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Original Article

Single Irrigation Enhanced Water Productivity of Rainfed Wheat under Mediterranean Environment

Abolfazl NASSERI[1]*, Hossein Ali FALLAHI[2], Vahid REZAVERDINEJAD[3]

[1]*East Azarbaijan Agricultural and Natural Resources Research and Education Center, Agricultural Engineering Research Department, AREEO, Tabriz, Iran;* nasseri.ab@gmail.com *(*corresponding author)*

[2]*Mazandaran Agricultural and Natural Resources Research and Education Center, Seed and Plant Improvement Research Department, AREEO, Sari, Iran*

[3]*Urmia University, Department of Water Engineering, Urmia, Iran*

Abstract

Single or double irrigations of wheat are necessary to obtain optimum yield in a humid region with insufficient rainfall for agricultural production. Therefore, the hereby study was conducted with the aim of analysis of water productivity under rainfed and (single or double) irrigated conditions in a Mediterranean environment during 11 cropping years. There were investigated four treatments for irrigation management of wheat viz. rainfed without irrigation (T0), single irrigation at the flowering stage (T1), single irrigation at the grain filling stage (T2) and double irrigation at the flowering and grain filling stages (T3). Results revealed that the highest water productivity and optimum yield were acquired with single irrigation at the grain filling stage. This scheme caused an increase of 20% in grain yield relative to yield from rainfed condition. Rainfall, grain yield and water productivity of rainfed wheat were analyzed over 11 years and averaged 3,614 m^3 ha^{-1}, 1,970 kg ha^{-1} and 0.63 kg m^{-3}, respectively. Results also showed that single or double irrigation had a high compensation effect on yield loss from water stress. Irrigation water productivity (1.31 kg m^{-3}), water productivity (0.68 kg m^{-3}) and irrigation ratio (2.2) indices determined for the 11 years. Water productivity of rainfed wheat by single irrigation at grain filling stage increased as 10% during 11 years.

Keywords: irrigation management; rainfed wheat; water use efficiency; wheat yield

Introduction

Wheat (*Triticum aestivum* L.) is one of the major and principal cereal food crops growing worldwide. The occurred rainfall in the some Mediterranean climate conditions is insufficient to meet wheat requirement for optimum production. Consequently, single or double irrigation is necessary for obtaining a potential yield of wheat in rainfed areas. Single and double irrigation are known as supplemental irrigation, defined as the application of limited water to rainfed crops when rainfall fails to provide the moisture requirement for normal plant growth (Oweis *et al*., 2000). An index identified as water productivity (WP) is applied to compare the productivity of water and recognizing factors that limit the efficiency of use of soil moisture or rainfall in crop production (Robinson and Freebarin, 2005). According to the Molden *et al.* (2010), enhancement of water productivity aims at producing more food and generating more income with a lesser amount of agricultural water for better livelihoods and ecosystem services in the world. Water productivity was extensively applied in crop irrigation researches in the farms (Nasseri and Fallahi, 2007; Zamani and Nasseri, 2008; Nasseri and Bahramloo, 2009; Abadi *et al*., 2010). Several findings have resulted that the range of WP for wheat production being from 0.8 to 1.00 kg m^{-3} (Musick *et al*., 1984), from 1.00 to 1.20 kg m^{-3} (Aggarwal *et al*., 1986), from 1.20 to 1.60 kg m^{-3} (Ehling and Le Mert, 1976) and from 1.50 to 1.90 kg m^{-3} (Rao and Bhardwaj, 1981). In addition, Zwart *et al.* (2010) reported that water productivity of wheat varies from 0.2 to 1.8 kg m^{-3} of water consumed. Balwinder-Singh *et al.* (2011) concluded that the highest water productivity occurred in the plots that received the least irrigation water. Previous researches showed that single irrigation produced high water productivity relative to more events for irrigation. Zhang *et al.* (1998) determined that water productivity of wheat using single irrigation increased by 24-30% relative to plots by four-irrigation and reported that WP ranged from 0.93 to 1.55 kg $m^{-3.}$ On applying irrigation at the critical growth stages by deficit irrigation WP is higher. Nasseri (1999) estimated WP of wheat to be from 0.54 to 1.22 kg m^{-3} in

