Effects of Water-Saving Irrigation and Nitrogen Fertilization on Yield and Yield Components of Rice (*Oryza sativa* L.)

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Abstract : The effects of nitrogen (N) application (32, 72 and 112 kg N ha^{-1} in 2000, and 32, 92 and 152 kg N ha^{-1} in 2001) and water-saving irrigation and their interaction on grain yield and yield components of the rice cultivar Champa-Kamphiroozi, which is a local cultivar in a semi-arid area in the south of Islamic Republic (I.R.) of Iran, were investigated. The plants were cultivated under sprinkler irrigation (1.0 ET_p and 1.5 ET_p), intermittent flooding (1-day and 2-day intervals) and continuous flooding (control). The experiments were conducted on a clay loam-clay soil under a semi-arid environment using four replications in a split plot design with irrigation method as main plots and N levels as subplots. The results indicated that intermittent flooding irrigation at 2-day intervals was as effective as continuous flooding for grain yield, showing high water-use efficiency (WUE). The soil moisture tension in the root zone before each irrigation under this condition was –300 to –400 cm. Sprinkler irrigation and intermittent flooding increased WUE by 20 to 60%, compared with continuous flooding, and the increase in N application rate to 112-152 kg ha^{-1} increased grain yield under any irrigation condition. Under sprinkler irrigation, grain yield was low and percentage of unfilled grain was high, although WUE was high. However, by adopting sprinkler irrigation, the amount of nitrogen fertilizer application necessary for cultivation was reduced. Furthermore, when nitrogen application must be limited due to groundwater pollution, the amount of nitrogen fertilizer necessary for cultivation can be reduced.

Key words : Nitrogen application, Rice, Sprinkler and intermittent irrigation, Water use efficiency.

Water scarcity for agricultural production is becoming a serious problem, but has development of new water resources is very costly. Thus more efficient use of water is essential for future food security in Asia where rice production has to be increased by 70% by 2025 (Tuong and Bhuiyan, 1999).

More than 90% of the world's rice is produced and consumed in Asia (FAO, 1997). Rice is the most widely grown of all crops under irrigation. More than 80% of the developed freshwater resources in Asia are used for irrigation purposes and about half of the total irrigation water is used for rice production (Dawe et al., 1998). The future of rice production will therefore depend heavily on how efficiently water is used in irrigation schemes. The rice plantation area in Fars province (I.R. of Iran) with a semi-arid climate is about 55400 ha and that in this study area is about 11000 ha. The rice in these areas is totally grown under irrigation, and continuous flooding with deep percolation of about 3-4 mm d^{-1} is the common irrigation system used by farmers (Pirmoradian et al., 2000).

Chandler (1979) stated that water management in lowland rice was ideal with flooding to 50 to 70 mm in depth. This suppresses weed growth, facilitates the use of granular insecticides and herbicides, and provides a continuous and adequate supply of water. Turner and McCauley (1983) indicated that the benefits of flooding are control of nonaquatic weeds, increased availability of nutrients, prevention of water stress, and reduction of disease risk. Thus flooding is used as a management tool, not because it is a requirement of the rice plant. Flooding, however, requires large quantities of water (Brown et al., 1978; Bettge and McCauley, 1985).

Comparison of continuous flooding, intermittent flooding and sprinkler irrigations showed that by intermittent flooding water could be conserved without significant reduction in yield (Tripathi et al., 1986; Ibrahim et al., 1995; Li and Cui, 1996). McCauley (1990) mentioned that water could be conserved by sprinkler irrigation of rice and resulting in lower production costs. Also, they indicated that due to more than 20% yield reduction, sprinkler irrigation does not appear to be a viable alternative to conventional irrigation in traditional rice-growing areas.

Nitrogen supply is an important factor for higher rice yield. Water and N supply often interact with each other. For example water stress reduces N uptake as a result of reduced transpiration rate (O'Toole and Baldia, 1982; O'Toole and Padilla, 1984; Yambao and O'Toole, 1984; Tripathi et al., 1997). Otoo et al. (1989)

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found an interaction between N supply and soil water deficit on photosynthesis and transpiration in rice. Application of N fertilizer increased grain yield of rainfed lowland rice even when the rice was exposed to water deficit (Castillo et al., 1992). These authors also concluded that the most effective timing of N application for continuously irrigated rice was when the rice was exposed to moderate water deficit before flowering. Yoshida (1975), on the other hand, pointed out that when water stress was the most limiting factor for growth, yield did not respond to increased N application under rain-fed upland conditions.

The objective of this research was to investigate the effects of N application and water-saving irrigation including a sprinkler, intermittent, and continuous flooding, and their interactions on grain yield and yield components of a local rice cultivar in a semi-arid area south of Islamic Republic (I.R.) of Iran.

