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Effect of intermittent irrigation with saline water on rice yield in Rasht, Iran

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ABSTRACT

Guilan, a well-known province in rice production in Iran, has been facing water shortage and water degradation. In order to study the effects of salinity stress as well as water stress on rice a pot experiment was conducted at Rice Research Institute of Iran. Five water salinity levels: fresh water (EC = 1 dS m^{-1}), 2, 4, 6 and 8 dS m^{-1} and five irrigation regimes: continues flooding, Alternative Wetting and Drying (AWD), intermittent irrigation at 100, 90 and 80 percent of field capacity (FC) were considered as irrigation treatments. The results showed severe effects of water and salinity stresses on rice yield and yield components. Fresh water produced the highest yield, 18.57 gr pot^{-1}, whereas, the yield in salinity levels of 2, 4, 6 and 8 dS m^{-1} were 13.78, 5.78, 3.61 and 0.74 gr pot^{-1}, respectively, with the yield losses of 25, 70, 80 and 97%, respectively. Intermittent irrigation at FC produced the highest yield. The yield increased 8 and 13% in AWD and intermittent irrigation at FC treatments respectively, while it decreased 8 and 27% in intermittent irrigation at 80 and 90% of FC treatments as compared with continues flooding treatment. The highest yield with application of intermittent irrigation at FC was valid only in water salinity less than 4 dS m^{-1}. When water salinity was higher than 4 dS m^{-1} all irrigation methods gave the same yield. This study showed that the best method to use saline water was intermittent irrigation at FC with EC = 2 dS m^{-1}. In case of more salinity, mixing fresh and saline water and intermittent irrigation can mitigate the severe effects of salinity on rice.

Key words: rice, irrigation, saline water, Iran

IZVLEČEK

UČINEK PERIODIČNEGA NAMAKANJA S SLANO VODO NA PRIDELEK RIŽA V PROVINCI GUILAN, RASHT, IRAN

Provinca Guilan v Iranu, ki je poznana po pridelavi riža se sooča s pomanjkanjem vode in slapšanjem njene kakovosti. Z raziskovanje učinka slanosti in vodnega stres na riž je bil izveden lončni poskus na Inštitutu za preučevanje riža v Iranu (Rice Research Institute of Iran). Uporabljeno je bilo pet slanostnih stopenj vode: sladka voda (EC = 1 dS m^{-1}), 2, 4, 6 in 8 dS m^{-1} in pet režimov namakanja: stalna poplavljenost, izmenično namakanje in osuševanje (AWD), in periodično namakanje pri 100, 90 in 80 procentni poljski kapaciteti (FC). Izsledki so pokazali močne učinke solnega in vodnega stresa na pridelek riža in njegove komponente. Pridelek je bil največji v sladki vodi, 18.57 g/lonec, medtem ko so bili pridelki pri slanostih 2, 4, 6 in 8 dS m^{-1} 13.78, 5.78, 3.61 in 0.74 g/lonec, z izgubo pridelka 25, 70, 80 in 97 %. Periodično namakanje pri poljski kapaciteti je dalo največji pridelek. Pri izmeničnem namakanju in osuševanju se je pridelek povečal za 8 in periodičnem namakanju za 13 %, vendar se je v primerjavi s postopkom stalne poplavljenosti zmanšal za 8 in 27 % pri izvedbi tretmajev pri 80 in 90 % poljski kapaciteti. Največji pridelek pri periodičnem namakanju pri poljski kapaciteti je bil dosežen samo pri slanosti vode manj kot 4 dS m^{-1}. Če je bila slanost vode večja, so dali vsi postopki namakanja enak pridelek. Raziskava je pokazala, da je najboljši način periodičnega namakanja s slano vodo pri poljski kapacite s prevodnostjo vode za namakanje 2 dS m^{-1}. V primeru večje slanosti je potrebno izmenično namakati s sladko in slano vodo, da se izognemu velikemu učinku slanosti na pridelek riža.

