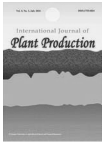

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Response of different rice cultivars (*Oryza sativa* L.) to water-saving irrigation in greenhouse conditions

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Abstract

Due to increasing water and growing demand for food a more efficient water use system is needed for agriculture. This is more evidence for rice production with a higher water use for economical production. A large cultivar×water regime interaction exists for grain yield in rice. Therefore, information is required to adopt new rice cultivars with high yield potential under water-saving conditions. The objectives of this study were to analyze the straw yield, grain yield, yield components, water use and water productivity of six rice cultivars (Anbarboo-22, Ghasroddashti, Cross-Domsiah, Hasani, Rahmat-Abadi, and Doroodzan) under water-saving irrigation regimes (intermittent flood irrigation with 1-and 2-day intervals, I-1-D, and I-2-D, respectively) compared with continuous flood irrigation (CFI) to adopt the elite cultivars of semi-arid area for water-saving conditions. Results indicated that under water-saving irrigation regimes (I-1-D), Doroodzan, Anbarboo-22, and Cross-Domsiah cultivars produced higher grain yields and are elite cultivars, however, under I-2-D irrigation regime only Anbarboo-22 cultivar was an elite cultivar. Based on the harvest index criterion, Doroodzan and Anbarboo-22 cultivars are the elite cultivars under water-saving irrigation regimes. The grain yield of the cultivars was mostly controlled by 1000-grain weight and the order of the other yield components were number of grains per panicle > number of panicles per unit area > unfilled grain percentages. Under CFI, Doroodzan cultivar resulted in highest water productivity (WP) as 0.52 kg m^{-3} and Cross-Domsiah and Anbarboo-22 cultivars with WP of 0.40 and 0.31 kg m^{-3} were in second and third place, respectively. Furthermore, based on the drought tolerance indices, it is concluded that Doroodzan at first place and Anbarboo-22 and Cross-Domsiah cultivars at second place may be considered as drought tolerant cultivars that can be used in further field study with water-saving irrigation regimes i.e., intermittent irrigation with 1-and 2-day intervals in Fars province.

Keywords: Grain yield; Harvest index; Rice cultivars; Water productivity; Water supply; Yield component.

Introduction

The availability of fresh water in agriculture is decreasing and therefore, there is a need to develop a more efficient water use system in agriculture. This is more evidence for rice production with a higher water use for economical production. One of the options to increase the rice production using the limited water resource is to develop new water-saving rice production systems. Growers of irrigated lowland rice are the main users of irrigation water in Iran, but this practice may not be sustainable if fresh water resources continue to decline.

Several water-saving rice production technologies have recently been developed (Tabbal et al., 2002; Belder et al., 2004; Hayashi et al., 2006; Kato et al., 2006a; Kato et al., 2006b; Pirmoradian et al., 2004a; Pirmoradian et al., 2004b). Among them, rice production without constant standing water on puddle soils, referred to as "intermittent flood irrigation" or "water-saving irrigation" is considered to be one of the most promising technologies (Wang et al., 2002; Pirmoradian et al., 2004a; Pirmoradian et al., 2004b). In Asia, investigators have tried to increase the grain yield of rice under water-saving irrigation regimes by genetic improvement, i.e., drought resistance cultivars (Nemoto et al., 1998).

The growth of rice cultivars is likely to differ under water saving conditions and it may also differ with the amounts of water supply. Cultivars that could maintain water uptake under lower soil water content may produce larger amounts of yield and these cultivars would become important as the water supply decreases. A large cultivar×water regime interaction exists for grain yield in upland rice (Lafitte and Courtois, 2002; Lafitte et al., 2002). Differences in plant characteristics such as panicle size, tillering, rooting, and phenology may cause differences in dry matter production (Kato et al., 2006a) and yield formation under different water regimes (Kato et al., 2006b). Furthermore, information required to adopt new rice cultivars with high yield potential under water-saving irrigation regimes is limited. For use in flooded lowlands, Jehade-Agriculture Research Organization in Fars province, I.R. of Iran has screened cultivars of rice that have higher yield potential under irrigated lowland conditions, however, their higher yield potentials have not yet been demonstrated under water-saving irrigation regimes.

The objectives of this study were to analyze the straw yield, grain yield, yield components, and water use and water productivity of six rice cultivars (Anbarboo-22, Ghasroddashti, Cross-Domsiah, Hasani, Rahmat-Abadi, and Doroodzan) under water-saving irrigation regimes (intermittent flood irrigation with 1-and 2-day intervals, I-1-D, and I-2-D, respectively) compared with continuous flood irrigation (CFI) to adopt the elite cultivars for these conditions in Fars province.