Materials and Methods

1. Site description

This research was conducted at Kooshkak Agricultural Research Station, of Shiraz University in I.R. of Iran (Lat. 30˚7' N; Long. 52˚34' E; Elevation of 1650 m.) using a local cultivar, Champa-Kamphiroozi during the two consecutive growing seasons of 2000 and 2001. The experimental site was the irrigated area of Doroodzan Irrigation District located at south of I.R. of Iran. Although the fields in the Experimental Station used in 2000 and 2001 were different, the same experimental layout was used in both years. The soil at the experimental site was fine, carbonatic, and mesic Aquic Calcixerepts soil with a pH of 6.9-7.1. Table 1 shows the physical and chemical properties of the soil. The daily maximum temperatures during the growing season (July-October) ranged from 23 to 39˚C in 2000 and from 28 to 40˚C in 2001, and the daily minimum temperature from 7 to 24˚C in 2000 and from 8 to 27 ˚C in 2001. The mean daily maximum and minimum temperatures during the growing season (July-October) are 32.8 and 13.2°C, respectively in 2000, and 35.4 and 16.2˚C, respectively in 2001. Reference crop potential evapotranspiration (ET_o) during the growing period in 2000 and 2001 determined by the FAO-Penman method were 578 and 650 mm, respectively. These may be converted to potential crop evapotranspiration (ET_p) multiplied by crop coefficient (K_c). To these the water loss by wind and evaporation should be added. There was no rainfall during the growing season in either year.

2. Experimental details

The experiment was conducted using four replications in a split plot design with irrigation method as main plots and N levels as subplots. Main plots consisted of five irrigation regimes: 1) sprinkler irrigation with applied water equal to ET_p , 2) sprinkler irrigation with applied water equal to $1.5ET_p$, 3) continuous flooding irrigation, 4) intermittent flooding irrigation at 1-day intervals, 5) intermittent flooding irrigation at 2-day intervals. Subplots were composed of three N levels of 32, 72, and 112 kg ha^{-1} in 2000 and 32, 92, and 152 kg ha^{-1} in 2001. N was applied as urea and ammonium phosphate, and the ammonium phosphate at a rate of 200 kg ha^{-1} was applied before transplanting (32 kg N ha^{-1}). Subplots were 3m×3m basins enclosed by 50 cm bunds. The land was prepared on 8 to 10 July in 2000 and 28 to 30 June in 2001. The experimental plots were separated after the plowed land was saturated and puddled by a wet plowing and harrowing. The seedlings of a cultivar Champa-Kamphiroozi with a low tillering ability were transplanted at the density of 16 hills per m^2 on 11 July in 2000 and 25 hills per m^2 on 1 July in 2001. The transplants were about 40 days old. During the first ten days, all plants were irrigated with continuous flooding to establish the seedlings. The applied water in this period was 142 and 166 mm in 2000 and 2001, respectively.

Table 1. Soil properties at experimental site.

Soil properties	Depth (cm)	
	0-30	30-60
Sand (%)	30	25
Silt (%)	39	32
Clay (%)	31	43
EC (dS/m)	1.4	1.1
pH	7.1	6.9
N-NO3 (mg/kg soil)	2.8	2.35
N-NH4 (mg/kg soil)	0.725	0.925
P (mg/kg soil)	3.9	2.4

Four sprinklers with a capacity of 0.5 l s^{-1} were placed at the corner of each sprinkler irrigation plot on a riser at a 1.0 m height. For sprinkler treatments, the designated amount of water for each irrigation was determined from the mean ET_p for three previous days plus evaporation rate from droplets in the air and wind drift losses with the sprinkler. Evaporation and wind drift losses were determined by measuring the water collected in 45 empty cans placed in each experimental plot during the water application period. The difference between the applied water and collected water in the cans was considered as evaporation and wind drift losses. Due to strong wind in the daytime and high day temperature, the mean value of this loss was 28.8% in the growing season. For flooding treatments, the water depth in the plots was maintained at 5 to 10 cm during irrigation period. The weed population was higher in the sprinkler irrigation and intermittent flooding plots. The weeds were removed by hand. In the intermittent flooding plots, the standing water disappeared within about 24 h and the plots were irrigated again before the surface cracked. Volumetric water meters were used to measure the volume of the

