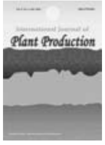

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Effects of water-saving irrigations on different rice cultivars (*Oryza sativa* L.) in field conditions

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Abstract

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 (WP) of five rice cultivars (Anbarboo-22, Ghasroddashti, Cross-Domsiah, Hasani, and Rahmat-Abadi) under water-saving irrigation regimes (intermittent flood irrigation with 1-and 2-day intervals after disappearance of standing water, I-1-D, and I-2-D, respectively) compared with continuous flood irrigation (CFI) to adopt the elite cultivars for these conditions. In general, Anbarboo-22 cultivar totally failed in field trial due to susceptibility to disease in 2005 and 2006. Among the other cultivars, Cross-Domsiah showed the highest grain yield, harvest index, number of panicles per hill and the lowest unfilled grain percentage in two years field experiments. Furthermore, its grain yield was the highest at water-saving irrigation regimes in comparison with the other cultivars, therefore, Cross-Domsiah is the elite cultivar in water-saving irrigation conditions especially with 1-day irrigation interval, however, Ghasroddashti cultivar is recommended in next order for I-1-D treatment. Based on the selected drought indices, Cross-Domsiah was the most drought tolerant cultivar and Ghasroddashti was in the second order. Furthermore, it is concluded that unfilled grain percentage and harvest index are found to be the most suitable traits for selection of rice cultivars with high yield potential.

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 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 paddled soils, referred to as "intermittent flood irrigation" or "water-saving irrigation" is considered to be one of the most promising technologies (Wang, 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; Abbasi and Sepaskhah, 2010). 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, Abbasi and Sepaskhah, 2010). Furthermore, information required to adopt new rice cultivars with high yield potential under water-saving irrigation regimes in field conditions 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 lowland conditions. Although, their higher yield potentials have been examined under water-saving irrigation regimes in greenhouse conditions by Abbasi and Sepaskhah (2010) however, their higher yield potentials have not yet been demonstrated in water-saving irrigation regimes in field conditions.

The objectives of this study were to analyze the straw yield, grain yield, yield components, and water use of five rice cultivars (Anbarboo-22, Ghasroddashti, Cross-Domsiah, Hasani, and Rahmat-Abadi) 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) for field conditions to adopt the elite cultivars for water-saving conditions in Far province.

Materials and Methods

Site description

This research was conducted at Kooshkak Agricultural Research Station, of Shiraz University in Islamic Republic (I.R.) of Iran (Lat. 30˚7´ N; Long. 52˚34´ E; elevation of 1650 m) during the two consecutive growing seasons of 2005 and 2006. The experimental site was placed in the irrigated area of Doroodzan Irrigation District located at south of I.R. of Iran, and the same spot of the Experiment Station Farm was used in growing seasons of 2005 and 2006 with the same experimental layout in both years. The soil of experimental site was a silty clay soil (fine, Carbonatic, mesic, Aquic Calcixerepts). Physical and chemical properties of soil are shown in Table 1. Maximum mean monthly air temperatures during the growing season (July-October) ranged from 29.7 to 37.7 ˚C in 2005 and from 21.7 to 37.9 ˚C in 2006, while the minimum temperature ranged from 7.2 to 15.2 ˚C in 2005 and from 7.9 to 17.8 ˚C in 2006, respectively. Reference crop potential evapotranspirations (ET_o) during the growing period for 2005 and 2006 determined based on FAO Penman-Montheith method (Allen et al., 1998) and were 800 and 780 mm, respectively. These may be converted to potential crop evapotranpiration (ET_p) by multiplying with crop coefficient (K_c). There was no rainfall during the growing season in either year.

Table 1. Some physical and chemical properties of soil used in experiment.

