Improving rice water productivity using alternative irrigation (case study: north of Iran)

Masoud Pourgholam-Amiji, Abdolmajid Liaghat, Mojtaba Khoshravesh and Hazi Mohammad Azamathulla

ABSTRACT

Increasing population and the need for more food has made demands on water resources due to crop productions. One of the strategies for preventing the overuses of safe water resources for agriculture is to increase agricultural productivity by reducing the amount of irrigation water with a slight reduction or even maintaining the yields. Rice production in the northern region of Iran which is strategically and economically very important, requires irrigation management changing with traditional irrigation methods (flood irrigation). This study was conducted in the 2017–2018 crop season to investigate the effect of different irrigation management on water consumption, rice yield and water productivity in paddy field of Babolsar, Mazandaran, Iran. The experiment was performed in the field in a randomized complete block design with three replicates and four treatments in 12 plots. The treatments were TI (Traditional/flood Irrigation), and AI1, AI3 and AI5 (Alternative Irrigation one, three and five days after the disappearance of water from the soil surface, respectively). The number of yield components and the water productivity indexes were determined. The results of this study showed a significant difference (at 1% level) between irrigation treatments in terms of yield components including tiller number, Panicle length, filling percentage, and water productivity, but they did not have any significant effect on plant height and grain yield. The applied irrigation water for TI, AI1, AI3, and AI5 treatments was measured to be 7,940, 4,910, 4,090 and 3,290 m^3/ha, respectively. The maximum yield (6.11 ton/ha) belonged to TI treatment and after that with the value of 6.02 ton/ha belonged to AI5 treatment with the least application of water. Rice water productivities for TI, AI1, AI3, and AI5 treatments were calculated to be 0.82, 1.05, 1.38 and 1.83 kg/m^3, respectively. Therefore, alternate irrigation five days after the disappearance of surface water (AI5) was accepted to be the best irrigation practices among the other different irrigation management due to 56.07% reduction in water use and only 1.47% reduction in grain yield compared to control treatment.

Key words | flood irrigation, irrigation management, traditional irrigation, water resources

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HIGHLIGHTS

- Due to water scarcity, it is necessary to use methods that reduce water consumption in agriculture.
- The results of using different irrigation managements showed that with small changes, water consumption can be reduced and water productivity can be increased.

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- Using Alternate Irrigation management reduced water consumption by half and increased rice water productivity by more than twice as much as by flood irrigation.

INTRODUCTION

Water scarcity in many countries including Iran is one of the main challenges that governments face. In such countries, more than 70 percent of renewable water resources are consumed in agriculture. In Iran, 90 percent of renewable water resources are used in agriculture (Pourgholam-Amiji *et al.* 2020). Droughts and global changes have also made serious problems and crises for the countries having water scarcity. These phenomena have caused some lakes to become dried and the underground water table in many plains of Iran is drawdown rapidly (Mirzaei *et al.* 2019).

Conversely, the excessive use and extraction of surface and groundwater resources in recent years have caused many problems (Zhao *et al.* 2019). These include the drop in groundwater levels, plus erosion and land subsidence, water quality effects, the influence of saline water on coastal aquifers and issues such as rural migration to cities, unemployment, and environmental-socio-economic problems were pointed out (Huang *et al.* 2017). Overall, this puts pressure on agricultural water resources and therefore, limited water resources should be optimally utilized. Various irrigation management improved methods of water management in the field, deficit irrigation, and increased productivity are some of the most effective methods (Rajwade *et al.* 2018; Mirzaei *et al.* 2019; Fadul *et al.* 2020).

Iran is a semi-arid country with an average annual rainfall of 240 mm and has an area of 0.62 million hectares of paddy fields. Approximately, irrigation in all areas of rice paddies is carried out using a flooding regime that holds 3–5 cm of water on the soil for the growing season (Morandini *et al.* 2020). Guilan province with the area of 220,000 hectares has the highest level of rice cultivation in Iran and Mazandaran province with the area of 214,052 hectares is in second place in terms of cultivation of paddy fields in Iran. These two provinces together account for about 70 percent of the area under rice cultivation in Iran. Therefore, special attention is needed to these two provinces and this study was conducted in one of the paddy fields of Mazandaran province with the aim of using alternative irrigation and demonstrating its effect on rice growth and yield. Mazandaran province with 1,113,715 tons and Guilan province with 1,093,665 tons have the highest amount of production in Iran (Ahmadi *et al.* 2019).