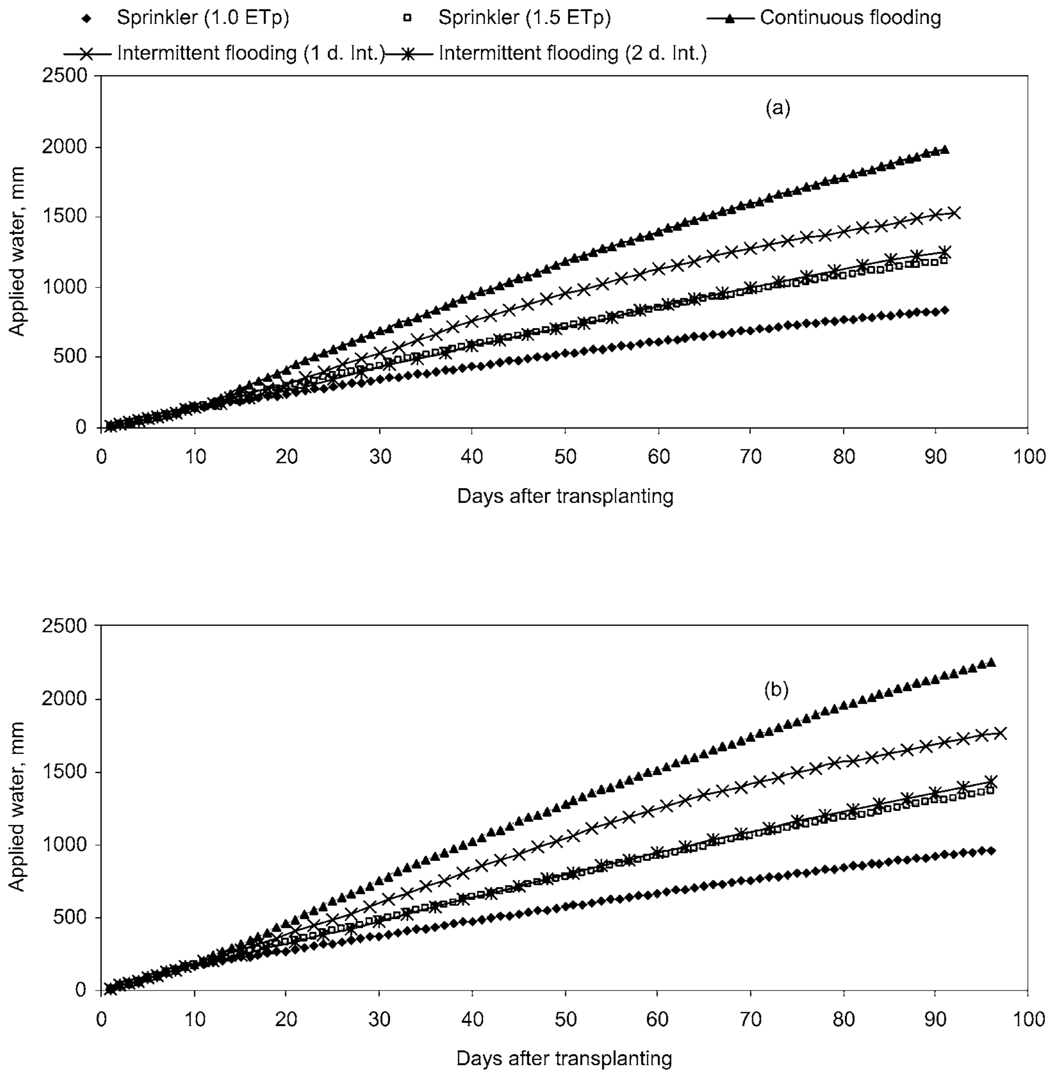

Fig. 1. The cumulative amounts of applied irrigation water for irrigation treatments in 2000 (a) and 2001(b).

delivered water for every main plot in four replications. Fig. 1 shows the cumulative amounts of applied water for each irrigation treatment.

Ten days after transplanting, one half the designated amount of N for each treatment (as urea) i.e., 20 and 40 kg N ha^{-1} in 2000, and 30 and 60 kg N ha^{-1} in 2001, was applied. The remaining N was applied at 40 and 50 days after transplanting (before flowering stage) in 2000 and 2001, respectively. During the growing season weeds were removed by hand. The crop was harvested manually on 8 and 13 October in 2000 and 2001, respectively.

At the end of growing season, the plants were harvested from a 1m×1m area at the middle of each plot. Samples were air dried for 5 days and then oven dried at 70°C for 48 h. Then, grain and straw yields and yield components (unfilled grain percent, harvest index, weight of 1000 grains, number of grain in panicle, and number of panicles per unit area) were determined. Ten panicles from each plot were selected randomly and the number of unfilled grains and their percentage were determined.

3. Soil moisture tension in intermittent irrigation plots

Before each irrigation, the soil water content at a depth of 0-30 cm was measured by a gravimetric procedure. The soil moisture retention curve for the soil at the experimental site was determined by pressure cell and hanging water column procedure as described by Klute (1986).