Soil properties	Soil depth	
	0-30 cm	30-60 cm
Sand (%)	10.6	4.6
Silt (%)	45.4	45.4
Clay (%)	44.0	50.0
Bulk density (g cm^{-3})	1.41	-
Field capacity (cm^3 cm^{-3})	34.0	-
Permanent wilting point (cm^3 cm^{-3})	24.0	-
EC_e (dS m^{-1})	0.75	0.39
pH	7.77	8.01
NH_4-N+NO_3-N in year 2005 (kg ha^{-1})	52.3	-
NH_4-N+NO_3-N in year 2006 (kg ha^{-1})	41.4	-

Experimental details

The experiment was conducted using four replications in a split plot design with irrigation method as main plots and cultivars as subplots. Main plots consisted of three irrigation regimes: 1) continuous flooding irrigation (CFI), 2) intermittent flooding irrigation with 1 day interval (I-1-D), 3) intermittent flooding irrigation with 2 days interval (I-2-D). Subplots were composed of five cultivars (Anbarboo-22, Ghsroddashti, Cross-Domsial, Hasani, and Rahmat-Abadi). However, Anbarboo-22 cultivar was very sensitive to plant disease and declined in the field experiment, therefore, it was discarded from experiment. The triple super-phosphate at a rate of 200 kg ha^{-1} was applied before transplanting (about 90 kg P_2O_5 ha^{-1}). Nitrogen was applied as urea at a rate of 100 kg N ha^{-1} in two parts, 50 kg ha^{-1} each, at 10 and 50 days (before flowering stage) after transplanting, respectively. Subplots were 2 m × 2 m basins enclosed by 50 cm bunds with 1.5 m distance between them. The land was prepared on the end of June in both years. The experimental plots were separated after the plowed land was saturated and puddled by a tiller. The five cultivars of rice seedlings with low tillering ability were transplanted with 25 hills per unit area, m^2 for 2005 and 2006 on 3 July and 29 June in 2005 and 2006, respectively. The transplants were about 40 days old. For first ten days, all of the treatments were irrigated with continuous flooding to establish the seedlings. The applied water in this period was about 200 mm in both years.

For flood irrigation treatment, the water depth in plots was maintained at 5 to 10 cm in irrigation period. For surface irrigation treatments, the water was distributed by pipe to each plot. Therefore, there was no effect of water flow from canals to the plots of surface irrigation treatments. The weeds were removed by hand weeding. In intermittent irrigation treatments, the standing water depths on the plots disappeared after about 24 h and the plots irrigated again before their surface were cracked. Volumetric water meters were used to measure the volume of the delivered water for every main plot in four replications.

At the end of growing season, yield samples were harvested from 1 m × 1 m area at the middle of plots. The crop was harvested manually on 1 October (for Ghsroddashti and Hasani cultivars) to 4 October (Cross-Domsiah and Rahmat-Abadi cultivars) and 18 September (for Ghsroddashti and Hasani cultivars) to 25 September (for Cross-Domsiah and Rahmat-Abadi cultivars) in 2005 and 2006, respectively. Samples were air dried for 5 days before being oven dried at 65 $^{\circ}$C for 48-72 h. Then, grain yield was determined based on 14% moisture content. The grain yield was divided by the applied water to determine water productivity. Among the harvested plant hills, three hills were randomly selected and plant height, unfilled grain percentage, number of panicles per hill or per unit area, number of grains per panicle, and 1000-grain weight were determined.

Samples of soils from the field were used to determine the soil water retention curve using a hanging water column and pressure plate apparatus (Soil Moisture Equipment Co., Santa Barbara, California, USA). The soil water retention was determined by pressure cell and its equation was presented by Sepaskhah and Yousofi-Falakdehi (2009) as follows:

$$\theta = 0.219 + 0.246\,[1 + (|0.0194 \times h|)^{1.435}]^{-0.301} \quad (1)$$

where θ is the soil volumetric water content in, $cm^3\ cm^{-3}$; and h is the soil water matric head, in cm. The soil water content of plots before each irrigation was measured by gravimetric method. Soil water content before each irrigation was converted to soil water matric head by using Equation (1).