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Moghan plain, Iran. Wang *et al.* (2001) and Zhang *et al.* (2003) respectively reported that WP of wheat were 1.07–1.29 and 1.28–1.82 kg m^{-3} in Luancheng, China environment. According to the report of Mrabet (2002), water productivity of wheat was from 0.32 to 1.06 kg m^{-3} in Morocco climate conditions. Bandyopadhyay and Mallick (2003) determined WP in wheat production to be from 1.11 to 1.29 kg m^{-3} at West Bengal, India climate conditions. Moreover, Sharma *et al.*, (2001) reported that wheat production in Uttar Pradesh, India, produced water productivity between 0.48 and 0.71 kg m^{-3}. Recently, Jin *et al.* (2018) concluded that the water use efficiency changes in wheat under water deficit conditions depends on the effects of water use efficiency components (i.e. crop yield and actual evapotranspiration), environmental conditions and water management.

The role of single irrigation on water productivity of wheat was not precisely detected in Mediterranean climate conditions. Therefore, the main objective of the present study is to investigate the effect of single and double irrigation on water productivity of rainfed wheat under a Mediterranean environment.

Materials and Methods

The linear relationship between relative wheat yield (Ya/Ym) and relative evapotranspiration (ETa/ETm) was analysed as the following relation, developed by Doorenbos and Kassam (1979):

$$\left(1-\frac{Ya}{Ym}\right) = Ky\left(1-\frac{ETa}{ETm}\right) \qquad (1)$$

where Ya and Ym are respectively actual and potential wheat yields; Eta and ETm are respectively actual and potential evapotranspiration for wheat production. Crop yield response factor (Ky) was 1.05 and ETm = 1,593 m^3 ha^{-1} for wheat production in this study.

To calibrate Doorenbos and Kassam (1979) relation for wheat production under Mediterranean environment, the field experiment was carried out at the North of Iran at the Agricultural Research Station of Gonbad located at 37° 16′ N, 55° 12′ E; elev. 37.2m , with 65-year averages of annual rainfall and relative humidity of 577 mm and 65%, respectively. Fig. 1 shows air temperature variation and Fig. 2 displays rainfall and relative humidity during the growing season of wheat. The cultivated crop received 326 mm rainfall during growing season.

Wheat (*Triticum aestivum* L.) variety 'Kohdasht' was sown on December in at seeding rate of 123 kg ha^{-1} on 12 rows 5 m long and 17 cm apart (5 × 2.21 m^2 plots). As shown in Table 1, there were four treatments for irrigation management of wheat viz. rainfed (without irrigation) (T0), single irrigation at the flowering stage (T1), single irrigation at the grain filling stage (T2) and double irrigation at the

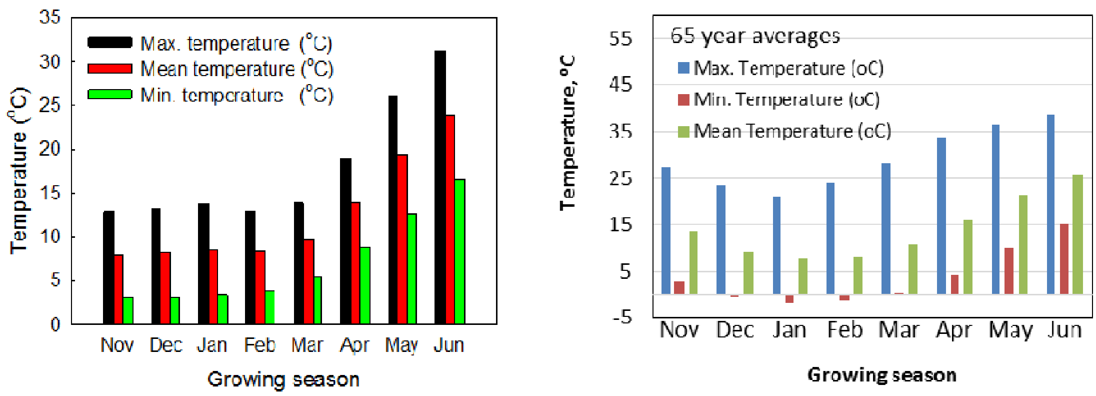

Fig. 1. Mean, maximum and minimum air temperature during wheat growing season (left) and 65 year averages (right)

