. Electrical conductivity, and concentrations of chloride, Ca+Mg and Na were determined in soil saturation extracts.

Results and Discussion

1. Grain weight

Table 3 shows the grain weight per pot in different treatments in 2005 and 2006. There was a significant interaction between the effects of the salinity level of water and the irrigation treatments on grain weight ($p < 0.001$). The salinity levels were not the same in the two consecutive years. Therefore, the mean grain weight per pot over two years was not determined and the data were presented separately. There was no significant difference between grain weights per pot at control salinity (0.6 dS m^{-1}) with continuous flood irrigation and 1-d interval intermittent irrigation at 1-d intervals and 1.5 dS m^{-1} salinity with continuous flood irrigation. However, grain weight per pot at the control salinity with continuous flood irrigation was significantly higher than that with 2-d interval intermittent irrigation. The mean soil water content and matric head before intermittent irrigation at 2-d intervals were 0.34 cm^3 cm^{-3} and −594 cm, respectively while they were 0.36 cm^3 cm^{-3} and −431 cm, respectively

Table 4. Straw weight per pot of rice (g pot^{-1}) at different levels of salinity with irrigation at different intervals in 2005 and 2006.

Salinity levels	Irrigation intervals		
dS m^{-1}	Continuous (W$_0$)	1-d (W$_1$)	2-d (W$_2$)
	2005		
0.6 (S$_0$)	51.41 b*	45.02 bcd	38.53 c
1.5 (S$_1$)	63.34 a	47.02 bcd	40.21 cde
3.0 (S$_2$)	41.87 bcde	47.53 bcd	43.93 bcd
4.5 (S$_3$)	26.90 fg	33.97 ef	36.35 de
6.0 (S$_4$)	12.71 h	33.97 ef	22.36 g
	2006		
0.6 (S$_0$)	37.80 ab	28.24 cd	30.47 bcd
1.5 (S$_1$)	40.73 a	41.11 a	33.17 abc
2.5 (S$_2$)	37.40 ab	37.38 ab	38.39 ab
3.5 (S$_3$)	22.41 de	37.31 ab	31.37 bcd
4.5 (S$_4$)	18.73 e	27.27 cde	24.89 cde

* Means followed by the same letter in each column and rows are not significantly different at 5% level of probability by Duncan multiple range test.

Table 5. Number of panicles per plant for rice at different levels of salinity with irrigation at different intervals in 2005 and 2006.

Salinity levels	Irrigation intervals		
dS m^{-1}	Continuous (W$_0$)	1-d (W$_1$)	2-d (W$_2$)
	2005		
0.6 (S$_0$)	2.68 a*	2.45 ab	2.23 abc
1.5 (S$_1$)	2.85 a	2.18 abc	1.93 abc
3.0 (S$_2$)	1.55 cd	2.18 abc	2.23 abc
4.5 (S$_3$)	0.00 e	1.50 cd	1.63 cd
6.0 (S$_4$)	0.00 e	1.05 d	0.90 d
	2006		
0.6 (S$_0$)	2.45 a	1.55 bc	1.68 bc
1.5 (S$_1$)	2.50 a	1.65 bc	1.63 bc
2.5 (S$_2$)	1.30 bcd	1.88 b	1.78 bc
3.5 (S$_3$)	0.50 ef	1.75 bc	1.15 cd
4.5 (S$_4$)	0.00 f	1.13 cd	0.90 de

* Means followed by the same letter in each column and rows are not significantly different at 5% level of probability by Duncan multiple range test.

before intermittent irrigation at 1-d intervals, which were similar to those obtained in the field by Pirmoradian et al. (2004a).

In continuous flood irrigation, increasing salinity of water to 3.0 dS m^{-1} in 2005 and to 2.5 dS m^{-1} in 2006 resulted in a significant reduction in grain weight per pot. However, the grain weight per pot in intermittent irrigation especially at a 2-d interval was not significantly reduced by increased salinity. Furthermore, the grain weight per pot in salinity level of 4.5 and 3.5 dS m^{-1} with intermittent irrigation was not statistically different from that at a salinity level of 3.0 and 2.5 dS m^{-1} with continuous flood irrigation in 2005 and 2006, respectively. This means that when salinity of irrigation water is higher than a threshold value, flood irrigation is not appropriate.