Ključne besede: riž, namakanje, slana voda, Iran

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1 INTRODUCTION

With 230 thousands hectares of rice cultivated land, Guilan province, in the north of Iran, is one of the most important rice production region. Sepidrood dam and its vast irrigation network provide required water for this region and the agricultural activities. Recently, a dramatically reduction in fresh water resources has been causing concerns about rice production sustainability in Guilan. Climate change, water scarcity and consequently drought as well as anticipation of increasing the trend speed (Abbaspour et al., 2009), have led us to be more worried about the future of agriculture and farmers' income. Previous studies by the authors proved intermittent irrigation as an applicable strategy to overcome the consequences of new circumstance. This method can reduce water consumption and increase water productivity, while no yield loss (Rezaei and Nahvi, 2007; Rezaei et al., 2010a). On the other side, reports anticipated water scarcity, quality changes and its degradation (Abbaspour et al., 2009). To turn the circumstance even worse, construction of numerous dams upstream to Sefidroud dam will result in reduction of inlet water and disposal of drainage water to the river. In this situation further increase of quality changing trend and related salinity stress are predictable (Rezaei et al., 2010b). Rice is a very sensitive crop to salinity (Doberman and Fairhurst, 2000; Zeng and Shannon, 2000). Some researches proved EC threshold of local varieties yield loss to be 1-2 dS m^{-1} (Homaee, 2002; Yousefi, 2006). In this situation, increasing tendency has been arisen to use saline and brackish water in rice production (Ghadiri et al., 2006). But the capability of intermittent irrigation methodology with saline water is questionable.

Several studies have been carried out to better understanding of rice reaction to drought stress and finding new solution for mitigating the effects of the new condition (Bouman and Tuong, 2001; Belder et al., 2005). Water stress prevents transferring nutrients to plants (Wopereis et al., 1999) which results in decrease of tillerings numbers, leaf area, dry matter, filled grains, number of panicle, kernel weight and yield, so it is recommend avoiding long drought period for decreasing water use (Belder et al., 2005; Rezaei and Nahvi, 2007). Reports confirmed rice tolerance to a mild soil water potential decline in root zone resulting from intermittent irrigation up to -30 kPa (Belder et al., 2005). Those studies led to finding different approaches such as raised beds and alternative wetting and drying (AWD). The role of AWD in reducing water consumption and increasing water productivity has been proved. Even some evidences of increasing rice yield were also presented in case of adequate soil moisture control (Tabbal et al., 2002; Belder et al., 2004, 2005, 2007; Tuong et al., 2005; Yang et al., 2007; Zhang et al., 2008, 2009).

Local studies showed the effectiveness of AWD method in decreasing water consumption and increasing water productivity in Iran. A procedure of 8 days irrigation interval for local and 5 days irrigation interval for hybrid and improved varieties were recommended in Guilan province. The studies suggest that local rice varieties are resistant to non-flooding condition. Water stress up to of 80% of saturation or irrigation 3 days after disappearing of water from field surface does not cut crop yield but lower moisture has negative effect on yield (Amiri, 2006; Rezaei and Nahvi, 2007; Rezaei et al., 2010a). In spite of promising achievements, it is still necessary to have more studies for better understanding of rice reaction to drought stress.

In addition to water scarcity, salinity problem in coastal line, changes of water resources quality due to decrease of water input into network and entering low quality waters from upstream have been also under consideration (Rezaei et al., 2010b). Reports indicated that salinity stress caused reduction in leaf water potential, evapotranspiration, stomatal conductance, leaf area and yield of plants (Asch et al., 2000; Casanova et al., 2000; Zeng and Shannon, 2000; Zeng et al., 2003; Castillo et al., 2007). Although some investigations were devoted on salinity effects on rice, the number of studies performed in Iran is still few.

Despite of all mentioned researches, not enough attention was paid to synchronise of drought and salinity stress on rice yield. The change in rice reaction to salinity stress with drought stress has been proved in only Iran experiment carried out in

Fars province by Yousefi (2006). She reported that in AWD, the effects of saline water will be alleviated. She attributed the phenomena to decrease in evapotranspiration leading to less water absorption and consequently low accumulation of salt in plant tissues. Plant will usually have low yield in unsuitable conditions due to less photosynthesis. This natural rice reaction could be considered as a strategy for using saline water in rice cultivation. There has been no special study in Guilan, being the largest rice cultivation area. This research has been carried out to study the effects of synchronization of drought and salinity stress on rice in Rasht.