Rice is one of the most popular plants that grow in the world. For about half of the world's population, rice accounts for about 80 percent of their food consumption (Djaman *et al.* 2020; Pourgholam-Amiji *et al.* 2020). Due to the flexibility and compatibility with natural conditions, rice is planted in about 113 countries (FAOSTAT 2016). Due to the nutritional value and economic importance of rice, this crop has been cultivated in more than 146.5 million hectares of world agriculture lands (Gill *et al.* 2014; Murumkar *et al.* 2014; Lampayan *et al.* 2015) whose production is significantly affected by climate change and subsequent water shortages (Pan *et al.* 2017).

The sustainability of irrigated rice production systems has also been challenged by water scarcity due to climate change and droughts, and rapid urbanization and industrialization are further depleting water reserves and limiting the availability of irrigation water (Bouman & Tuong 2001; Yan *et al.* 2015; Pourgholam-Amiji *et al.* 2020). These necessitate the adoption of water-efficient techniques for rice production in order to reduce water use in the agricultural sector while maintaining or increasing yield to support a growing population (Carrijo *et al.* 2017; Brar *et al.* 2018). Periodic or alternative irrigation is one of these techniques.

The popular continuous flooding (CF) system provides favorable water and nutrient supply as well as weed management under anaerobic conditions; however, rice cultivation under this traditional system demands higher water input than the other cereal crops (Datta *et al.* 2017). Permanent flood irrigation in rice, with very low efficiency, consumes more water than the actual needs, so it is necessary to evaluate and use some management practices to save and increase water productivity (WP) for rice production. One of the existing strategies is the use of alternate irrigation or water stress (Carracelas et al. 2019).

Rezaei & Nahvi (2007) showed that alternate irrigation reduces water consumption and improves water use efficiency in rice, which can be used as an irrigation management strategy for droughts and water scarcity. This methodology was developed in Madagascar in the early 1980s (Bhuiyan 1992). Bouman & Tuong (2001) considered alternate irrigation a way to increase rice WP, reduce water consumption, and increase or maintain performance at the lowest cost and without the need for expensive equipment.

Alternate wetting and drying (AWD) are among the most widely promoted water-saving irrigation technique introduced by the International Rice Research Institute (IRRI) to cope with the increasing threat of water scarcity in rice cultivation (Belder et al. 2004; Azamathulla et al. 2008; Datta et al. 2017; Yang et al. 2017; López-López et al. 2018). Under this system, fields are subjected to intermittent flooding (alternate cycles of saturated and unsaturated conditions) where water of about 2–5 cm is applied at an interval of 2–7 days depending on the soil type and weather conditions followed by disappearance of pond water from the soil surface and appearance of visible signs of some fine cracks on the soil surface (Tuong & Bouman 2003).

Maneepitak et al. (2019) reported that the AWD reduced total water input by 19% in the wet season and by 39% in the dry season resulting in an improvement in total WP by 46% in the wet season and by 77% in the dry season relative to CF. Zhen et al. (2019) investigated the effect of alternating stresses of drought and waterlogging on rice yield. Their results showed that light drought periods reduced yields by only 19.01%, but in severe drought and long periodic irrigation, rice yields decreased by 80.39%. The results also showed that in intermittent irrigation with a short period and light waterlogging + light drought, water use efficiency increased by 46.77% compared to permanent flood regime.

Water productivity can be quantified with respect to water use in different production sectors as the amount of output per unit of water used. Therefore, for rice cultivation, it is the grain yield obtained based on the water volume used in production (Cao et al. 2015). Thus, WP can be defined as the weight of the rice grain over the cumulative volume of water used for irrigation (WP_I) and irrigation and precipitation (WP_{I+P}) (López-López et al. 2018).

Many researchers have reported that the WP of rice is 0.4 kg/m^3, based on the total water input (irrigation plus rainfall) (Tuong et al. 2005). However, alternate irrigation and water saving can result in an increase in WP up to 0.8–1 kg/m^3 (Belder et al. 2005; Kato et al. 2009; Pourgholam-Amiji et al. 2020).

Carracelas et al. (2019) examined strategies of irrigation management to increase rice WP in Uruguay. Intermittent flooding until panicle initiation (IP) and intermittent flooding during all crop growth period (i) over the three seasons resulted in significant water savings in the northern and central regions (averaged 35% or 3,986 m^3 ha^{-1} compared to the control treatment, i.e., early continuous flooding). In the eastern region, AWD saved water use by 29% or 2,067 m^3 ha^{-1} over four seasons compared to the control treatment. It should be noted that irrigation water productivity (WP_I) increased by 0.23 kg m^3 in IP treatment and 0.68 kg m^3 in treatment I compared to control treatment.