Table 3 shows that with intermittent irrigation, the grain weight pet pot at a salinity of 3.0 and 2.5 dS m^{-1} was statistically similar to that obtained at a salinity of 0.6 and 1.5 dS m^{-1}. Furthermore, no grain was obtained at a salinity of 4.5 and 6.0 dS m^{-1} with continuous flood irrigation, while considerable grain was obtained at a salinity of 4.5 dS m^{-1} with intermittent irrigation. In Khuzestan province of I.R. Iran, water with a salinity of 2.7 dS m^{-1} is used in rice production in the fields equipped with a subsurface drainage system and produces an acceptable grain yield (unpublished observation). These results indicated that when harmful saline water is used for rice irrigation, intermittent irrigation may reduce the soil salinity and cause less yield reduction.

In the study region with heavy texture soils, the most intensified root depth was about 30 cm. Furthermore,

the grain weight per pot of rice in the continuous flood irrigation with non-saline water (0.6 dS m^{-1}) in this pot experiment was equivalent to about 4.6 t ha^{-1}, being similar to that obtained in field conditions, which was about 5.0 t ha^{-1} (Pirmoradian et al., 2004a). These findings indicate that the height and diameter of pot (23 cm) is least limiting to the root and plant growth. A similar pot experiment at the Rice Research Institute in Guilan province (North of I.R. Iran with sub-humid climate) showed that grain weight per pot was equivalent to the grain yield in the field. The same method of planting, i.e., 10 plants per pot, was used in different treatments and the growth response was studied. Since the grain weight per pot in the control pot on a unit area basis, is close to that reported in the field (Pirmoradian et al., 2004a), the effects of treatments on grain weight per pot and yield components are comparable to those in the field conditions.

2. Straw weight

There was a significant interaction between the effects of the salinity level of water and the irrigation treatments (p<0.001) on straw weight per pot. In continuous flood irrigation, the increase in the salinity level to 1.5 dS m^{-1} increased the straw weight per pot significantly especially in 2005 (Table 4). At higher salinity levels (higher than 3.5 dS m^{-1}) straw weight per pot was reduced drastically. However, this decrease in straw weight per pot was smaller at higher salinity levels with intermittent irrigation.

Table 6. Unfilled grain of rice (%) at different levels of salinity with irrigation at different intervals in 2005 and 2006.

Salinity levels	Irrigation intervals		
dS m^{-1}	Continuous (W_0)	1-d (W_1)	2-d (W_2)
	2005		
0.6 (S_0)	23.25 h*	34.45 gh	39.60 fg
1.5 (S_1)	33.45 h	41.47 fg	53.40 def
3.0 (S_2)	46.88 efg	60.40 cde	64.95 cd
4.5 (S_3)	100.00 a	74.55 bc	68.43 cd
6.0 (S_4)	100.00 a	87.50 ab	93.50 a
	2006		
0.6 (S_0)	22.04 h	28.15 gh	30.59 g
1.5 (S_1)	32.01 g	29.50 gh	31.94 g
2.5 (S_2)	70.56 c	51.92 f	53.27 ef
3.5 (S_3)	94.32 a	60.48 de	65.44 cd
4.5 (S_4)	100.00 a	72.71 bc	78.76 b

* Means followed by the same letter in each column and rows are not significantly different at 5% level of probability by Duncan multiple range test.

Table 7. Weight of 1000-seed for rice (g) at different levels of salinity with irrigation at different intervals in 2005 and 2006.

Salinity levels	Irrigation intervals		
dS m^{-1}	Continuous (W_0)	1-d (W_1)	2-d (W_2)
	2005		
0.6 (S_0)	19.26 a*	18.81 ab	17.55 ab
1.5 (S_1)	17.47 abc	17.37 ab	15.85 abc
3.0 (S_2)	15.41 abc	16.41 abcde	15.86 abc
4.5 (S_3)	0.00 f	13.22 cd	13.71 bcde
6.0 (S_4)	0.00 f	10.21 de	22.36 e
	2006		
0.6 (S_0)	20.70 a	19.76 ab	18.75 abc
1.5 (S_1)	19.13 abc	17.74 bcd	17.08 bcde
2.5 (S_2)	16.15 cde	17.54 abcde	17.19 abcde
3.5 (S_3)	6.71 f	16.40 bcde	16.01 cde
4.5 (S_4)	0.00 g	14.00 e	14.25 de

* Means followed by the same letter in each column and rows are not significantly different at 5% level of probability by Duncan multiple range test.