2 MATERIALS AND METHODS

A pot experiment was performed in a randomized complete block design (RCBD, and three replications) with Hashemi, a local variety at Rice Research Institute of Iran under a five-meter high shelter with plastic sheet coverage surrounded by paddy field. To avoid temperature rising, the sides of the shelter were not covered to let the air flow. Five levels of salinity, S0 = fresh water (EC = 1 dS m^{-1}) S1, S2, S3 and S4: saline water with 2, 4, 6 and 8 dS m^{-1}, respectively were used along with five Irrigation methods including: Permanent irrigation (PI), Alternative wetting and drying (AWD), Irrigation at field capacity (FC), 90% of FC and 80% of FC. About 9 kg of rice farm soil was put into each plastic pot. After flooding the soil; transplantation began with three 25-day old seedlings. The pots were irrigated by fresh water for a week as a recovery period then treatments were applied. All phosphorus (100 kg ha^{-1}) and potassium (150 kg ha^{-1}) and half of nitrogen (75 kg ha^{-1}) fertilizers from triple super phosphate, potassium and urea were mixed with soil in paddy preparation operation time. Those amounts of fertilizers are common fertilizer doses in the region, recommended by legal organizations. The remaining nitrogen was applied at the maximum tillering. Saline water was prepared based on canal water using NaCl and $CaSO_4$ (2:1). In order to prevent salt accumulation in pots, leaching and washing with fresh water in several stages was applied. Irrigation was set at specified time as high as 5 cm from the soil surface. All cultivation practices were performed as local practices. Finally yield, straw yield, tillering numbers, fertile and non-fertile panicle were measured. Mean comparison was done after analysis of variance using the Duncan multiple range test (DMRT).

3 RESULTS AND DISCUSSION

The results of soil chemical and physical analysis and Rasht meteorological station data were shown in Table 1, Table 2, and Table 3, respectively.

Table 1: Soil chemical analysis

Potassium ppm	Phosphorus ppm	Total Nitrogen %	pH
290	17	0.155	7.4

Table 2: Soil physical analysis

Soil texture	80% FC	90% FC	FC*	saturation	
Silty-Clay	40	45	50	65	Water content (volumetric, %)

*FC at -33 kPa

Table 3: Rasht meteorological station data in 2010

ETo mm	Sunshine hours	Rainfall mm	Relative humidity (%)		Temperature ºC		Month
			Max	Min	Max	Min	
47	114	67	98.8	68.3	16.2	8.3	Apr
72	123	149	98.8	71.5	21	14	May
149	277	2	95.2	59.5	29.8	20.4	Jun
168	371	22	95.1	55.1	32	22.7	July
184	217	23	93.8	51.2	33.9	21.5	Aug
103	200	55	98	57.6	29.9	19.5	Sep

ETo = reference evapotranspiration

The result (Table 4) showed that salinity of irrigation water had statistically significant effects on all traits except of unfilled panicles, but water stress showed significant effects only on yield, biomass and total panicles. It seems that salinity had more severe effects on rice in comparison with water stress. No interaction between water and salinity stress was observed. Some reports proved that rice in general and Iranian local variety, Hashemi, particularly to be resistant to intermittent irrigation and non-submerged irrigation (Belder et al., 2005; Amiri, 2006; Rezaei et al., 2010a).

3.1 Salinity stress

The analysis of mean comparison of the yield (Table 5) showed that rice is sensitive to salinity of irrigation water. Among treatments, control (EC = 1 dS m^{-1}) with 18.57 gr pot^{-1} had the highest yield. Increasing in salinity to 2 dS m^{-1} resulted in yield loss to 13.78 gr pot^{-1}, a considerable yield loss of about 25%. The same trend observed with increasing in salinity to 4 dS m^{-1}, which showed a 70% yield loss with 5.78 gr pot^{-1}. The yield loss with the salinity of 6 and 8 dS m^{-1} were remarkable amount of 80 and 97%, respectively. Some reports proved the high sensitivity of rice to salinity of irrigation water (Kavoosi, 1995; Sultana et al., 1999; Yousefi, 2006). It seems relatively high temperature of the cropping season, being of 22.4 °C (being normally of 18.9 °C) intensified the effects of salinity of irrigation water on rice (Asch et al., 2000).

As stated, while yield loss was about 97%, the maximum decline in straw was about 20% (Figure 2). This conclusion showed that in salinity stress, yield loss in contrast with decrease in production of straw suffers from a faster rate. Reviewing yield in different salinities (Figure 1), showed clearly that quadratic equation presents yield loss more accurately (R^2 = 0.98) in comparison with linear equation (R^2 = 0.91) presented by Mass and Huffman (1997).

Table 4: Analysis of variance

Error	Salinity× Irrigation	Irrigation	Salinity	Rep.	Source of variance
48	16	4	4	2	Degree of freedom
43.7	36.2 ns	88.9 ns	350.2 **	78	Straw weight (gr pot^{-1})
9	16.3 ns	29.1 **	828.7 **	60.6	Yield (gr pot^{-1})
76.5	135.6 ns	124.5 ns	3810.3 **	443	Yield / Straw
48.4	30.7 ns	141.6*	1604 **	33.1	Biomass (gr pot^{-1})
28.3	43.4 ns	42.1 ns	1716.7 **	196.6	Harvest Index
39.4	25.7 ns	7.4 ns	308.7 **	18.5	No. of tillering
15.7	14.3 ns	12.3 ns	228.2 **	9.6	No. of filled panicle
13.1	23 ns	22.9 ns	23.4 ns	2.8	Unfilled panicle
20.5	20.8 ns	30 **	846.6 **	19.5	Total panicle
4081	3153.8 ns	3697.7 ns	9990.4 **	3589.3	Filled panicle (%)
4.2	1.8 ns	2 ns	17.3 **	12.2	Unfilled /filled panicle