Amiri et al. (2011) evaluated irrigation management of rice in Guilan province on the Hashemi type of rice and calculated WP_I in the range of 0.29–0.92 kg/m^3. In a research study, Rejesus et al. (2011) concluded that intermittent irrigation methods reduced about 38% of the use of rice water without decreasing yield. Zhuang et al. (2019) evaluated the effects of water-saving irrigation (WSI) for rice production in China. Shallow-wet irrigation (SWI), controlled irrigation (CI), intermittent irrigation (II), and rain-gathering irrigation (RGI) were the four common WSI regimes investigated in this study. The results of this study showed that intermittent irrigation with a water-saving rate (WSR) of 19.21%, pollutant reduction rate (WRR) of 24.76% and yield increase rate (YIR) of 5.40% is one of the best methods of water saving in rice fields.

Mote et al. (2017) examined the effects of wet and dry periods and management of rice irrigation in low and low altitude areas in the state of Telangana, India. The results of this study showed that by maintaining the rice yield (more than seven tons per hectare), water consumption can be saved by 26.6–35%. Also, higher WP in the AWD method shows that the rice can be grown by adopting an optimal irrigation regime with success and without reduced yield (Rejesus et al. 2011; Monaco & Sali 2018).

The most required water in the agricultural sector in the north of Iran is supplied from the surface and underground water resources. Rice cultivation in the north of Iran is the main product that supplied most of the rice requirements of people in Iran. However, due to the traditional method of cultivation and high water consumption in rice, it still needs to be managed and should be reduced by using methods such as alternative irrigation to reduce rice water consumption.

In irrigation management, it is necessary to determine what amount and type of deficit irrigation should be applied, which depends on the type of cultivation, the economic value, the time of irrigation, and the awareness of plant physiology and soil morphological conditions. Similar studies with this research focused on the practice of alternate irrigation with attention to the water requirement, different irrigation intervals based on evaporation from the pan, different growth stages and plant type. However, the method of alternate irrigation management in this research differs from other studies and is implemented by farmers due to its ease of use. Regarding the importance of revising the traditional and flooding methods of water use in rice fields and presenting new solutions, the present study was conducted to compare the different irrigation management practices in paddy fields, in terms of water consumption, yield, and productivity.

MATERIALS AND METHODS

Study area and climate

This research was carried out in the paddy fields in Babolsar city, Mazandaran province, north of Iran. Babolsar is one of the coastal towns of Mazandaran province with 52 degrees and 39 minutes longitude (°E) and 36 degrees and 43 minutes altitude (°N) with a level of −21 meters from sea level which is located in the north of Iran and on the southern coast of the Caspian Sea. The average annual rainfall of this region is 977 mm with a very humid climatic type A based on the classification of the Do-Marten method. The spatial distribution of rainfall from the west to the east of the province decreases, while the time distribution is a relatively regular situation. In this way, the maximum rainfall occurs in the autumn and the minimum in the spring. One important point to note is that in fieldwork such as this research, plant cultivation should be two years or more, but the answer is to say that rice conditions are specific. During the growing season the amount of irrigation is relatively high and the climate has little effect on the production process. This is especially true for plants with low water consumption. Therefore, one-year cultivation is not a reason for the weakness of the research, as in the second year it will yield similar results.

Meteorological statistics including temperature, relative humidity, rainfall, evaporation, and sunshine were collected and recorded from the meteorological station of Babolsar, as shown in Table 1. Figure 1 also shows the geographic location of the study area.