3. Yield component

(1) Number of panicles per plant

There is a significant interaction between the effects of the salinity level of water and the irrigation treatments (p<0.001) in the number of panicles per plant. The number of panicles in plants was significantly smaller at the salinity levels greater than 1.5 dS m^{-1} in continuous flood irrigation (Table 5) while in intermittent irrigation, the number of panicles per plant was decreased significantly at salinity levels greater than 4.5 dS m^{-1}. Thus, it is indicated that number of panicles per plant was affected less by salinity at intermittent irrigation. This occurred because at a low salinity, panicle number is affected by intermittent irrigation, and at a high salinity by salinity itself. In other words, the magnitude of the effect of salinity is masked in intermittent irrigation, because at a low salinity the plant experiences drought stress. Furthermore, it is assumed that the effect of salinity in intermittent irrigation is less than in continuous irrigation because the absolute amount of salt added is less.

(2) Unfilled grain percentage

There was a significant interaction between the effects of the salinity level of water and the irrigation treatments (p<0.001) on unfilled grain percentage. The unfilled grain percentage increased at salinity levels higher than 1.5 dS m^{-1} in all irrigation treatments (Table 6). At lower salinity levels, more unfilled grains were obtained in intermittent irrigation. This was in accordance to the findings of other investigators (Pirmoradian et al., 2004a). However, the trend was reversed at higher salinity levels. This was due to the

Table 8. Root weight of rice (g pot^{-1}) at different levels of salinity with irrigation at different intervals in 2005 and 2006.

Salinity levels	Irrigation intervals		
dS m^{-1}	Continuous (W_0)	1-d (W_1)	2-d (W_2)
	2005		
0.6 (S_0)	14.88 abcd*	18.68 a	16.70 ab
1.5 (S_1)	13.38 abcde	15.12 abc	13.66 abcde
3.0 (S_2)	8.72c defg	10.82 bcdef	10.05 bcdefg
4.5 (S_3)	4.17 h	8.27 cdefg	7.24 defg
6.0 (S_4)	2.53 h	6.60 efg	4.95 fg
	2006		
0.6 (S_0)	16.90 b	21.92 a	19.40 ab
1.5 (S_1)	15.78 b	18.21 ab	17.38 b
2.5 (S_2)	8.31 cde	11.76 c	11.02 c
3.5 (S_3)	6.53 de	11.02 c	10.25 cd
4.5 (S_4)	4.50 e	7.79 cde	6.13 e

* Means followed by the same letter in each column and rows are not significantly different at 5% level of probability by Duncan multiple range test.

fact that in intermittent irrigation, soil salinity might be reduced and its effect on the unfilled grains was reduced.

(3) 1000-grain weight

There was a significant interaction between the effects of the salinity level of water and the irrigation treatments on 1000-grain weight (p<0.001). In

Table 9. Chemical properties of soil at harvest.

Salinity level dS m⁻¹	Irrigation interval	Year of experiment					
		2005			2006		
		EC dS m⁻¹	Cl mg L⁻¹	SAR mmol L⁻¹	EC dS m⁻¹	Cl mg L⁻¹	SAR mmol L⁻¹
S_0	W_0	1.35	493.6	0.51	1.23	465.5	0.53
S_0	W_1	0.75	154.5	0.27	0.74	84.3	0.31
S_0	W_2	0.65	159.2	0.25	0.70	78.0	0.28
S_1	W_0	4.55	2274.7	0.80	6.09	3828.6	0.73
S_1	W_1	2.01	1601.4	1.00	2.35	879.2	0.98
S_1	W_2	2.28	1095.5	0.81	3.16	1075.2	0.77
S_2	W_0	5.91	3802.0	0.23	6.40	4112.2	1.18
S_2	W_1	4.35	2397.4	1.78	4.04	3296.9	1.00
S_2	W_2	4.79	2016.3	1.52	4.60	3004.3	1.42
S_3	W_0	11.76	5651.6	0.94	7.35	4608.5	1.72
S_3	W_1	4.64	2485.9	1.59	5.05	3836.0	1.09
S_3	W_2	5.29	2207.5	1.33	5.56	4025.3	1.42
S_4	W_0	15.19	7103.3	0.71	10.25	7185.2	1.36
S_4	W_1	7.59	5689.7	0.97	6.80	4524.4	1.13
S_4	W_2	8.58	5558.3	0.56	7.05	4163.0	1.23

different irrigation treatments, salinity levels of 4.5 dS m⁻¹ or greater decreased 1000-grain weight significantly (Table 7). Furthermore, a significantly higher 1000-grain weight was obtained in intermittent irrigation at salinity levels greater than 3.5 dS m⁻¹ than in continuous flood irrigation. These results indicated that intermittent irrigation alleviated the reduction of 1000-grain weight by salinity.