Materials and Methods

This research was conducted in a greenhouse at College of Agriculture, Shiraz University in year 2007. 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 4-mm sieve. Plastic pots with 23.5 cm of height and 23 cm of diameter filled with 6.25 kg of air dried soil. Twenty five pre-soaked (7 days) seeds of different cultivars (Anbarboo-22, Ghasroddashti, Cross-Domsiah, Hasani, Rahmat-Abadi, and Doroodzan) were planted in each pot on 6 June and each pot irrigated with tap water to field capacity with 250 cm^3 for each irrigation event during the first four weeks of the growing season.

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

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

Nitrogen and 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, $Ca(H_2PO_4)_2$ (equivalent to 50 kg ha^{-1} P), respectively. After 2 weeks seedlings were thinned to 15 per pot and after 4 weeks they were thinned to 10 per pot. The planting scenario in pot is in accordance to that in field conditions, 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 is almost similar to that planted in fields. At this stage, the irrigation treatments started. Three irrigation treatments consisted of continuous flooding, intermittent flooding with 1-day interval and intermittent flooding with 2-day interval. A flexible drain tube was connected to the bottom end of pot wall for water drainage for intermittent irrigation treatments. These tubes were closed for continuous flood irrigation treatment. A 3.0 cm of standing water 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 days 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. Mean total water use was 1292, 1180, and 1003 mm for CFI, I-1-D, and I-2-D, respectively.

The experimental layout was a 3×6 factorial arrangement with four replications and analysis of variance (ANOVA) used for this arrangement. The mean maximum and minimum air temperatures during the growing season in greenhouse were 37±7 and 15±5 ˚C, respectively.

Soil water content before each irrigation in pots was measured by weighing the pots. In field conditions with similar soil 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 of that in the field conditions. Therefore, in this experiment the drain was kept closed in continuous flood irrigation and then, opened monthly (five times during the growing season) for salt washout to simulate the field conditions in continuous flood irrigation.

Before harvest, the number of panicles per plant and pot and grains per panicle was determined. Plant tops were dried in an oven at 65 ˚C for 48-72 h. 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. Statistical analysis was conducted on the obtained data and the means were compared by Duncan multiple range test.

Drought tolerance evaluation

There are different indices for evaluation of drought resistance of cultivars (Sio-SeMarde et al., 2006). Application of these indices were evaluated for rice cultivars by Abbasi (2008) and it is found that mean productivity (MP), geometric mean productivity (GMP), and stress tolerance index (STI) are preferred for rice cultivar adoption. These indices are obtained by the following equation:

Mean productivity (MP) (Hossain et al., 1990):

$$MP=(y_p+y_s)/2 \quad (1)$$

where y_p is the potential grain yield under continuous flood irrigation (CFI), and y_s is the grain yield in water-saving irrigation regimes.

Geometric mean productivity (GMP) (Fernandez, 1992):

$$GMP=(y_p \times y_s)^{0.5} \quad (2)$$

Stress tolerance index (STI) (Bouslama and Schapaugh, 1984):

$$STI=(y_p \times y_s)/\tilde{y}_p^2 \quad (3)$$

where $\tilde{y}_p$ is the mean grain yield of different rice cultivars under CFI.

Results and Discussion

Plant height

There was no significant interaction effect between irrigation treatments and cultivars on plant height (Table 2). Water stress at irrigation treatment of I-2-D resulted in significantly lower plant height. Furthermore, plant heights in cultivars were statistically different. Highest plant height obtained for Ghasroddashti, Cross-Domsiah, and Rahmat-Abadi was in first order, plant height for Hasani cultivar was in second order, and plant height of Doroodzan cultivar was lowest.

Straw dry weight per pot

Straw dry weight per pot (SDW) (g pot^{-1}) at different irrigation treatments and cultivars are presented in Table 2. There is a statistically significant interaction effect between irrigation treatments and cultivars. In CFI and I-2-D irrigation regimes, Hasani and Doroodzan cultivars had a lower SDW and other cultivars showed similarly higher SDW. However, in I-1-D irrigation regime, Cross-Domsiah produced higher SDW and others resulted in lower SDW. Furthermore, data in Table 2 indicated that Cross-Domsiah, Hasani and Doroodzan cultivars had statistically similar SDW in CFI and I-1-D irrigation regimes, while their SDW decreased in I-2-D irrigation regime. It may be concluded that Cross-Domsiah, Hasani and Doroodzan cultivars tolerated water stress conditions in I-1-D, but Cross-Domsiah had higher growth potential than that of Hasani and Doroodzan cultivars. Furthermore, at higher water stress conditions (I-2-D) Cross-Domsiah along with other cultivars except Hasani showed higher growth potential compared with other cultivar.