Water and soil characteristics

The source of irrigation water for the study area was supplied from a shallow well and its chemical characteristics are shown in Table 2. This table shows the average chemical properties of irrigation water during the growing season. ECe was measured at a ratio of EC 1:5. Ion chromatography is a useful method for separating ions and polar molecules based on their charge. The principles of this device are based on separation and measurement with the conductivity

Table 1 | Meteorological information during the period of cultivation

	Temperature (°C)			Relative humidity (%)					
Month	**Min**	**Max**	**Average**	**Min**	**Max**	**Average**	**Rain (mm/month)**	**Evaporation (mm/month)**	**Sunny Hours (hr/month)**
6 May–21 May	18.4	26.1	22.2	55	89	72	0.1	67.7	136.5
22 May–21 June	20.8	27.3	24	60	91	75	18.2	147.3	203.2
22 June–22 July	25.2	33	29.1	60	90	75	32.8	185.7	292.9
23 July–26 July	25.7	32.6	29.1	65	92	78	0	14.5	19

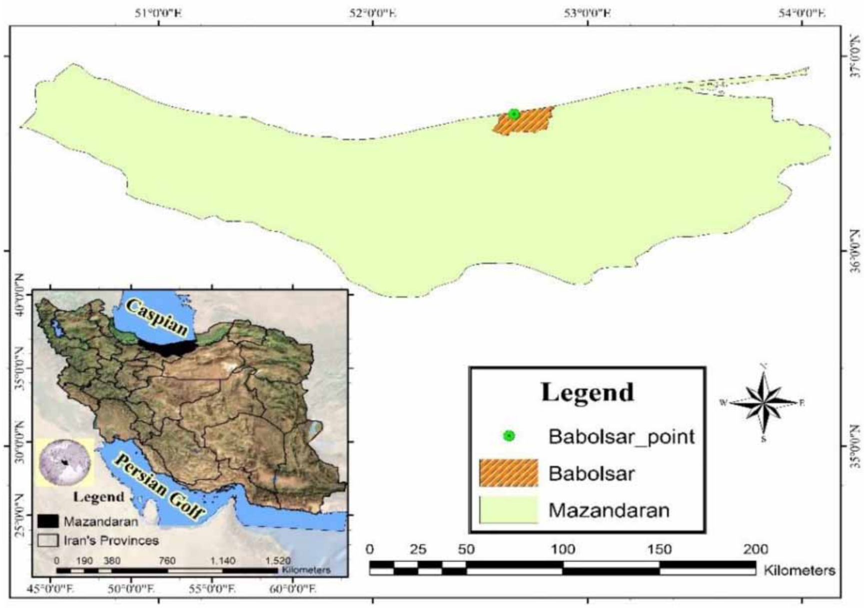

Figure 1 | Geographical location of the studied area.

Table 2 | Chemical properties of irrigation water

Type of experiment	Unit of measurement	Results of the experiment
EC	dS/m	1.286
pH	–	6.81
Chlorine	meq/l	9.6
Carbonate	meq/l	0
Bicarbonate	meq/l	8.9
Calcium	meq/l	7.8
Sodium	meq/l	6.73
potassium	meq/l	0.065
magnesium	meq/l	3.8
Sulfate	mg/l	18.96
Nitrate	mg/l	0.5

detector, so many disturbances will be eliminated during the analysis. Ion chromatography is used for chemical analysis of water as well as biochemical species such as amino acids and proteins. With this method, anions and cations in the usual water are accurately measured in ppb.

Plowing and preparation of the land were done uniformly in the field and 12 plots were prepared for irrigation treatments. Three soil samples were collected from the top layer (30 cm) and the average physical and chemical characteristics of the soil were measured (Table 3) in the laboratory. The soil texture in the plots is loam type. Other important properties of the tested soil such as total nitrogen, phosphorus, and potassium available for fertilization recommendation are also shown in Table 3. Total nitrogen was measured using the Kjeldahl method (wet oxidation). Potassium is adsorbed by photometric method and phosphorus adsorbed by the Olsen method.

Table 3 | Physical and chemical characteristics of the soil in the studied area at 0–30 cm depth

Type of experiment	Unit of measurement	Results of the experiment
EC	dS/m	1.189
Texture	Type	Loam
Clay	%	22.94
Silt	%	50
Sand	%	27.06
ρ_s	g/cm^3	2.67
FC	%	37.86
PWP	%	18.93
Total nitrogen	%	0.168
Acceptable potas.	mg/l	200
Absorbable phos.	mg/l	94.45

Treatments

The statistical design in this study was based on the completely randomized block design with three replicates and four treatments as follows:

- The Traditional Irrigation (TI) or permanent flood irrigation as a control treatment (traditional irrigation or permanent flood is applied so that during the rice-growing period, the soil surface is always full of water and is prevented from drying. The two methods mentioned are practically an irrigation method; sometimes they are called a traditional or permanent flood. In this study, the irrigation method was used for control treatment and during the rice growth period, the amount of water given to the plots was measured to flood it).
- Alternate Irrigation one day after the disappearance of water from the soil surface (AI1). In this treatment, the soil moisture varies between the saturation and field capacity.
- Alternate Irrigation three days after the disappearance of water from the soil surface (AI3).
- Alternate Irrigation five days after the disappearance of water from the soil surface (AI5). Figure 2 illustrates the schematic of the treatments arrangement on the field.