4. Root weight

There was a significant interaction between the effects of the salinity level of water and the irrigation treatments on root weight (p<0.001). The root weight was reduced considerably at salinity levels greater than 2.5 to 3.0 dS m⁻¹ (Table 8). Similar reduction was obtained in different irrigation treatments. Root weight was not changed significantly by different irrigation treatments, but their values were higher in intermittent irrigation than in continuous flood irrigation. The relative increase in root weight with intermittent irrigation was greater at a higher salinity levels. This might be due to the fact that in intermittent irrigation smaller amount of water was used which resulted in lower soil salinity.

5. Soil salinity at harvest

Table 9 shows the soil salinity, chloride and sodium adsorption ratio in the saturation extract at harvest. At each salinity level, these parameters are lower with intermittent irrigation compared with continuous flood irrigation. These might be the main reasons for higher growth and yield in intermittent irrigation at
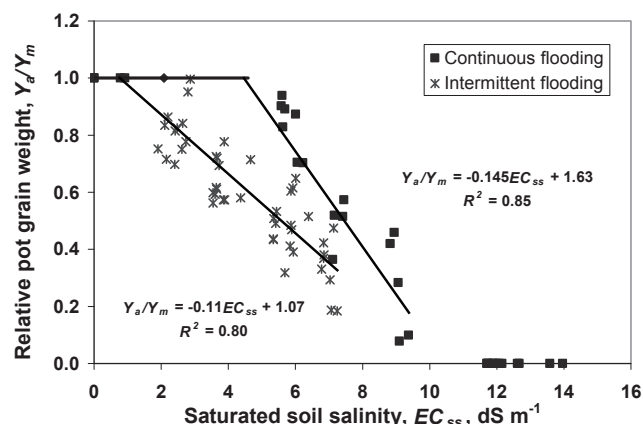

Fig. 1. Relationship between relative rice grain weight per pot (Y_a/Y_m) and mean saturated soil salinity in the continuous and intermittent irrigation treatments, not including the data at zero Y-intercept value (2005 and 2006)

higher salinity levels compared with continuous flood irrigation. Lower salinity in intermittent irrigation might also be due to the fact that soil water is lower than saturation and leaching after application of irrigation water is more efficient in washing salts from the soil.

Due to periodical washout of the accumulated salts in the continuous flood irrigation treatment, the seasonal mean salinity of drainage water in this treatment was about 2.0 dS m⁻¹ that is not limiting for rice growth with non-saline irrigation water. This value is about 13.0 dS m⁻¹ for irrigation water at a salinity of 6.0 dS m⁻¹ due to lower drainage rate in rice fields
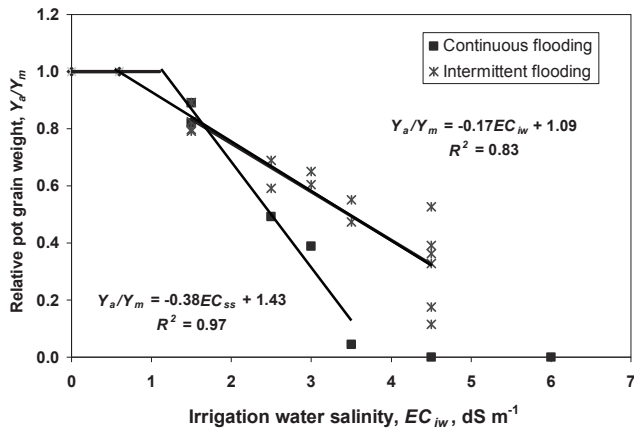
Fig. 2.   Relationship between relative rice grain weight per pot (Y_a/Y_m) and mean irrigation water salinity in the continuous and intermittent irrigation treatments, not including the data at zero Y-intercept value (2005 and 2006).

with heavy texture soils. Furthermore, the salinities of soil saturation extract at the time of harvest were 1.35, 4.55, 5.91, 11.76 and 15.19 dS m^{-1} for water salinities of 0.6, 1.5, 3.0, 4.5 and 6.0 dS m^{-1}, respectively, which are common in the field situations.