Drought tolerance evaluation

There are different indices for evaluation of drought resistance of cultivars (Sio-SeMardeh 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

Soil water content and suction head

Most of the rice root concentrated in 0-30 cm of soil depth, therefore, measured soil water contents and suction heads at this depth for different water-saving irrigation treatments for different cultivars are shown in Table 2. Soil water contents were lower than saturation at water-saving irrigations at longer intervals. Its value was about field capacity in I-1-D regime and decreased to lower than field capacity at I-2-D regime. In general, soil water content was lower in 2006 than that in 2005. This may occurred due to higher amounts of cracks in 2006 for consecutive soil paddling. Similar trends were observed for soil water suction heads.

Table 2. Seasonal mean soil water content and suction head before irrigation events for different water-saving irrigations (I-1-D and I-2-D) and cultivars in 2005 and 2006.

Year	Cultivar	Water-saving irrigation			
		I-1-D		I-2-D	
		Water content, cm^3 cm^{-3}	Suction head, (-cm)	Water content, cm^3 cm^{-3}	Suction head, (-cm)
2005	Ghasroddashti	0.356	180	0.333	289
	Cross-Domsiah	0.396	83	0.323	365
	Hasani	0.363	157	0.320	388
	Rahmat-Abadi	0.380	113	0.315	440
	Mean	0.369	149	0.323	373
2006	Ghasroddashti	0.335	279	0.312	474
	Cross-Domsiah	0.326	341	0.295	783
	Hasani	0.339	258	0.312	485
	Rahmat-Abadi	0.329	315	0.303	619
	Mean	0.333	295	0.307	567

Plant height

Statistical analysis indicated no differences in plant height in two years. Therefore, combined data in these years were analyzed statistically. Plant heights as influenced by irrigation regimes (IR) and cultivars are shown in Table 3. There was no interaction effect between cultivars and IR on plant height. The height of Cross-Domsiah cultivar was higher than those obtained for Hasani, while its height was statistically similar to Ghasroddashti and Rahmat-Abadi. Mean plant height of cultivars was highest in CFI and it decreased statistically in I-1-D and I-2-D regimes. Therefore, it is indicated that the water-saving irrigation reduced the plant height and this reduction is enhanced by IR of higher interval.

Table 3. Seasonal mean plant height (cm) combined of two years at different cultivars and irrigation treatments.

Cultivar	Irrigation treatment[#]			
	CFI	I-1-D	I-2-D	Mean
Ghasoddashti	96	83	75	84^{ab}[*]
Cross-Domsiah	97	86	84	89^{a}
Hasani	86	81	72	80^{b}
Rahmat-Abadi	93	83	76	84^{ab}
Mean	93^{a}	83^{b}	77^{c}	

[*] Means followed by the same letters in row and column are not significantly different at 5% level of probability.

[#] CFI: Continuous flooding, I-1-D: Intermittent flood irrigation (1-day interval), I-2-D: Intermittent flood irrigation (2-day interval).

Yield

Straw

There was a significant interaction effect between cultivars and IR on straw yield (Table 4) in 2005 and 2006. Hasani cultivar had statistically lowest straw yield in CFI in 2005 while the other cultivars produced similar straw yield. Straw yields in 2005 for I-1-D regime were similar for all cultivars and were statistically similar to those obtained in CFI. However, in I-2-D regime, straw yields were statistically reduced compared with I-1-D regime, and there was no significant difference between straw yields of Cross-Domsiah, Hasani and Rahmat-Abadi, while their straw yields were significantly lower than that obtained for Ghasorddashti.

Table 4. Straw and grain yields and harvest index in 2005 and 2006 for different cultivars and irrigation treatments.