Table 2. Plant height, straw and grain weight of different rice cultivars at different irrigation regimes.

Cultivar	Irrigation regimes**			Mean
	CFI	I-1-D	I-2-D	
		Plant height, cm		
Anbarboo-22	115	115	117	116^{b}
Ghasroddashti	128	124	120	125^{a}
Cross-Domsiah	124	123	113	120^{ab}
Hasani	95	107	99	100^{c}
Rahmat-Abadi	128	114	116	119^{ab}
Doroodzan	91	78	79	83^{d}
Mean	114^{A}	110^{AB}	107^{B}	
		Straw weight, g pot^{-1}		
Anbarboo-22	42.0^{a*}	30.6^{bc}	27.5^{bc}	
Ghasroddashti	42.4^{a}	31.5^{b}	26.3^{bc}	
Cross-Domsiah	41.3^{a}	41.3^{a}	30.6^{bc}	
Hasani	27.8^{bc}	29.4^{bc}	19.6^{d}	
Rahmat-Abadi	42.5^{a}	42.7^{b}	32.9^{b}	
Doroodzan	30.8^{b}	28^{bc}	23.8^{cd}	
		Grain weight, g pot^{-1}		
Anbarboo-22	19.3^{bc}	19.1^{bc}	17.0^{cd}	
Ghasroddashti	5.8^{efg}	8.0^{efg}	7.0^{efg}	
Cross-Domsiah	23.7^{b}	16.4^{cd}	7.8^{efg}	
Hasani	4.1^{fg}	9.5^{ef}	2.9^{g}	
Rahmat-Abadi	8.0^{efg}	8.7^{efg}	7.1^{efg}	
Doroodzan	30.4^{a}	19.6^{bc}	11.5^{de}	

**CFI: Continuous flood irrigation, I-1-D: Intermittent flood irrigation with 1-day interval, I-2-D: Intermittent flood irrigation with 2-day interval.
*Means follow by the same letters in each column and each row (capital) are not significantly different at 5% level of probability by Duncan multiple range test.

Generally, it is reported by Kato et al. (2006a) that total dry matter (TDM) increased with increasing water supply. They also reported a cultivar-water regime interaction in TDM. These effects were different for various cultivars. Kato et al. (2006a) indicated that different cultivars responded differently to the water conditions and that the total water supply greatly affected TDM in upland conditions through its effects on the amount of N uptake, which was associated with the depth of root development.

Grain weight per pot

Grain weight per pot (GW) (g pot^{-1}) at different irrigation treatments and cultivars are shown in Table 2. There is a statistically significant interaction effect between irrigation treatment and cultivars. In CFI, GW of Doroodzan cultivar was the highest and Anbarboo-22 and Cross-Domsiah placed in second place and the other cultivars showed lowest GW. However, in I-1-D treatment, Anbarboo-22, Cross-Domsiah and Doroodzan cultivars were statistically superior to the other cultivars. In addition, in the I-2-D treatment, Anbarboo-22 cultivar had the highest GW and Doroodzan placed in second and the other cultivars had lowest GW.

Kato et al. (2006b) found a cultivar-water regime interaction for grain yield of rice. They also found that some of the cultivars produced the highest grain yield under upland conditions. They believed that the reason for the highest grain yield of elite cultivars across upland conditions were large panicle and high harvest index maintenance. Different studies compared grain yield of rice between favorable upland and flooded lowland conditions (Bouman et al., 2005; Yang et al., 2005; Kato et al., 2006b). Yield disadvantages of 10 to 32% under upland conditions were found, even though there were no obvious environmental stresses and crop management was adequate. The yield reduction in upland conditions was due to a low biomass production and a reduction in the number of spikelet per panicle (Kato et al., 2006b).