The total number of experimental plots was 12 and the plot area was 1 × 1 m. Primary and secondary plowing, leveling and creating intermediate grooves between plots were applied to all plots in the same way and fertilizers consisting of nitrogen, phosphorus and potash were applied equally in all plots based on the soil test results (Table 3). Rice planting was carried out in a three-four-leaf stage (20 cm height) with 25 rice clumps per square meter.

Due to the type of flood irrigation and in order to prevent leakage losses, the boundaries of plots were raised to 30 cm high and covered with plastics. The plastic cover was placed into the soil as an impenetrable layer (50 cm depth) to prevent lateral seepage. Another advantage of the plastic cover is the prevention of weed growth on the ridges. All stages of land preparation, amount and time of application of fertilizer for all treatments were done in the same way based on the soil test (Table 3). For ease of harvesting and sampling, irrigation water was stopped ten days before the end of growth (after completing the dough stage and hardening of the grain).

First Repeat	TI	AI1	AI3	AI5
Second Repeat	AI5	AI3	TI	AI1
Third Repeat	AI1	TI	AI5	AI3

Figure 2 | Schematic of experimental design and placement of treatments and repetitions.

Measurements

Irrigation treatments were started after transplantation and crop establishment. During those stages, which last for two weeks, water was applied in all plots through a flood or TI. From the transplanting date to the starting date of treatments (2017–2018 crop season), each plot consumed about 84 liters of water. The variety of rice used in this research was Tarom-Hashemi (*Oryza sativa* L.). In the early stages of growth, water consumption was relatively high due to longitudinal growth, and after that more days remained until the water had disappeared from the soil surface, due to cooling of the air and rainfall. In the mid and end growth periods, the irrigation cycle returned to its constant state due to crop fixation or low growth. Fifty days after transplanting, rice panicles appeared and these were harvested about two weeks later.

The irrigation water was applied on each plot by a known volume container and it was recorded in all treatments during the growth period. Some parameters and components of the yield, such as height, number of tillers, panicle length and grain fill percentage were recorded. The water productivities of the rice were obtained by dividing the yield on the cumulative amount of water consumed in each treatment during the growth period. Table 4 shows the dates of land preparation and the agronomic growth period of the rice.

In this research, the various water management scenarios were used to find out the high WP of the rice. Irrigation water productivity (W_{PI}) and Irrigation + Rainfall productivity (WP_{I+R}) were determined by the following relationships (Tuong & Bouman 2003):

$$WP_I\ (Kg/m^3) = \frac{Y}{I} \tag{1}$$

$$WP_{I+R}\ (Kg/m^3) = \frac{Y}{I+R} \tag{2}$$

Table 4 | Dates of land preparation and the agronomic growth periods

Plowing the farm	Farm plotting	Fertilization	Transplanting	Beginning treatment	Appearance of panicles	End of the test	Harvesting of yield	Total period
2018/4/4	2018/4/21	2018/5/4	2018/5/6	2018/5/20	2018/6/28	2018/7/14	2018/7/26	82 days

where W_{PI} is the WP based on the irrigation water, WP_{I+R} is the WP based on the irrigation water and rainfall, which is an important index for evaluation of irrigation management (Kijne *et al.* 2003), Y is the yield of rice (kg/ha), I is the amount of irrigation water (m^3/ha), and R is the total rainfall during the growth period (m^3/ha).

Finally, the data were analyzed using the SAS program version 9.4 and the comparison of the mean values was evaluated by Duncan test at a 1% level.

RESULTS AND DISCUSSION

Impact of irrigation water management on rice yield

Table 5 shows the variance analysis of yield components including height, the number of tillers, panicle length, filling percentages and WP of the rice for different irrigation management practices. This table shows a non-significant difference in the blocks that pointed to the fact that there is no difference between the replications which indicates the homogeneity of the soil and the marginal error of the blocks (Roy & Chan 2015). Among the seven traits examined in Table 5, irrigation management practices did not have any significant effect on plant height and rice yield, but it had significant differences at a 1% level for the other traits. These results are consistent with the findings of the investigation of Sedaghat *et al.* (2014) and Monaco & Sali (2018). It should be noted that the grain yield in rice cultivation is very important and vital to the farmer's economy. Therefore, rice productivity should be increased using hardware or software methods in order to maintain or increase rice performance. Table 5 shows significant differences at a 1% level between the different irrigation management in terms of the number of tillers, panicle length, filling percentage, and WP. But, there was not a significant difference between irrigation management in terms of grain yield indicating that alternate irrigation is a good practice for improving rice productivity.