Fig. 2 shows the soil moisture characteristic curve (soil moisture tension (h) vs. soil water content (θ)) for the experimental site. The fitted equation to the measured data (h and θ) is as follows (van Genuchten, 1980):

$$\frac{\theta-\theta_r}{\theta_s-\theta_r}=\left[\frac{1}{1+(ah)^m}\right]^n \quad \text{.............................}(2)$$

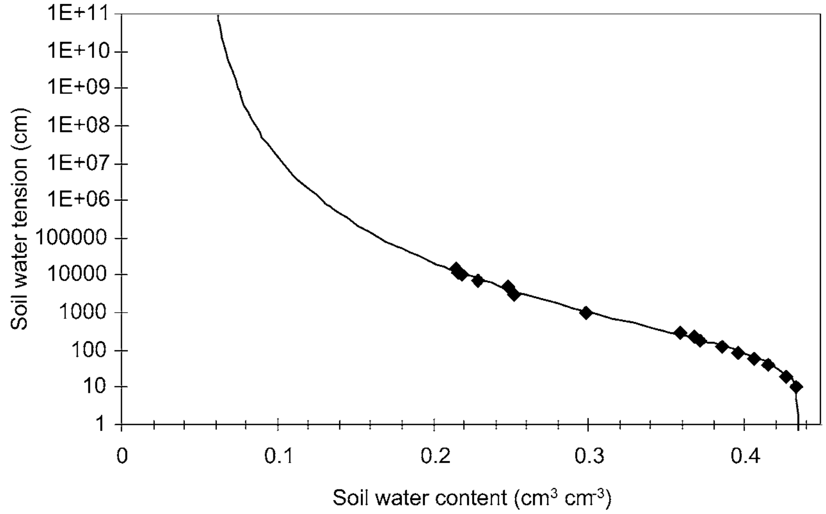

Fig. 2. Soil moisture characteristic curve for experimental site.

Table 2. Mean soil water tension (cm) and soil water content (cm^3 cm^{-3}) before irrigation.

Irrigation treatment	Water content		Tension	
	2000	2001	2000	2001
Sprinker (1*ETp)	0.331	0.336	-495.5	-450.7
Sprinkler (1.5*ETp)	0.352	0.356	-303.2	-276.6
Intermittent fl.(1d. Int.)[1]	0.365	0.376	-228.7	-170.8
Intermittent fl.(2d. Int.)[2]	0.340	0.353	-410.7	-298.4

1-Intermittent flooding(1-day interval).
2-Intermittent flooding(2-day interval).

where α is 0.0122 cm^{-1}, m is 0.1451, n is 1.1698, θ_r is 0.05 cm^3 cm^{-3}, and θ_s is 0.442 cm^3 cm^{-3}.

Rice roots usually grow in the puddled soil layer or the surface layer (0-30 cm). Table 2 shows the mean water content of soil (θ) in surface layer and soil moisture tension (h) calculated by using the θ values in Eq. 2. to calculate the corresponding h values. The results are shown in Table 2.

4. Statistical analysis

All collected data were statistically analyzed in a split plot design with four replications using analysis of variance to evaluate main and interaction effects. Means among treatments were compared using the Duncan multiple range test at $P \leq 0.05$ probability level. Statistical analyses were conducted using SPSS and MSTAT softwares.

Results and Discussion

1. Yield

The effect of irrigation treatments on grain yield was significant in both years (Table 3). Grain yield was highest in continuous flooding plot in 2000, and in the plot with intermittent flooding at 2-day intervals in 2001. It was lowest in the sprinkler irrigation plot, and the differences between the grain yields in the sprinkler irrigation and flooding irrigation plots were significant, in both years. On the other hand, the difference between the grain yields in the continuous and intermittent flooding plots was significant only in 2000.

In 2000, the grain yield over different N application treatments were decreased 54, 52.8, 32.1, and 26.5% by sprinkler irrigation at 1.0 ET_p, sprinkler irrigation at 1.5 ET_p, intermittent flooding at 1-day intervals and intermittent flooding at 2-day intervals, respectively, as compared with continuous flooding. In 2001, it was decreased 29.1 and 23.3% by sprinkler irrigation at 1.0 ET_p and 1.5 ET_p, respectively. Furthermore, it was increased 1.4 and 3.4% by intermittent flooding at 1-day intervals and 2-day intervals, respectively, as compared with continuous flooding, though the difference was not significant.

Reduction in grain yield by sprinkler irrigation as compared with continuous flooding has been reported previously (Westcott and Vines, 1986; McCauley, 1990; Surek et al., 1996). Also, similar yield reduction has been reported by Tripathi et al. (1986), Ibrahim et al. (1995), Li and Cui (1996), and Bouman and Tuong (2001) for intermittent flooding irrigation.

The effect of nitrogen fertilization on grain yield was significant in both years (Table 3). The highest yield was obtained in the plot with the highest level of

Table 3. Grain yields (kg ha $^{-1}$) in irrigation plots with different nitrogen application rates (2000 and 2001).