Unfilled grain

The effects of irrigation treatments on percent of unfilled grains for different cultivars are shown in Table 3. There was no significant interaction effect between irrigation treatment and cultivars, therefore, the main effects are compared. In general, the Anbarboo-22 and Doroodzan cultivars showed significantly lowest unfilled grains and the other cultivars indicated higher percent of unfilled grains. Furthermore, I-1-D irrigation regime statistically resulted in similar percent of unfilled grains to those of CFI, however, the values of percent of unfilled grains were statistically higher in I-2-D treatment compared with those in I-1-D treatment. These results are in accordance with those reported by Pirmoradian et al. (2004a) indicating that water stress caused increase in percent of unfilled grains.

1000-grain weight

There was no significant interaction effect between irrigation treatments and cultivars on the 1000-grain weight (Table 3). It is indicated that the 1000-grain weight was similar for all irrigation treatments. Furthermore, Doroodzan cultivar statistically showed the highest 1000-grain weight, Cross-Domsiah, Hasani, and Rahmat-Abadi were in second order, and Anbarboo-22 and Ghasroddashti cultivars had lowest 1000-grain weight.

Number of grains per panicle

There was significant interaction effect between irrigation treatments and cultivars on the number of grains per panicle (Table 3). Water-saving irrigations did not statistically decrease the number of grains per panicle for Anbarboo-22, Hasani, Rahmat-Abadi, however, I-2-D treatment statistically resulted in reduced number of grains per panicle for Doroodzan and Cross-Domsiah cultivars. Surprisingly, the number of grains per panicle for Ghasroddashti cultivar was significantly higher in I-2-D treatment that we have no explanation for this occurrence.

Number of panicles per pot

There was significant interaction effect between irrigation treatments and cultivars on the number of panicles per pot (Table 3). In general, Cross-Domsiah, and Doroodzan cultivars significantly produced high number of panicles per pot in CFI treatment, however, there was no significant difference between cultivars in I-1-D and I-2-D irrigation regimes. Ghasroddashti and Hasani cultivars produced significantly higher number of panicles per pot in I-1-D irrigation treatment due to the effect of water stress on prolonging the growth duration of these cultivars that resulted in higher number of panicles. However, some of these panicles were not fertile due to water stress. Kato et al. (2006b) reported that grain yields of some cultivars declined sharply with suboptimal water conditions with greater reduction in both panicle and spikelet number. This might be due to shallower roots that resulted in reduced N uptake and decreased dry matter production (Kato et al., 2006a).

Table 3. Unfilled grain percentage, 1000-grain weight, number grains per panicle, and numbers of panicle per pot of different rice cultivars at different irrigation regimes.

Cultivar	Irrigation regimes**			Mean
	CFI	I-1-D	I-2-D	
		Unfilled grain percentage		
Anbarboo-22	27	19	30	25[b*]
Ghasroddashti	56	29	63	49[a]
Cross-Domsiah	35	52	64	50[a]
Hasani	58	60	52	56[a]
Rahmat-Abadi	55	42	61	53[a]
Doroodzan	23	33	47	34[b]
Mean	42[B]	39[B]	53[A]	
		1000-grain weight, g		
Anbarboo-22	17.0	18.4	17.3	17.6[c]
Ghasroddashti	16.0	16.7	16.7	16.5[c]
Cross-Domsiah	20.1	20.5	19.8	20.2[b]
Hasani	22.3	20.8	16.8	20.0[b]
Rahmat-Abadi	18.6	17.2	18.0	17.9[bc]
Doroodzan	23.8	24.4	24.3	24.2[a]
	19.6[a]	19.7[a]	18.8[a]	
		Number of grains per panicle		
Anbarboo-22	69[bcde*]	65[cdef]	76[abcd]	
Ghasroddashti	60[def]	59[def]	89[ab]	
Cross-Domsiah	94[a]	85[abc]	71[bcde]	
Hasani	47[fg]	38[g]	45[fg]	
Rahmat-Abadi	73[abcd]	58d[efg]	71[bcde]	
Doroodzan	76[abcd]	55d[efg]	50[efg]	
		Number of panicle per pot		
Anbarboo-22	8[cde]	10[abcd]	9[abcde]	
Ghasroddashti	7[de]	13[ab]	9[abcde]	
Cross-Domsiah	13[a]	12[abc]	10[abcd]	
Hasani	5[e]	10[abcd]	8[cde]	
Rahmat-Abadi	9[abcd]	12[abc]	12[abc]	
Doroodzan	12[abc]	9[bcde]	10[abcd]	

**CFI: Continuous flood irrigation, I-1-D: Intermittent flood irrigation with 1-day interval, I-2-D: Intermittent flood irrigation with 2-day interval.