Yield components in different treatments

Figure 3 showed yield components in different irrigation treatments. The amount of rice height in all irrigation management (TI, AI1, AI3, and AI5) was affected by different irrigation management, but there was not a significant difference between them. This figure illustrates that there is a significant difference among the number of tillers, filling percentage and panicle length in all treatments at a 1% level.

Table 5 | Analysis of variance of studied traits under the influence of different irrigation management

		Average of squares						
Source of variation	Degrees of freedom	Plant height cm	Number of tillers -	Panicle length cm	Filling percentage %	Grain yield ton/ha	Productivity kg/m³	Productivity + Rainfall kg/m³
Block	2	813.61^{ns}	0.01^{ns}	0.14^{ns}	0.002^{ns}	0.50^{ns}	0.008^{ns}	0.006^{ns}
Irrigation levels	3	993.44^{ns}	10.14**	5.22**	2.15**	0.56^{ns}	0.58**	0.38**
Error	6	835.57	0.035	0.08	0.006	0.41	0.009	0.007
CV	–	19.96	1.07	1	0.085	11.27	7.53	7.58

**Significant at 1% probability level and ^{ns} Not significant.

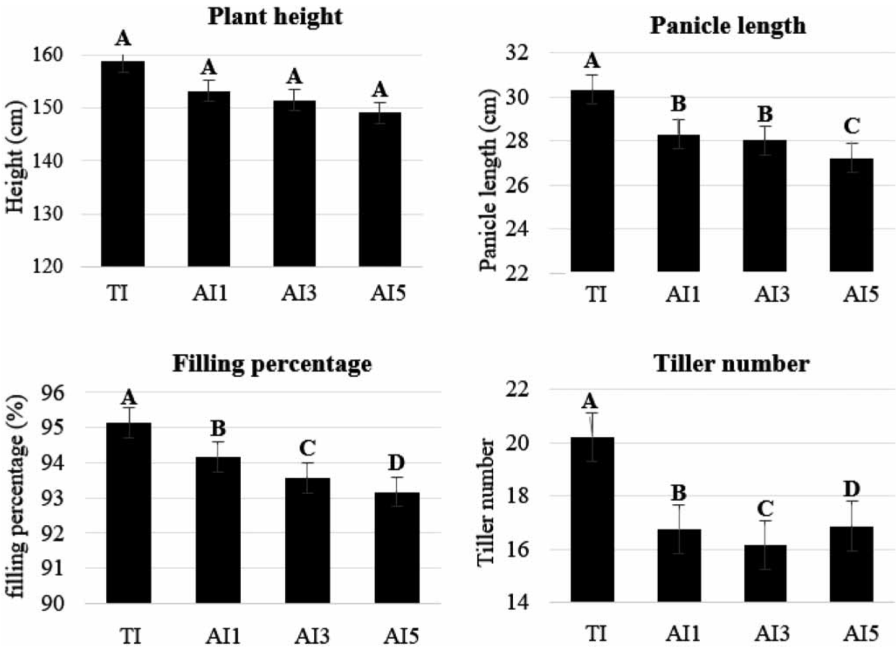

Figure 3 | Comparison of the average yield components in different irrigation management (in each column, averages with the same letter, do not have a significant difference at the 1% level based on the Duncan test).

The highest amount of yield components belonged to flood irrigation (TI) and the lowest one to alternate irrigation five days after the disappearance of water (AI5) with the exception of tiller number, for which the lowest one belonged to AI3 (Figure 3).

As expected, irrigation with a constant head of 3–5 centimeters or TI had the highest application of water which was 7,940 m^3/ha. After that, AI1 with 4,910 m^3/ha, AI3 with 4,090 m^3/ha and then AI5 with 3,290 m^3/ha were in the next order which are consistent with the results of Sedaghat *et al.* (2014), Joko (2010), Rejesus *et al.* (2011) and Yang *et al.* (2017); Carracelas *et al.* (2019) and Mote *et al.* (2017).