Year	Cultivar	Irrigation treatment[#]		
		CFI	I-1-D	I-2-D
		Straw yield, g m^{-2}		
2005	Ghasroddashti	456.1^{a*}	431.1^{ab}	343.3^{cde}
	Cross-Domsiah	412.1^{abc}	375.1^{bcd}	259.9^{fg}
	Hasani	308.2^{def}	357.8^{bcde}	298.0^{ef}
	Rahmat-Abadi	395.2^{abc}	419.0^{abc}	263.3^{fg}
		Grain yield, g m^{-2}		
2006	Ghasroddashti	682.0^{ab}	270.4^{def}	195.2^{f}
	Cross-Domsiah	657.0^{b}	391.1^{c}	335.9^{cd}
	Hasani	646.8^{b}	360.3^{cd}	218.8^{f}
	Rahmat-Abadi	763.0^{a}	333.9^{cd}	237.2^{ef}
2005	Ghasroddashti	258.5^{b}	279.3^{ab}	85.1^{de}
	Cross-Domsiah	331.6^{a}	307.8^{ab}	289.9^{ab}
	Hasani	131.9^{cd}	156.8^{c}	42.3^{e}
	Rahmat-Abadi	252.5^{b}	166.8^{c}	133.4^{cd}
2006	Ghasroddashti	380.9^{b}	63.5^{f}	54.2^{f}
	Cross-Domsiah	601.4^{a}	231.8^{cd}	172.5^{de}
	Hasani	246.1^{c}	40.3^{f}	29.5^{f}
	Rahmat-Abadi	407.5^{b}	133.1^{e}	57.8^{f}
		Harvest index		
2005	Ghasroddashti	0.36^{cd}	0.39^{bc}	0.20^{fg}
	Cross-Domsiah	0.44^{b}	0.45^{b}	0.53^{a}
	Hasani	0.30^{de}	0.30^{de}	0.13^{g}
	Rahmat-Abadi	0.39^{bc}	0.28^{de}	0.32^{cd}
2006	Ghasroddashti	0.36^{bc}	0.19^{def}	0.22^{de}
	Cross-Domsiah	0.48^{a}	0.37^{b}	0.34^{bc}
	Hasani	0.27^{cd}	0.10^{f}	0.14^{ef}
	Rahmat-Abadi	0.35^{bc}	0.29^{bcd}	0.20^{def}

[*] Means followed by the same letters in columns for each trait are not significantly different at 5% level of probability.

[#] CFI: Continuous flooding, I-1-D: Intermittent flood irrigation (1-day interval), I-2-D: Intermittent flood irrigation (2-day interval).

In 2006, Rahmat-Abadi cultivar produced significantly higher straw yield than those obtained for Cross-Domsiah and Hasani in CFI regime, while it was similar to Ghasroddashti cultivar. Straw yield for all cultivars reduced significantly in I-1-D regime, however, straw yield for Cross-Domsiah and Ghasroddashti cultivars were not reduced significantly in I-2-D regime while straw yield of Hasani and Rahmat-Abadi cultivars reduced significantly in I-2-D regime.

Kato et al. (2006a) reported that it is possible to achieve equally large total dry matter (TDM) values under upland and flooded lowland conditions with an adequate and sufficiently frequent supply of water. Similar results were reported by Wada et al. (2005). However, contradictory results were reported by Bouman et al. (2005). They stated that TDM of aerobic rice or under upland conditions was smaller than flooded lowlands in the Philippines, despite the supplementary irrigation to keep the soil matric potential above 0.03 MPa at a depth of 15 cm. Under upland conditions some cultivars had the largest TDM under adequate water supply and had the least TDM under low water supply (Kato et al., 2006a). The reason for small TDM may be related to the relatively shallow root system and stomata closure and reduced photosynthesis in response to surface soil drying (Lafitte and Benett, 2002).

Different trends in straw yield response to water-saving irrigation regimes are due to the different soil water suction heads before water events in different irrigation regimes in different years (Table 2). Therefore, linear relationships between straw yields and soil water suction heads were determined for different cultivars by using data in 2005 and 2006. Results are presented in Table 5. Slope of linear regression is a measure of sensitivity of cultivar to water stress. The slopes of these equations are lowest for Cross-Domsiah (-0.25) compared with the other cultivars, and Hasani and Rahmat-Abadi showed higher slope and Ghasroddashti cultivar had highest slope. In general, based on the straw yield data obtained in 2005 and 2006, and Table 5, it is indicated that Cross-Domsiah cultivar was less affected by water-saving irrigation regimes.

Table 5. Linear relationships between straw yields (y_s, g m^{-2}), grain yield (y_g, g m^{-2}), harvest index (HI) and 1000 grain weight (GW, g) and soil water suction head (h, cm) for different cultivars.