*Means follow by the same letters in each column and each row (capital) are not significantly different at 5% level of probability by Duncan multiple range test.

Harvest index

Harvest index (HI) is the ratio of grain weight to total biomass, i.e., sum of straw and grain. HI at different irrigation treatments and cultivars are given in Table 4. There is a statistically significant interaction effect between irrigation treatments and cultivars on HI. In CFI, the value of HI for Doroodzan cultivar was highest, and the values of HI for Cross-

Domsiah and Anbarboo-22 were in the second place and the other cultivars had the least values of HI. However, in I-1-D treatments with mild water stress, Doroodzan and Anbarboo-22 cultivars resulted in higher HI than those obtained for the other cultivars, but the values of HI for Doroodzan and Anbarboo-22 were not statistically different from those obtained in CFI treatment. Furthermore, HI of Anbarboo-22 was similar in all irrigation treatments, while its value for Doroodzan was similar for I-1-D and I-2-D, but they were lower than CFI.

Table 4. Harvest index, water use and water productivity of different rice cultivars at different irrigation regimes.

Cultivar	Irrigation regimes**			Mean
	CFI	I-1-D	I-2-D	
		Harvest index		
Anbarboo-22	0.31^{bcd*}	0.38^{b}	0.37^{bc}	
Ghasroddashti	0.12^{g}	0.20^{efg}	0.21^{efg}	
Cross-Domsiah	0.36^{bc}	0.28^{cde}	0.20^{efg}	
Hasani	0.13^{g}	0.24^{def}	0.13^{g}	
Rahmat-Abadi	0.16^{fg}	0.21^{efg}	0.18^{fg}	
Doroodzan	0.50^{a}	0.41^{ab}	0.33^{bcd}	
		Water use, mm		
Anbarboo-22	1445^{a}	1110^{bc}	1072^{bc}	
Ghasroddashti	1225^{b}	1117^{bc}	970^{c}	
Cross-Domsiah	1416^{a}	1439^{a}	1106^{bc}	
Hasani	1048^{bc}	1064^{bc}	800^{d}	
Rahmat-Abadi	1214^{b}	1132^{bc}	1016^{c}	
Doroodzan	1046^{a}	1216^{b}	1051^{bc}	
		Water productivity, kg m^{-3}		
Anbarboo-22	0.31^{bcd}	0.42^{b}	0.38^{bc}	
Ghasroddashti	0.12^{gh}	0.17^{efgh}	0.18^{efgh}	
Cross-Domsiah	0.40^{b}	0.28^{cde}	0.17^{fgh}	
Hasani	0.09^{h}	0.22^{defg}	0.09^{h}	
Rahmat-Abadi	0.16^{fgh}	0.20^{efgh}	0.17^{fgh}	
Doroodzan	0.52^{a}	0.39^{bc}	0.26^{def}	

**CFI: Continuous flood irrigation, I-1-D: Intermittent flood irrigation with 1-day interval, I-2-D: Intermittent flood irrigation with 2-day interval.
*Means follow by the same letters in each column are not significantly different at 5% level of probability by Duncan multiple range test.

Water use

There was a significant interaction effect between irrigation treatments and cultivars on water use (Table 4). Water use for Anbarboo-22 and Doroodzan cultivars were significantly reduced by I-1-D irrigation regime compared with CFI treatment, however, their water use were not significantly decreased further by I-2-D treatment. For the other cultivars, water use was not significantly different in CFI and I-1-D irrigation regime. However, it was significantly decreased in I-2-D irrigation treatment compared with CFI.

Water productivity

There was a significant interaction effect between irrigation treatments and cultivars on water productivity (WP) (Table 4). Water productivity was obtained by ratio of grain yield to the applied irrigation water. WP for Doroodzan, Cross-Domsiah, and Anbarboo-22 was higher than those obtained for the other cultivars in CFI and its value is twice common values of field WP (Pirmoradian et al., 2004a). However, their values of WP significantly decreased in water-saving irrigation regimes except Anbarboo-22 cultivar. It is worth noting that Doroodzan cultivar showed a WP value statistically similar to that of Anbarboo-22 in I-1-D irrigation regime, but its value was significantly lower in I-2-D irrigation treatment.

Different WP was reported for different cultivars by Kato et al. (2006b). They reported that WP for some cultivars under upland conditions ranged from 0.43 to 0.91 kg m^{-3} or 2.4 to 5.1 times the value for the same cultivars in flooded lowland conditions (0.18 kg m^{-3}) (Hayashi et al., 2006; Kamoshita et al., 2007).