Year	Irrigation treatment	N applied (kg ha^{-1})					
		32		72		112	
2000	Sprinker (1*ETp)	1728	efg*	1643	efg	1614	efg
	Sprinkler (1.5*ETp)	1371	g	1488	fg	2258	de
	Continuous flood	3821	a	3318	ab	3707	ab
	Intermittent fl.(1d. Int.)[1]	2141	def	2150	def	3072	bc
	Intermittent fl.(2d. Int.)[2]	1698	efg	2686	cd	3587	ab
		N applied (kg ha^{-1})					
		32		92		152	
2001	Sprinker (1*ETp)	3541	f	3353	f	3745	ef
	Sprinkler (1.5*ETp)	3476	f	3726	ef	4293	cde
	Continuous flood	4196	de	4838	bc	5964	a
	Intermittent fl.(1d. Int.)[1]	4262	cde	4885	bc	6061	a
	Intermittent fl.(2d. Int.)[2]	4448	cd	5085	b	5975	a

*Means followed by the same letters in each column are not significantly different at 5% level of probability.
1-Intermittent flooding (1-day interval).
2-Intermittent flooding (2-day interval).

Table 4. Unfilled grain (%) in irrigation plots with different nitrogen application rates (2000 and 2001).

Year	Irrigation treatment	N applied (kg ha^{-1})					
		32		72		112	
2000	Sprinker (1*ETp)	44.5	bc*	61.8	a	66.2	a
	Sprinkler (1.5*ETp)	61.9	a	53.9	ab	61.7	a
	Continuous flood	24.9	def	36.4	cde	37	cd
	Intermittent fl.(1d. Int.)[1]	21.9	f	28.5	def	27.6	def
	Intermittent fl.(2d. Int.)[2]	32.6	cdef	29.6	def	23.1	ef
		N applied (kg ha^{-1})					
		32		92		152	
2001	Sprinker (1*ETp)	41.8	a	45.6	a	38.9	ab
	Sprinkler (1.5*ETp)	28.7	bc	23.9	cde	28.5	bcd
	Continuous flood	15.7	efg	13.7	efg	10.6	g
	Intermittent fl.(1d. Int.)[1]	21.9	cdef	17.5	defg	12.5	fg
	Intermittent fl.(2d. Int.)[2]	21	cdefg	21.3	cdefg	19.3	cdefg

*Means followed by the same letters in each column are not significantly different at 5% level of probability.
1-Intermittent flooding (1-day interval).
2-Intermittent flooding (2-day interval).

nitrogen application. Nitrogen applied at 72 kg ha^{-1} in 2000 and 92 kg ha^{-1} in 2001 did not show a significant effect as compared with the control treatment (32 kg N ha^{-1}). The application of 112 kg N ha^{-1} 2000 and 152 kg N ha^{-1} in 2001 were significantly different from 32, 72, and 92 kg N ha^{-1} treatments. Similarly, Castillo et al. (1992) reported that application of N fertilizer increased grain yield of rain-fed lowland rice even when the rice crop was exposed to water deficit. Also, Zhong and Huang (2002) indicated that grain yield and dry matter increased as applied N rate was increased.

In both years, the both irrigation and nitrogen treatments had significant effects on grain yield (Table 3). In 2000, the highest grain yield was obtained in continuous flooding with 32 kg ha^{-1} nitrogen application. However, it was not significantly different from those obtained in continuous flooding with 72 and 112 kg ha^{-1} nitrogen application and intermittent flooding (2-day inter.) with 112 kg ha^{-1} nitrogen application. In this year, the grain yield was lowest in sprinkler irrigation (1.5 ET_p) with 32 kg ha^{-1} nitrogen application.

In 2001, the highest grain yield was obtained in

Table 5. Weight of 1000 grains (g) in irrigation plots with different nitrogen application rates (2000 and 2001).

Year	Irrigation treatment	N applied (kg ha^{-1}) 32		72		112		Mean	
2000	Sprinker (1*ETp)	19	ab*	18.3	ab	18.6	ab	18.6	A
	Sprinkler (1.5*ETp)	17.4	b	21.1	a	18.3	ab	18.9	A
	Continuous flood	20	ab	19.9	ab	20.6	ab	20.2	A
	Intermittent fl.(1d. Int.)[1]	19	ab	20.1	ab	20.3	ab	19.8	A
	Intermittent fl.(2d. Int.)[2]	19.2	ab	20.3	ab	18.7	ab	19.4	A
	Mean	18.9	A	19.9	A	19.3	A		
		N applied (kg ha^{-1}) 32		92		152		Mean	
2001	Sprinker (1*ETp)	20.4	ef	19.5	fg	18.7	g	19.5	C
	Sprinkler (1.5*ETp)	21	cde	20.7	def	20.7	def	20.8	BC
	Continuous flood	23	a	22.4	abc	23.3	a	22.9	A
	Intermittent fl.(1d. Int.)[1]	22.1	abcd	21.9	abcd	22.6	ab	22.2	AB
	Intermittent fl.(2d. Int.)[2]	21.3	bcde	21.2	bcde	22.3	abc	21.6	AB
	Mean	21.5	A	21.1	A	21.5	A		

*Means followed by the same letters in each column and row (capital letters) are not significantly different at 5% level of probability.
1-Intermittent flooding (1-day interval).
2-Intermittent flooding (2-day interval).

Table 6. Number of panicles per unit area, m^2, in irrigation plots with different nitrogen application rates (2000 and 2001).