Cultivar	Equation	Correlation coefficient	Significant level
Straw yield			
Ghasroddashti	$y_s=639.3-1.043h$	-0.96	0.01
Cross-Domsiah	$y_s=498.0-0.300h$	-0.61	ns
Hasani	$y_s=578.3-0.784h$	-0.92	0.05
Rahmat-Abadi	$y_s=625.8-0.748h$	-0.87	0.05
Grain yield			
Ghasroddashti	$y_g=349.3-0.737h$	-0.92	0.01
Cross-Domsiah	$y_g=415.0-0.353h$	-0.72	0.10
Hasani	$y_g=186.1-0.361h$	-0.85	0.05
Rahmat-Abadi	$y_g=292.5-0.406h$	-0.84	0.05
Harvest index			
Ghasroddashti	$HI=0.365-3.84h$	-0.77	0.10
Cross-Domsiah	$HI=0.472-1.41h$	-0.61	ns
Hasani	$HI=0.291-3.93h$	-0.85	0.05
Rahmat-Abadi	$HI=0.359-2.18h$	-0.84	0.05
1000 grain weight			
Ghasroddashti	$GW=21.2-0.005h$	-0.68	n.s
Cross-Domsiah	$GW=25.6-0.003h$	-0.80	0.05
Hasani	$GW=29.6-0.013h$	-0.90	0.05
Rahmat-Abadi	$GW=21.9-0.005h$	-0.98	0.001

Grain

There was a significant interaction effect between cultivars and IR on grain yield Table 4) in 2005 and 2006. Grain yield variation between cultivars were similar in CFI regime, and Cross-Domsiah cultivar produced significantly highest grain yield, followed by Ghasroddashti and Rahmat-Abadi with lower grain yield than that of Cross-Domsiah, but similar among themselves. However, grain yield of Hasani was lowest. Grain yield of cultivars in water-saving irrigations did not follow the same trends as in CFI due to the difference in soil water content and soil water suction head in 2005 and 2006 (Table 2). In 2005 and I-1-D regime, Cross-Domsiah and Ghasroddashti cultivars produced significantly higher grain yield, the grain yield in I-2-D regime was higher only for Cross-Domsiah. In 2006, Cross-Domsiah cultivar resulted in significantly higher grain yield in water-saving irrigation regimes (I-1-D and I-2-D).

In upland conditions some cultivars had highest grain yield under optimal conditions with proper irrigation management (Kato et al., 2006b). The reasons for low grain yield of some cultivars were low biomass production with a small sink size (numbers of spikelet per unit area) and low fertility.

Different trends in grain yield response to water-saving irrigation regimes are due to the different soil water suctions before irrigation events in different irrigation regimes in different years (Table 2). Therefore, linear relationships between grain yields and soil water suction heads were determined for different cultivars by using data for 2005 and 2006. Results are presented in Table 5. Slope of linear regression is a measure of sensitivity of cultivars to water stress. The slopes of these equations are lower for Cross-Domsiah, Hasani and Rahmat-Abadi cultivars (0.353-0.406) compared with 0.737 for Ghasroddashti cultivar. However, the intercept of this equation was the highest for Cross-Domsiah cultivar. Therefore, this cultivar was less affected by water-saving irrigation regimes and can be considered as an elite cultivar among the cultivars used in this study.

Harvest index

There was a significant interaction effect between cultivars and IR on harvest index, HI (Table 4) in 2005 and 2006. Cross-Domsiah cultivar showed highest HI in 2005 and 2006 at all irrigation regimes. However, its value increased at I-2-D regimes in 2005 and decreased at water-saving irrigation regimes in 2006. Anyhow, its value for Cross-Domsiah is higher than those for the other cultivars. Therefore, this cultivar is superior to the other cultivars to be adopted in rice cultivation area in Fars province.