Yield and water consumption in different treatments

Figure 4 shows the comparison of average grain yield, water consumption, WP_I and WP_{I+R} under different irrigation management. According to Figure 4, the TI treatment with the highest grain yield (6.11 ton/ha), and after that, the AI5 treatment with the amount of 6.02 ton/ha were recorded as the marked treatment. The three treatments mentioned were all less effective than the control treatment. However, in the mean of AI5 treatment, the yield decreased less, indicating that with more irrigation intervals, rice yield did not change significantly. There was a decrease in yield in all treatments compared to the control treatment, but the aim of the study was to increase WP, which was reported to be acceptable with respect to applied irrigation management. Perhaps the high amount of rice yield in the Irrigation treatment five days after the disappearance of water (AI5) may be due to drought stress which causes soil cracking and ventilation and the plant's root system becomes stronger to get water from lower depths. The greater the frequency of irrigation, the stronger the root system of the plant, absorbing water and solids from lower depths. The same expansion of the root system of the plant has shown its effect on increasing rice grain yield. There are no significant differences among the grain yield in all irrigation management practices (Figure 4). Drought stress was quite palpable through observation of soil surface and measurement of water and irrigation intervals. The creation of cracks at the soil surface in treatment AI3, and in particular AI5, demonstrated this claim (Rejesus *et al.* 2011; Mote *et al.* 2017; López-López *et al.* 2018). As already mentioned, rice farmers irrigate paddy fields using the flood

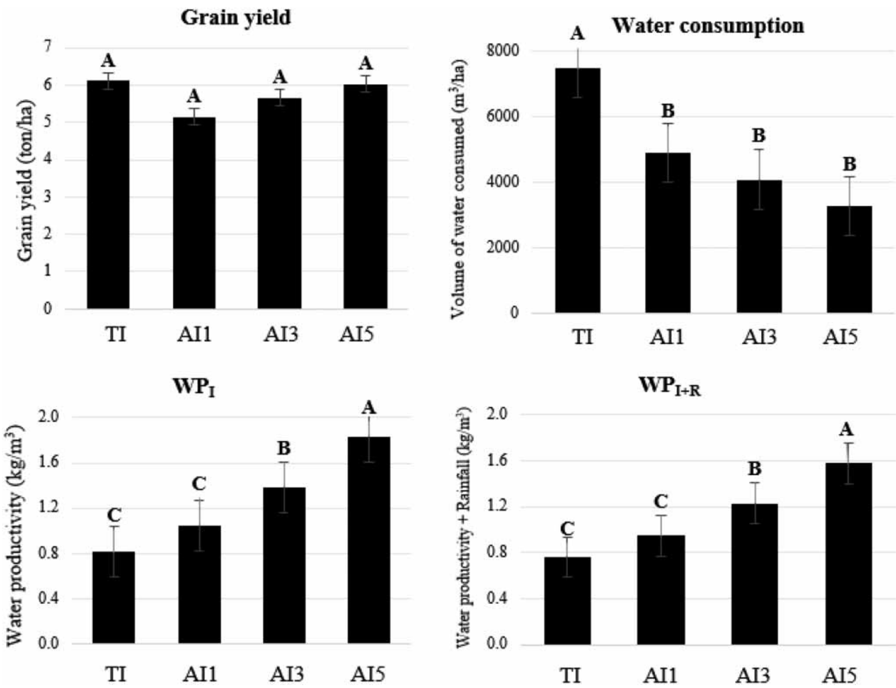

Figure 4 | Comparison of the average grain yield, water consumption, WP_I and WP_{I+R} under different irrigation management.

irrigation method to prevent weed growth and alternative irrigation methods may be able to supply rice water requirements without any stress to the crops. Therefore, AI practices with sufficient water for crops and stronger root systems and better soil ventilation have comparative and marked grain yield. The yield of the control treatment is reasonable in terms of environmental conditions and is consistent with the results of the research by Palangi *et al.* (2015) and Ahmadi *et al.* (2019). Various sources have shown that rice does not consistently require a high level of water and that soil saturation and alternative irrigation good management to reduce water consumption is without stress on the plant. In this study, the apparent growth of rice and clustering and ripening dates were similar to the control treatment and the water requirement of the plant was quite evident.