Year	Irrigation treatment	N applied (kg ha^{-1}) 32		72		112		Mean	
2000	Sprinker (1*ETp)	332	cde*	373	bcde	467	ab	391	A
	Sprinkler (1.5*ETp)	318	de	312	de	468	ab	366	A
	Continuous flood	406	abcd	445	abc	520	a	457	A
	Intermittent fl.(1d. Int.)[1]	280	e	308	de	364	bcde	317	A
	Intermittent fl.(2d. Int.)[2]	305	de	380	bcde	414	abcd	367	A
	Mean	328	B	363	AB	447	A		
		N applied (kg ha^{-1}) 32		92		152		Mean	
2001	Sprinker (1*ETp)	447	a	442	a	420	ab	436	A
	Sprinkler (1.5*ETp)	312	cd	327	bcd	368	abcd	336	AB
	Continuous flood	288	d	305	cd	357	abcd	316	B
	Intermittent fl.(1d. Int.)[1]	359	abcd	376	abcd	421	ab	385	AB
	Intermittent fl.(2d. Int.)[2]	404	abc	408	abc	438	a	417	AB
	Mean	362	A	371	A	400	A		

*Means followed by the same letters in each column and row (capital letters) are not significantly different at 5% level of probability.
1-Intermittent flooding (1-day interval).
2-Intermittent flooding (2-day interval).

intermittent flooding (1-day inter.) with 152 kg ha^{-1} of nitrogen application, while it was not significantly different from the yield in continuous flooding or intermittent flooding (2-day inter.) with 152 kg ha^{-1} nitrogen application (Table 3). It is worth mentioning that farmers in the study area use more than 150 kg ha^{-1} nitrogen on average. The grain yield in intermittent irrigation plot is higher than or comparable with that obtained by local farmers (about 4-5 t ha^{-1}) in favorable conditions. In this year, the grain yield was lowest in sprinkler irrigation (1.0 ET_p) plot with 92 kg ha^{-1} nitrogen application, however, it

Table 7. Harvest index in irrigation plots with different nitrogen application rates (2000 and 2001).

Year	Irrigation treatment	N applied (kg ha^{-1}) 32		72		112		Mean	
2000	Sprinker (1*ETp)	0.32	ab*	0.31	ab	0.24	b	0.29	B
	Sprinkler (1.5*ETp)	0.36	ab	0.42	ab	0.47	a	0.41	AB
	Continuous flood	0.38	ab	0.51	a	0.49	a	0.46	AB
	Intermittent fl.(1d. Int.)[1]	0.44	ab	0.49	a	0.5	a	0.47	A
	Intermittent fl.(2d. Int.)[2]	0.44	ab	0.47	a	0.43	ab	0.44	AB
	Mean	0.39	A	0.44	A	0.43	A		
		N applied (kg ha^{-1}) 32		92		152		Mean	
2001	Sprinker (1*ETp)	0.34	de	0.32	e	0.5	ab	0.38	A
	Sprinkler (1.5*ETp)	0.38	bcde	0.45	abcde	0.5	ab	0.44	A
	Continuous flood	0.37	bcde	0.45	abcd	0.36	cde	0.39	A
	Intermittent fl.(1d. Int.)[1]	0.38	bcde	0.37	bcde	0.41	bcde	0.38	A
	Intermittent fl.(2d. Int.)[2]	0.56	a	0.49	abc	0.45	abcde	0.5	A
	Mean	0.41	A	0.42	A	0.44	A		

*Means followed by the same letters in each column and row (capital letters) are not significantly different at 5% level of probability.
1-Intermittent flooding (1-day interval).
2-Intermittent flooding (2-day interval).

was not significantly different from those obtained in other sprinkler irrigation plot, except that with 1.5 ET_p with 152 kg ha^{-1} nitrogen application.

The mean straw yields for two consecutive years were 5284 and 5806 kg ha^{-1}. This difference is much smaller than that in grain yield, which indicates that the difference in grain yield is not due to differences in the plant population.

2. Yield components

In 2000, the percentage of unfilled grains in flooding plot was significantly lower than that in sprinkler irrigation plot (Table 4). Similar results were obtained in 2001. These results were in accordance with those reported by Guidice et al. (1974) and McCauley (1990). They found that sprinkler irrigation reduced the filled grain ratio compared with that in flooded rice. Sprinkling of irrigation may increase the air humidity and decrease the air temperature below critical level especially during the flowering stages. This might increase the unfilled grain ratio and decrease grain yields.

The 1000-grain weight in 2001 was significantly lighter in the sprinkler irrigation plot, especially with 1.0 ET_p (Table 5). But no significant difference was obtained in 2000. Guidice et al. (1974) demonstrated that the seed weight was decreased by sprinkler irrigation compared with flooding, but according to Westcott and Vines (1986) and McCauley (1990), seed weight was not influenced by the irrigation method.

Table 8. Amount of water (mm) used for each irrigation treatment.