Different trends in HI response to water-saving irrigation regimes are due to the different soil water suction heads before irrigation events in different irrigation regimes in different years (Table 2). Therefore, linear relationships between HI and soil water suction heads were determined for different cultivars by data for 2005 and 2006. Results are presented in Table 5. Slope of linear regression is a measure of sensitivity of cultivars to water stress. The slope of these equations is lower for Cross-Domsiah (-1.41) indicating it is more tolerant to soil water stress. Furthermore, the intercepts of these equations are the potential HI of cultivars. The intercept of these equations is higher for Cross-Domsiah. Therefore, this cultivar was less affected by water-saving irrigation regimes and can be considered as an elite cultivar among the cultivars used in this study.

Yield components

Unfilled grain

There was a significant interaction effect between cultivars and irrigation treatments on unfilled grain percentage (Table 6) in 2005 and 2006. Ghasroddashti and Cross-Domsiah cultivars significantly produced lower unfilled grain percentage at CFI regime in 2005 and 2006, and I-1-D regime in 2005. However, in this irrigation regime in 2006, Cross-Domsiah resulted in significantly lower unfilled grain percentage. Furthermore, these cultivars in I-2-D regime showed lower unfilled grain percentage compared with the other cultivars. In general, Cross-Domsiah had good performance in filling grains under water-saving irrigation regimes and it can be considered as an elite cultivar under water stress conditions.

Table 6. Yield components in 2005 and 2006 for different cultivars and irrigation treatments.

Year	Cultivar	Irrigation treatment#			
		CFI	I-1-D	I-2-D	Mean
Unfilled grain, %					
2005	Ghasroddashti	12^{d*}	11^{d}	42^{bc}	
	Cross-Domsiah	15^{d}	14^{d}	33^{cd}	
	Hasani	41^{bc}	46^{bc}	63^{ab}	
	Rahmat-Abadi	34^{cd}	21^{cd}	46^{bc}	
2006	Ghasroddashti	20^{gh}	48^{cde}	61^{bc}	
	Cross-Domsiah	18^{h}	26^{fgh}	58^{bc}	
	Hasani	35^{efg}	77^{a}	85^{a}	
	Rahmat-Abadi	23^{fgh}	28^{fgh}	71^{ab}	
1000-grain weight, g					
2005	Ghasroddashti	21.1^{d}	22.0^{cd}	20.2^{d}	
	Cross-Domsiah	26.0^{b}	26.3^{b}	24.2^{bc}	
	Hasani	30.0^{a}	29.2^{a}	26.4^{b}	
	Rahmat-Abadi	22.0^{cd}	21.4^{cd}	20.1^{d}	
2006	Ghasroddashti	20.8^{ef}	18.3^{h}	18.8^{gh}	
	Cross-Domsiah	24.9^{b}	23.7^{bc}	23.6^{bc}	
	Hasani	28.1^{a}	22.8^{cd}	23.7^{bc}	
	Rahmat-Abadi	21.7^{de}	20.0^{efgh}	18.4^{h}	
Number of panicles per hill					
2005	Ghasroddashti	9	10	8	9^{ab}
	Cross-Domsiah	13	9	8	10^{a}
	Hasani	8	8	7	8^{b}
	Rahmat-Abadi	10	11	9	10^{a}
	Mean	10^{a}	9^{ab}	8^{b}	
2006	Ghasroddashti	18	8	10	12^{b}
	Cross-Domsiah	32	25	17	25^{a}
	Hasani	15	15	12	14^{b}
	Rahmat-Abadi	19	12	11	14^{b}
	Mean	19^{A}	13^{B}	12^{B}	

[*] Means followed by the same letters in columns and rows (capital) for each trait are not significantly different at 5% level of probability.

[#] CFI: Continuous flooding, I-1-D: Intermittent flood irrigation (1-day interval), I-2-D: Intermittent flood irrigation (2-day interval).

1000-grain weight

There was a significant interaction effect between cultivars and IR on 1000-grain weight (Table 6) in 2005 and 2006. Hasani cultivar resulted in significant higher 1000-grain weight in 2005 and 2006 at CFI regime due to lower number of panicles per plant and number of grains per panicle. On the other hand, 1000-grain weight of Cross-Domsiah cultivar was statistically similar in different irrigation regimes indicating that 1000-grain weight of this cultivar tolerated the water stress and resulted in no reduction in grain weight.