Water productivity in different treatments

Water productivities (WP_I) for irrigation methods TI, AI1, AI3, and AI5 were calculated to be 0.82, 1.05, 1.38 and 1.83 kg/m^3, respectively (Figure 4), which indicates that the alternative irrigation management in paddy fields can improve the rice WP up to twice (in AI5) as compared to the TI method. Longer irrigation intervals may increase the WP of the rice more than the maximum values obtained in this research. Therefore, further research is necessary to investigate the other time intervals in alternative irrigation management. The results of this study agreed with the ones obtained by Wang *et al.* (2016) and Ultra *et al.* (2017). Also, WP_{I+R} for irrigation methods TI, AI1, AI3, and AI5 were calculated to be 0.76, 0.95, 1.23 and 1.58 kg/m^3, respectively. The amount of WP_{I+R} with attention to the rainfall in the denominator and considering it as water entering the land is less than the WP_I. But the important point is the significant difference in productivity in treatments with irrigation intervals more than the control or TI. These results are consistent with the findings of Joko (2010), Rejesus *et al.* (2011), Sedaghat *et al.* (2014), Wang *et al.* (2016) and Monaco & Sali (2018).

Indicator changes compared to control treatment

Table 6 was prepared due to the importance of water use and productivity, as well as grain yields relative to other yield components. The results showed that alternative

Table 6 | Variations of water consumption, WP and yield in alternate irrigation treatments compared to the control treatment

Treatments	Reduced water use compared to TI (%)	Reduced yield compared to TI (%)	Increased WP_I compared to TI (%)	Increased WP_{I+R} compared to TI (%)
AI1	34.45	15.71	27.91	25.00
AI3	45.39	7.36	68.76	61.86
AI5	56.07	1.47	123.14	107.07

irrigation management played a major role in saving water consumption and improving irrigation WP. The amount of saved water was significant with the application of alternative irrigation as compared to the control treatment. The AI1 with 34% and AI5 with 56% of saved water had the lowest and the highest amount of saved water. Inversely, the rice yield decreased in different irrigation management, but not as much as water reduction percentages. The yield reduction percentages for different irrigation management ranged from 1.5% (in AI5) to 15% (in AI1). This indicates that the amount of grain yield increased by longer interval irrigation in alternate irrigation treatments. The reasons may be due to the readily available water which exists in the root zone, proper ventilation and lower leaching of chemical fertilizer which provide a better condition for root development and crop production (Wang *et al.* 2016; Monaco & Sali 2018). The AI5 treatment has a yield reduction of only 1.5% due to a 56% reduction in water use, and it is important to note that the WP of this treatment is more than twice compared to the control treatment (TI). This relationship exists between the two other treatments in terms of water consumption, grain yield, and productivity (Table 6). Table 6 shows that the WP of rice increased 27.91, 68.76, and 123.14% in AI1, AI3, and AI5 treatments, respectively. Similar results were also found for irrigation + rainfall productivity of the rice, but with lower values.

Singh *et al.* (2008), Bouman (2007), Mahajan *et al.* (2009), Mote *et al.* (2017), Monaco & Sali (2018), Maneepitak *et al.* (2019) and Pourgholam-Amiji *et al.* (2020) reported that rice had the highest level of irrigation compared to other irrigated crops, and its irrigation efficiency was less than the other cereal crops. For example, to produce one kilogram of rice, the water consumption varies from 500 to 2000 liters, which is about three times more than the volume for wheat. According to the results of this study, it was found that it is not necessary to keep the water depth high in paddy fields and alternate irrigation practices could improve the rice WP. By implementation of such management, water can be saved from 2,580 to 4,200 m^3/ha, WP could be increased by two- or three-fold and finally, the production costs are reduced and the farm incomes increased (Yang *et al.* 2017).

CONCLUSION

Flood irrigation in paddy fields is the common and conventional irrigation in Iran that is applied by farmers in order to control weeds, but it does not necessarily result in maximum yield and WP. The results of this study indicated that the grain yield of rice does not reduce significantly when irrigation water is applied alternatively. This reduction is not effective until the soil moisture is in the range of readily available water for the rice. Therefore, it is concluded that the alternate irrigation is one of the best irrigation management practices in paddy fields by which a considerable amount of water is saved and the rice WP increased markedly. In this study, a 5-day irrigation interval showed a 56.07% reduction in water consumption and a 1.47% reduction in yield, but this treatment produced the highest WP. Higher WP may have resulted in longer irrigation intervals. Therefore, further studies are needed to investigate other irrigation management practices.

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DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

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