Irrigation treatment	Year 2000	2001
Sprinker (1*ETp)	836.3	971.1
Sprinkler (1.5*ETp)	1183.6	1373.9
Continuous flood	1948	2262.3
Intermittent fl.(1d. Int.)[1]	1530.1	1778.8
Intermittent fl.(2d. Int.)[2]	1256	1441.8

1-Intermittent flooding(1-day interval).
2-Intermittent flooding(2-day interval).

Prasertsak and Fukai (1997) also indicated that water stress reduced the spikelet number and HI, but increased the unfilled grain ratio.

In 2001, the number of panicles per unit area was significantly decreased by continuous flooding as compared with sprinkler (1.0 ET_p) irrigation, especially at 32 kg ha^{-1} N application (Table 6). This is in contrast to the report by Westcott and Vines (1986) and McCauley (1990). For other yield components, there was no significant difference between continuous flooding and sprinkler irrigation.

In 2000, increasing nitrogen application rates significantly increased the number of panicles per unit area (Table 6). Although, a similar result was observed in 2001, there was no significant difference between the treatments. For other yield components, there was no significant difference between N treatments. Prasertsak and Fukai (1997) found out a positive effect

Table 9. Water use efficiency (WUE) (kg mm^{-1} ha^{-1}) in irrigation plots with different nitrogen application rates (2000 and 2001).

Year	Irrigation treatment	N applied (kg ha^{-1}) 32		72		112	
2000	Sprinker (1*ETp)	2.07	b*	1.96	b	1.93	b
	Sprinkler (1.5*ETp)	1.16	e	1.26	de	1.91	b
	Continuous flood	1.83	b	1.67	bcd	1.87	bc
	Intermittent fl.(1d. Int.)[1]	1.4	cde	1.41	cde	2.01	b
	Intermittent fl.(2d. Int.)[2]	1.35	de	2.14	b	2.85	a
		N applied (kg ha^{-1}) 32		92		152	
2001	Sprinker (1*ETp)	3.64	bc	3.45	cd	3.85	ab
	Sprinkler (1.5*ETp)	2.53	g	2.71	g	3.12	de
	Continuous flood	1.85	I	2.14	hi	2.63	g
	Intermittent fl.(1d. Int.)[1]	2.39	gh	2.75	fg	3.41	cde
	Intermittent fl.(2d. Int.)[2]	3.08	ef	3.53	bc	4.15	a

*Means followed by the same letters in each column are not significantly different at 5% level of probability.
1-Intermittent flooding (1-day interval).
2-Intermittent flooding (2-day interval).

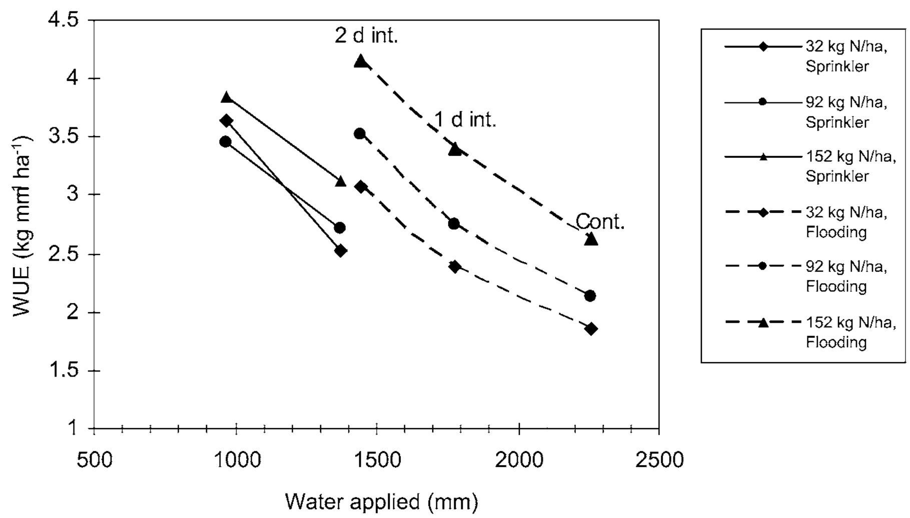

Fig. 3. Relationship between WUE and the amount of water applied (Data from Table 9, 2001).

of N application on yield components.

Interaction between irrigation and N treatments on yield components were significant for percentage of unfilled grain in both years. The unfilled grain percentage was higher in sprinkler irrigation than in flooding irrigation but was not significantly affected by with nitrogen application rates (Table 4). The unfilled grain percentage was lowest in intermittent flooding (1-day inter.) with 32 kg ha^{-1} nitrogen application in 2000 and in continuous flooding with high level of N application in 2001.

Among yield components, the unfilled grain had the strongest effect on the grain yield and the 1000-grain weight had the next strongest effect. The unfilled grain rate had a negative effect on yield, and other yield components a positive effect. This result is similar to that reported by Westcott and Vines (1986) and McCauley (1990).