Linear relationships between 1000-grain weight and soil water suction head were determined for different cultivars by using data for 2005 and 2006. Results are presented in Table 5. Slope of linear regression equation is a measure of sensitivity of cultivars to water stress. The intercept of linear equation indicates the potential of 1000-grain weight at CFI. Hasani cultivar had highest potential 1000-grain weight (29.6 g) but it was very sensitive to soil water suction head with a slope of -0.0133. Furthermore, Cross-Domsiah showed a 1000-grain weight of 25.6 g with least sensitivity to water stress with slope of -0.0031. Ghasroddashti and Rahmat-Abadi cultivars were similar in potential of 1000-grain weight and sensitivity to water stress.

Number of panicles per hill

There was no significant interaction between cultivars and IR on number of panicles per hill (Table 6). Number of panicles per hill was higher in 2006 than those obtained in 2005. This is due to higher number of seedling per hill planted in 2006. In general, Cross-Domsiah cultivar produced significantly higher number of panicles per hill in 2005 and 2006, even in water-saving irrigation regimes especially in 2006.

Linear relationships between number of panicles per hill and soil water suction head were determined for different cultivars by using data for 2005 and 2006. There was no statistically significant relationship (data not shown).

Number of panicles per unit area

There was no difference in number of panicles per unit area in two years. Therefore, combined effects between two years were statistically analyzed. There was no interaction effect between cultivars and irrigation treatments on number of panicles per unit area (Table 7). Cross-Domsiah cultivar produced significantly higher number of panicles per unit area and this was statistically similar in CFI and I-1-D regime. However, it was significantly reduced in I-2-D regime.

Linear relationship between number of panicles per unit area and soil water suction head was not statistically significant, therefore, this trait was not influenced by soil water stress (data not shown).

Table 7. Mean number of panicles per unit area, seasonal water use, and water productivity (combined of two years) at different cultivars and irrigation treatments.

Cultivar	Irrigation treatment[#]			
	CFI	I-1-D	I-2-D	Mean
Number of panicles per unit area				
Ghasroddashti	329	224	168	241^{ab*}
Cross-Domsiah	360	279	223	287^{a}
Hasani	293	204	171	223^{b}
Rahmat-Abadi	353	285	188	275^{ab}
Mean	328^{a}	228^{b}	186^{b}	
Seasonal water use, mm				
Ghasroddashti	2258	1780	1592	1877^{a}
Cross-Domsiah	2196	1903	1636	1912^{a}
Hasani	2288	1776	1582	1882^{a}
Rahmat-Abadi	2082	1846	1568	1832^{a}
Mean	2174^{a}	1892^{b}	1630^{c}	
Water productivity, kg m^{-3}				
Ghasroddashti	0.15	0.11	0.05	0.10^{b}
Cross-Domsiah	0.22	0.16	0.15	0.17^{a}
Hasani	0.09	0.06	0.02	0.06^{c}
Rahmat-Abadi	0.16	0.08	0.06	0.10^{b}
Mean	0.13^{a}	0.09^{b}	0.06^{c}	

[*] Means followed by the same letters in row and column are not significantly different at 5% level of probability.

[#] CFI: Continuous flooding, I-1-D: Intermittent flood irrigation (1-day interval), I-2-D: Intermittent flood irrigation (2-day interval).

Water use and productivity

There was no difference in water use in two years. Therefore, combined effects between 2005 and 2006 were statistically analyzed. There was no interaction effect between cultivars and irrigation regimes on water use (Table 7). There was no significant difference between cultivars, but, significantly lower water was used in water-saving irrigations compared with CFI regime, with significant difference between I-1-D and I-2-D regimes. In general, it is indicated that there was no difference between cultivars in water use under different irrigation regimes.

Water productivity (WP) was calculated by ratio of grain yield to water use. Results are shown in Table 7. There was no interaction effect between cultivars and irrigation regimes on WP. Cross-Domsiah cultivar had significantly highest WP, and the values of WP for Ghasroddashti and Rahmat-Abadi cultivars were placed in second order and Hasani was third in WP. Furthermore, WP was significantly lower in water-saving regimes compared with CFI, and there was significant difference between I-1-D and I-2-D regimes.