*, **: represent statistically significant differences at 95 and 99 respectively
ns: represent not statistically significant differences

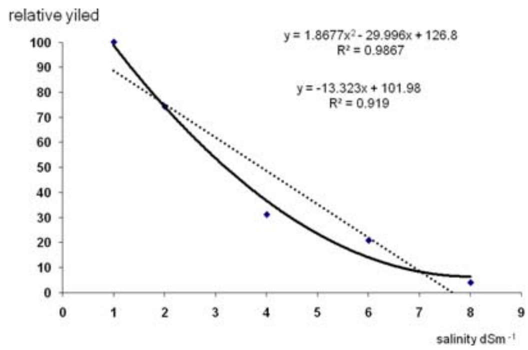

Figure 1: Relative yield in different salinity levels

Since statistically significant effects of salinity on yield and straw dry weight, it could be expected that harvest index would be completely influenced by this tension. As expected, salinity of irrigation water had a high influence on harvest index, so that the index is declined from 28.5% when irrigated with fresh water to 1.99% when irrigated with saline water of 8 dS m^{-1} (Table 6). In this case water salinity adversely influenced the number of rice tillerings. While decreasing in number of tillering due to salinity stress, number of filed panicle and ratio of filed panicle to tillering highly declined too. Effect of salinity on percent of filled panicles has also been reported by other researchers (Clermont-Dauphina et al., 2010). In fact these traits are the most important_factors to reach the maximum yield of rice (Casanova et al., 2000). Therefore any kind of reduction in these traits highly affects the yield.

Table 5: Analysis of mean comparison of rice yield (gr pot^{-1})

Irrigation	Salinity (dS m^{-1}) 1	2	4	6	8	mean
FI	22.2 A a	11.9 B b	5.9 A bc	2.9 A c	0.8 A c	8.7 AB
AWD	21.9 A a	15.6 AB a	5.7 A b	2.9 A b	1.2 A b	9.5 AB
FC	19.4 A a	18.8 A a	6.4 A b	4.2 A b	0.8 A b	9.9 A
90FC	18 A a	11.9 B ab	5.7 A bc	4.3 A c	0.3 A c	8 AB
80FC	11.3 B a	10.7 B a	5.3 A ab	3.7 A b	0.7 A b	6.4 B
mean	18.6 a	13.8 b	5.8 c	3.6 c	0.7 d	

Table 6: Analysis of mean comparison for different water salinity levels

Salinity dS m^{-1}	Straw weight gr pot^{-1}	No. of tillering	No. of filled panicle	Filled panicle (%)	Harvest index (%)
1	39.8 ab	34.4 a	29.2 a	67.3 a	28.5 a
2	40.9 a	31.4 a	26.0 a	64.4 a	22.7 b
4	41.8 a	30.2 a	19 b	50.1 ab	10.5 c
6	33.9 bc	25.6 b	16.6 b	51.6 ab	10.2 c
8	30.7 c	23.1 b	10.3 c	16.6 b	2 d

Same letter means no diffrence at 99 % by DMRT (Duncan multiple range test)

Salinity decreased number of tillerings per pot. Number of tillerings in fresh water and saline water of 8 dS m^{-1} were 34.4 and 23.1, the maximum and minimum amount, respectively. This trend of reduction due to salinity stress was observed for total number of panicles and numbers of filled panicles and the ratio of the number of filled panicles to the number of tillerings. It would be interesting to know that although majority of measured traits were affected by salinity, regardless to water salinity, the number of unfilled panicles remained unchanged. Contrasting to straw dry weight production, increasing salinity to 4 dS m^{-1} had no adverse effect on rice vegetative growth (Figure 2 and Table 6) but increasing water salinity to 8 dS m^{-1} decreased rice growth and biomass accumulation of the plant by 15 and 23% comparing with fresh water, respectively.