Harvest index (HI) in sprinkler irrigation (1.0 ET_p) was significantly lower than that in other irrigation plots, especial at 112 kg ha^{-1} N application rate in 2000 and 32 and 92 kg ha^{-1} N application rates in 2001 (Table 7).

3. Amount of water used for each irrigation treatment

Table 8 shows the amounts of water used for each irrigation treatments. In both years, the smallest amount of water used for sprinkler irrigation with 1.0

ET_p and the largest amount of water for continuous flooding. Intermittent flooding at 2-day intervals expended smaller amount of water compared with sprinkler irrigation with 1.5 ET_p. However, the grain yield was higher in the former than in the latter (Table 3). Thus, the intermittent flooding seemed to be more efficient than sprinkler irrigation.

4. Water use efficiency (WUE)

The water use efficiency (WUE) with each irrigation treatment was calculated as the ratio of grain production (kg ha^{-1}) to the amount of water applied during the cultivation (mm). The WUE significantly varied with the irrigation treatment (Table 9).

The WUE in 2000 was increased 9.3 and 15.9% by sprinkler irrigation at 1.0 ETp and intermittent flooding at 2-day intervals, respectively, as compared with continuous flooding, but was decreased 20.9 and 12.1% by sprinkler irrigation at 1.5 ETp and intermittent flooding at 1-day intervals, respectively, compared with continuous flooding. In 2001, the WUE was increased 61.1, 26.2, 28.9 and 62% by sprinkler irrigation at 1.0 ETp, sprinkler irrigation at 1.5 ETp, intermittent flooding at 1-day intervals and intermittent flooding at 2-day intervals, respectively, as compared with continuous flooding. Thus, the WUE in intermittent flooding was higher than that in continuous flooding and similar to that in sprinkler irrigation. The rice cultivation in Fars province (I.R. of Iran) is faced with serious water shortage, especially in drought years, and the farmers in this area are advised to practice intermittent irrigation at 2-day intervals.

According to Tripathi et al. (1986), Ibrahim et al. (1995), and Li and Cui (1996), intermittent flooding could conserve water without significant reduction in grain yield. Tabbal et al. (2002) reported that in transplanted and wet-seeded rice, keeping the soil moisture continuously at near saturation level, reduced yields by 5% and water input by 35%, and increased water use efficiency by 45% compared with flooded condition. These results indicated that sprinkler irrigation and intermittent flooding could reduce the amount of water needed for irrigation and consequently increase the WUE. Surek et al. (1996) also showed that sprinkler irrigation can be used to increase WUE in the field where irrigation water is scarce.

The effect of N application on WUE was significant in both years (Table 9). The WUE was highest with intermittent flooding at 2-day intervals with 112 and 152 kg ha^{-1} N applied in 2000 and 2001, respectively. In 2000, the WUE in intermittent flooding at 2-day intervals with 72 kg ha^{-1} N application was not significantly different from that in continuous flooding with 32-112 kg ha^{-1} N applied. However, in both years, N applied at 112-152 kg ha^{-1} significantly increased the WUE in rice. In most cases, WUE was increased by intermittent irrigation at 2-day intervals as compared with continuous flooding, especially at a high N application rate (112-152 kg ha^{-1}). Some farmers in this study area apply N fertilizer at a rate higher than this range, but this may not be necessary. The WUE was lowest with sprinkler (1.5 ET_p) irrigation with 32 kg ha^{-1} N applied in 2000, and with continuous floodind with 32 kg ha^{-1} N applied in 2001.

In Fig. 3, WUE shown in Table 9 (2001) was plotted against the amount of water used for each irrigation treatment (shown in Table 8). The WUE was highest with the intermittent irrigation at 2-day intervals (applied water was 1442 mm) with 152 kg N ha^{-1} applied. The highest WUE was observed with sprinkler (1.0 ET_p) irrigation with 152 kg N ha^{-1} applied. The results showed that the higher the N application rate, and the smaller the amount of water used for irrigation, the higher the WUE (Fig. 3).

Conclusion

The results of our experiments indicated that intermittent flooding at 2-day intervals with a high N application rate (112-152 kg N ha^{-1}) is preferable for water-saving purposes. Under this condition, the soil moisture tension in the root zone before each irrigation was –300 to –400 cm. It should be mentioned that water-saving irrigation did not cause a salinity problem in this study area, because there was enough winter rainfall in this area to leach out the accumulated salt in the soil and the quality of irrigation water was high (0.6 dS m^{-1}). For the cultivation of the local lowland rice cultivar, sprinkler irrigation is not recommended as a water-saving method because the grain yield was low. However, WUE is increased by sprinkler irrigation compared with continuous flooding and the amount of nitrogen fertilizer necessary for cultivation may be reduced by sprinkler irrigation. When N application must be limited due to groundwater pollution, the amount of nitrogen fertilizer application may be reduced by adopting intermittent flooding instead of continuous flooding.

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