The WP of some cultivars in Kato et al. (2006b) study under upland conditions ranged from 0.43 to 0.91 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). The values of WP for Cross-Domsiah cultivar was similar to those obtained for lowland rice as reported by Hayashi et al. (2006) and Kamoshita et al. (2007), however, WP of water-saving conditions were lower than those reported by Kato et al. (2006b). This indicated that our cultivars are not adapted to the upland conditions and breeding plan is needed in Iran to develop cultivars suitable for upland conditions.

Relationship between grain yield and yield components

Relationship between grain yield and yield components was determined by multiple regression analysis. Results are shown in Table 8. It is indicated that yield components except number of grains per panicle have potential to predict grain yield. The influence of unfilled grain percentage is negative and the other yield components positively affected grain yield. 1000-garin weight has the greatest effect on grain yield as shown by the highest value of coefficient (1.9) compared to others.

Table 8. Result of multiple regression analysis between Log of grain yield and Log of yield components.

Variable	Coefficient value	Probability level
Intercept	-3.4	0.17
Ln(Unfilled grain percentage)	-0.9	0.001
Ln(1000-grain weight)	1.9	0.002
Ln(Number of grains per panicle)	0.2	0.522
Ln(Number of panicles per unit area)	0.9	0.001

Drought tolerance index

Drought tolerance index (DTI) calculated based on Equations (1) to (3) is shown in Table 9. 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 obtained for Cross-Domsiah cultivar at water-saving irrigations in 2005 and 2006. Therefore, it is indicated that among the cultivars used in this study Cross-Domsiah is drought tolerant cultivar in Fars province conditions. On the other hand, in a later study in 2007 in greenhouse conditions, it is found that Doroodzan cultivar is most drought tolerant cultivar and Cross-Domsiah placed in second order (Abbasi and Sepaskhah, 2010). Therefore, further field study is required to determine drought tolerance of new cultivars, i.e., Doroodzan in field conditions.

Table 9. Drought tolerance index of different cultivars at different water-saving regimes in 2005 and 2006.

Irrigation* regime	Cultivar	Mean productivity	Geometric mean productivity	Stress tolerance index
		2005		
I-1-D	Ghasroddashti	268.9	268.7	1.65
	Cross-Domsiah	319.7	319.4	2.33
	Hasani	144.4	143.8	0.47
	Rahmat-Abadi	209.6	205.2	0.96
I-2-D	Ghasroddashti	171.8	148.3	0.50
	Cross-Domsiah	310.7	310.0	2.19
	Hasani	89.1	78.1	0.14
	Rahmat-Abadi	192.9	183.5	0.77
		2006		
I-1-D	Ghasroddashti	222.2	155.5	0.21
	Cross-Domsiah	416.6	373.4	1.23
	Hasani	143.2	99.6	0.09
	Rahmat-Abadi	270.3	232.9	0.48
I-2-D	Ghasroddashti	217.5	143.7	0.18
	Cross-Domsiah	387.0	322.1	0.92
	Hasani	137.8	85.2	0.06
	Rahmat-Abadi	232.7	153.5	0.21

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

Conclusions

In general, Anbarboo-22 cultivar totally failed in field trial due to susceptibility to disease in 2005 and 2006. Among the other cultivars, Cross-Domsiah showed the highest grain yield, harvest index, number of panicles per hill and the lowest unfilled grain percentage in two years field experiments. Furthermore, its grain yield was the highest at water-saving irrigation regimes in comparison with the other cultivars, therefore, Cross-Domsiah is the elite cultivar in water-saving irrigation conditions especially in intermittent irrigation with 1-day interval, however, Ghasroddashti cultivar is recommended in next order for I-1-D treatment.

Based on the selected drought indices, Cross-Domsiah was the most drought tolerant cultivar and Ghasroddashti was in the second order. Furthermore, it is concluded that unfilled grain percentage and harvest index are found to be the most suitable traits for selection of rice cultivars with high yield potential.

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