6. Analysis of soil salinity and grain weight per pot

Fig. 1 shows the relationship between relative grain weight per pot and soil solution salinity at saturation for continuous flood irrigation. Relative grain weight (Y_a/Y_m) is shown by the following equation

$Y_a/Y_m = -0.145EC_{ss} + 1.63$, $R^2 = 0.85$, $n = 16$,
SE $= 0.58$, $p = 3.6 \times 10^{-7}$ (2)

where: Y_a is the grain weight per pot at the designated salinity level and Y_m is the grain weight per pot at salinity level of 0.6 dS m^{-1} (Constant) and EC_{ss} is the soil solution salinity at saturation in dS m^{-1}. Equation 2 indicated that the threshold soil solution salinity for the reduction of grain weight per pot is 4.34 dS m^{-1} and the slope of the reduction of grain weight per pot is 14.5% per unit soil solution salinity at saturation. This relationship for intermittent irrigation is shown in Fig. 1 and its equation is as follows:

$Y_a/Y_m = -011EC_{ss} + 1.07$, $R^2 = 0.80$, $n = 60$,
SE $= 0.099$, $p = 1.29 \times 10^{-4}$ (3)

Eqn (3) indicated that the threshold soil solution salinity for the reduction of grain weight per pot is 0.64 and the slope of the reduction is 11.0% per unit soil solution salinity. This slope for intermittent irrigation is smaller than that for continuous flood irrigation. The lower EC threshold intermittent irrigation may be due to lower leaching fraction used in this irrigation than, in continuous irrigation.

Considering Tables 3–8 and Fig. 1, in general, continuous flood irrigation is better than intermittent irrigation for irrigation water at a low salinity, but it is worse for high salinity irrigation. There are two

kinds of stresses: drought, and salinity stress. Under low salinity, drought stress is limiting yield, and hence continuous flood irrigation is better than intermittent irrigation. Under a high salinity condition, the opposite is the case; salinity becomes limiting and because more salt are added under continuous flood irrigation, grain weight per pot was lower than that obtained under intermittent irrigation. These results suggest that there is some threshold level of salt above which salinity reduced the grain weight per pot (Fig. 1).

7. Water salinity and grain weight per pot analysis

Fig. 2 shows the relationship between relative grain weight per pot and irrigation water salinity for continuous flood irrigation in 2005 and 2006. The relationship is as follows:

$Y_a/Y_m = -0.38EC_{iw} + 1.43$, $R^2 = 0.88$, $n = 5$,
SE $= 0.71$, $p = 2.4 \times 10^{-3}$ (4)

Eqn (4) indicated that threshold of irrigation water salinity for the reduction of grain weight per pot is 1.13 dS m^{-1} and the slope of the reduction of grain weight per pot is 38% per unit salinity of irrigation water. Fig. 2 shows this relationship for intermittent irrigation and its equation is as follows:

$Y_a/Y_m = -0.17EC_{iw} + 1.09$, $R^2 = 0.83$, $n = 16$,
SE $= 0.98$, $p = 9.2 \times 10^{-7}$ (5)

Eqn (5) indicated that the threshold salinity of irrigation water for the reduction of grain weight per pot for intermittent irrigations is 0.53 dS m^{-1} and the slope of the reduction is 17% per unit salinity of irrigation water. The slope of the reduction of grain weight per pot for intermittent irrigation is much smaller than that for continuous flood irrigation. The lower EC threshold in intermittent irrigation may be due to less leaching fraction used in this irrigation than that in continuous irrigation.

Conclusions

Grain weight per pot, number of panicles per plant, percent of filled grains, 1000-grain weight, and root weight decreased with increasing salinity of irrigation water. While straw weight per pot increased with increasing salinity up to 1.5 dS m^{-1}. In general, application of saline water with intermittent irrigation reduced the grain weight per pot and yield components to a lesser degree.

Intermittent irrigation at 1-d intervals resulted in a similar grain weight per pot and average soil water content and soil matric head of 0.36 cm^3 cm^{-3} and −431 cm, respectively. The results indicated that soil water content before the intermittent irrigation at 1-d intervals is higher than soil field capacity.

Yield reduction per unit soil salinity of soil solution in intermittent irrigation (11.0% per unit salinity) was less than that in continuous flood irrigation (14.5% per unit salinity). The reduction of grain weight per pot per unit salinity of irrigation water in intermittent

irrigation (17% per unit salinity) was much lower than that in continuous flood irrigation (38% per unit salinity).

It is concluded that with saline water at 2.5–3.0 dS m^{-1}, intermittent irrigation is preferable for rice production and with saline water at 3.5 dS m^{-1} or higher no grain weight per pot was obtained in continuous flood irrigation while about 50% of that with non-saline irrigation water was obtained in intermittent irrigation. However, long-term use of saline water accumulates salts in soil and results in unsustainable irrigation practice leading to the necessity of land drainage and land leaching. Although these results can be applied to field conditions, it remains to be validated in field conditions in a future investigation.

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