Drought tolerance evaluation

Drought tolerance index (DTI) calculated based on Equations (1), (2), and (3). Results are presented in Table 5. According to the analysis reported by Abbasi (2008), it is shown that STI, GMP and MP are superior to the other indices. Highest values of these indices at I-1-D irrigation regime obtained for Doroodzan cultivar and at I-2-D irrigation treatment, they are obtained for Doroodzan, Anbarboo-22 and Cross-Domsiah cultivars. Therefore, it is indicated that Doroodzan at first place and Anbarboo-22 at second place are drought tolerant cultivars that can be used in water shortage conditions with water-saving irrigation regime with intermittent irrigation with 1-day and 2-day intervals in Fars province conditions. However, unpublished results reported by Abbasi (2008) indicated that Anbarboo-22 cultivar is very susceptible to plant disease in field conditions, therefore, this cultivar should not be recommended without further research in this regards.

Table 5. Drought tolerance index of different cultivars at different water-saving regimes.

Irrigation regimes**	Cultivar	Mean productivity	Geometric mean productivity	Stress tolerance index
I-1-D	Anbarboo-22	19.2	19.2	1.60
	Ghasroddashti	6.9	6.8	0.20
	Cross-Domsiah	20.0	10.7	1.68
	Hasani	6.8	6.2	0.17
	Rahmat-Abadi	8.3	8.3	0.30
	Doroodzan	25.0	24.4	2.58
I-2-D	Anbarboo-22	18.1	18.1	1.42
	Ghasroddashti	6.4	6.4	0.17
	Cross-Domsiah	15.8	13.6	0.80
	Hasani	3.5	3.5	0.05
	Rahmat-Abadi	7.5	7.5	0.24
	Doroodzan	21.0	18.7	1.51

*I-1-D: Intermittent flood irrigation with 1-day interval, I-2-D: Intermittent flood irrigation with 2-day interval.

Relationship between grain yield and yield components

By using multiple regression analysis, a relationship between grain yield per pot and different yield components was obtained as follows:

$$Lny=-5.0-0.3\ Ln(UGP) + Ln(UGW) + 0.8\ Ln(GPP) + 0.4\ Ln(PPP), \quad R^2=0.64 \qquad (4)$$

where y is the grain weight per pot (g), UGP is the unfilled grain percentage, UGW is the 1000-grain weight (g), GPP is the number of grains per panicle, and PPP is the number of panicles per pot. It is indicated that grain yield per pot is inversely dependent on unfilled grain percentage, but it is directly dependent on 1000-grain weight, number of grains per panicle and number of panicle per unit area. However, among different yield components, the order of effects on grain weight per pot was 1000-grian weight > number of grain per panicle > number of panicle per unit area > unfilled grain percentage, and the effect of 1000-grain weight was about 2 times of number of grains per panicle, about 4 times of number of panicles per unit area, and 5 times of unfilled grain percentage.

Conclusions

In order to develop new elite cultivars for water-saving rice production in upland systems, we should consider higher potential yield, harvest index and sink size as well as plant characteristics adapted to upland conditions (Kato et al., 2006a) i.e., a deep root system and high N uptake, yield stability under different water regimes. Results indicated that under water-saving irrigation regimes (I-1-D), Doroodzan, Anbarboo-22, and Cross-Domsiah cultivars produced higher grain yield and are elite cultivars, however, under I-2-D irrigation regime only Anbarboo-22 cultivar was an elite cultivar. Based on the harvest index criterion, Doroodzan and Anbarboo-22 cultivars are the elite cultivars under water-saving irrigation regimes. The grain yield of the cultivars was mostly controlled by 1000-grain weight and the order of the other yield components were number of grains per panicle > number of panicles per unit area > unfilled grain percentages. Under CFI, Doroodzan cultivar resulted in highest water productivity (WP) as 0.52 kg m^{-3} and Cross-Domsiah and Anbarboo-22 cultivars with WP of 0.40 and 0.31 kg m^{-3} were placed in second and third order, respectively. Furthermore, based on the drought tolerance indices, it is concluded that Doroodzan at first place and Anbarboo-22 and Cross-Domsiah cultivars at second place may be considered as drought tolerant cultivars that can be used in further field study with water-saving irrigation regimes i.e., intermittent irrigation with 1-and 2-day intervals in Fars province. When we consider all the characteristics, these three elite cultivars could be candidate for further field studies under either fully irrigated or deficit irrigated conditions in Fars province.

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