Table 7: Analysis of mean comparison for different irrigation treatments

Irrigation	Straw weight gr pot^{-1}	No. of tillering	No. of filled panicle	Filled panicle (%)	Harvest index (%)
FI	39.3 a	29.6 a	21.8 a	50 a	14.2 a
AWD	40.8 a	28.3 a	21.7 a	51 a	15.1 a
FC	39.6 a	29.7 a	19.3 a	51.8 a	17.2 a
90FC	35.9 a	29 a	19.2 a	49.5 a	14.7 a
80FC	36 a	28.2 a	19.2 a	48.1 a	12.6 a

Same letter means no diffrence at 99% by DMRT (Duncan multiple range test)

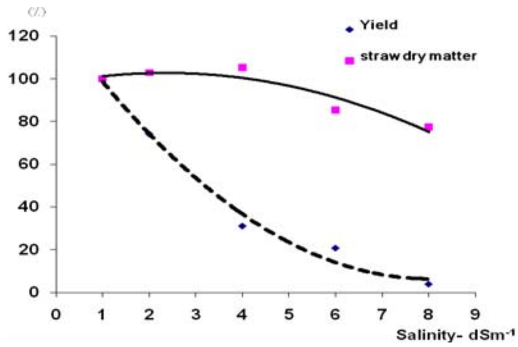

Figure 2: Rice relative yield and dry matter in different salinity levels

3.2 Water stress

The table of mean comparison (Table 7) showed that applied irrigation treatments had no statistically significant effects on measured yield components such as number of tillerings, filled and unfilled panicles, ratio of unfilled/filled panicles and straw dry weight and all placed in the same class but biomass and water tension decreased biomass production. Due to ignorable change in straw dry matter, this phenomenon could be attributed to the change in yield. Reviewing yield in different irrigation methods (Table 5) showed that performing intermittent irrigation not only did not decrease yield but also water tension up to FC caused a yield increase, a finding which had been proved by the authors (Rezaei and Nahvai, 2007). Irrigation treatment of 90% FC and 80% of FC had the minimum yield. Comparing with PI which had a yield of 8.74 gr pot^{-1}, applying intermittent irrigation at FC and AWD with 9.89 and 9.46 gr pot^{-1}showed an increase in yield as much as 13 and 8%, respectively. Two treatments of 80 and 90% of FC with 27 and 8% decrease in yield (comparing with PI) had the least amount of yield, respectively. The roles of intermittent irrigation on increasing rice production have been reported by other researches too. Belder et al. (2004) also reported that water tension up to 33 kPa did not cause yield reduction. According to the mentioned report, increasing water tension more that FC decreased yield. Using intermittent irrigation to reduce water consumption has been applying in North farms of Iran for a while. The method is based on wide studies by authors in the Rice Research Institute of Iran (RRII) and was accepted as an applicable method to mitigate water scarcity.

3.3 Salinity and water stress interactions

Rice response to salinity stress remained unchanged in all applied irrigation methods in this research; yield decreased when salinity increased (Figures 1 and 2). The reduction trend in low water stress including PI, AWD and FC was quadratic equation but in other two sever water tension treatments i.e. 80 and 90% of FC, linear equation. According to the figures 1 and 2, it is concluded that in quadratic equation, yield reduction slope with salinity to 4 dSm^{-1} is very high and after that the reduction continues with fewer slopes and in harmony with slope of first class linear equations. On the other side with fresh water although applying intermittent irrigation treatments i.e. FI, AWD, FC and 90% of FC did not cause yield differences, using saline water of 2 dS m^{-1} showed a significant difference. In this circumstance posing water stress up to FC resulted in a trend of yield rise which followed by a falling trend with more severe water stress. Yield in severe salinity stress, salinity more than 4 dS m^{-1}, all irrigation treatments yielded the same, suggesting that in excessive salinity, irrigation management did not have any effect on yield. Yousefi (2006) also reported that alternative irrigation reduced effect of salinity tension and attributed it to less absorption of water and saline solvable in water and as a result to less accumulation of salt in plant tissue.

4 CONCLUSIONS

According to Figure 2 and Table 5, it is concluded that if irrigation water salinity is about 1 dS m^{-1}, the best irrigation methods are permanent flooding, alternative irrigation or irrigation at FC, and 90% of FC, but as applying intermittent irrigation (non-submerged) reduces water use, non-submerged is suggested. In this case, in contrast with other treatment, more yields will produce. When water salinity is 2 dS m^{-1} irrigation at FC is suggested, since alternative irrigation decreases salinity effects. When salinity is more than that amount, all methods of irrigation has the same result; in this case irrigation at 90% of FC has a little more yield. In any case in this condition, yield reduction is so high that rice cultivation is not recommended. Generally, we concluded that in some cases, mixing fresh water and saline water to decrease water salinity to an acceptable level of 2 dS m^{-1} and using alternative irrigation at FC, prevents yield losses.

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