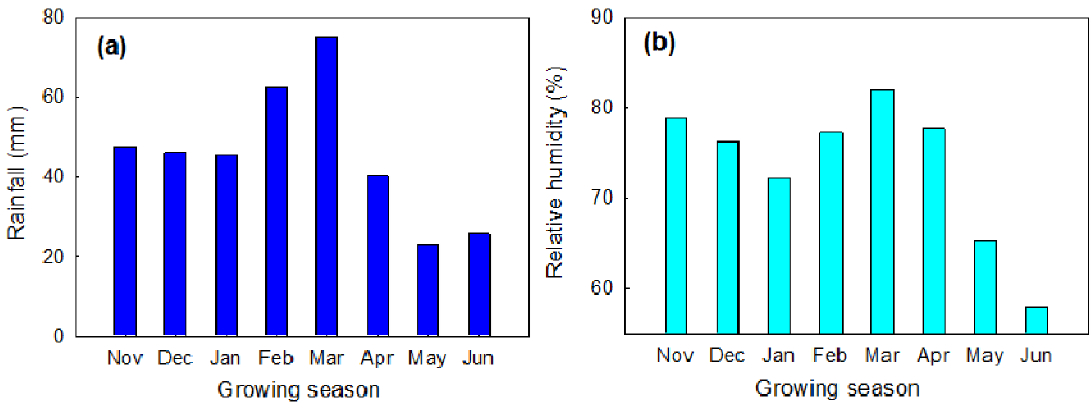

Fig. 2. Rainfall (a) and relative humidity (b) during wheat growing season

flowering and grain filling stages (T3). Applied water for irrigation had Ec of 1,260 µSm^{-1} and SAR of 2.92, which classified as C3S1. Soil moisture contents measurements were made by gravitational method and mean was recorded from three samplings. Irrigation water was measured using a connected-flow-meter to a polyethylene pipe. The water volume for irrigating plots was estimated based on moisture deficit from field capacity. Applied water at the T0, T1, T2 and T3 treatments were as 0, 3, 2.5 and 5.5 cm. Net nitrogen was applied meanly with 45 kg ha^{-1} by three divisions at planting, tillering and stem elongation stages and other fertilizers with rates of 100 kg P ha^{-1} and 50 kg K ha^{-1} were applied according to wheat requirement. The field soil was classified as silt loam having average field capacity and bulk density of 25% and 1.4 g cm^{-3}, respectively. The field soil had 0.15% total N, 15 mg P kg^{-1}, 350 mg K kg^{-1}, 2.6 mg Fe kg^{-1}, 0.60 mg Zn kg^{-1} and 20 mg B kg^{-1}. Electrical conductivity and pH were as 0.73 dSm^{-1} and 8.1 respectively.

The data were analysed statistically by analysis of variance techniques and the treatment means were compared by Duncan's multiple range tests (DMRT). Significance level was established at 5%. The least squares procedure was applied for develop regression models.

Grain yield (GY in kg ha^{-1}) divided by rainfall (R in m^3) and irrigation water (W_{irr} in m^3) was considered as water productivity (WP in kg m^{-3}).

$$WP = \frac{GY}{W_{irr} + R} \quad (2)$$

Irrigation water productivity (IWP) was determined according to the method proposed by Cassel and Edwards (1985) and Edreira *et al.* (2018), as follows:

$$IWP = \frac{Y_{irr} - Y_{dray}}{W_{irr}} \quad (3)$$

where Y_{irr} and Y_{dray} are grain yield (kg ha^{-1}) from irrigated and non-irrigated treatments; and W_{irr} irrigation water (m^3).

Rainfall water productivity (RWP in kg m^{-3}) was estimated as follows which grain yield (GY in kg ha^{-1}) divided by rainfall (R in m^3 ha^{-1}).

$$RWP = \frac{GY}{R} \quad (4)$$

To determine the effectiveness of single and double irrigation, an irrigation ratio (IR) was obtained (Fan *et al.*, 2005) as follows:

$$IR = \frac{IWP}{WP} \quad (5)$$

An IR > 1 indicates that single and double irrigation had a high compensation effect on yield loss from water stress; an IR ≈ 1 indicates yield losses resulting from water stress were completely compensated by single and/or double irrigation and an IR < 1 indicates that irrigation is ineffective in increasing WP, generally because slight or no water stress occurred.

Results and Discussion

Applied water and wheat grain yield from irrigation treatments was depicted, as seen in Fig. 3. Eq.s 2 and 3 and irrigation ratio with Eq. 5 for cultivated wheat under different treatments of irrigation management (Fig. 3) estimated water productivity and irrigation water productivity.

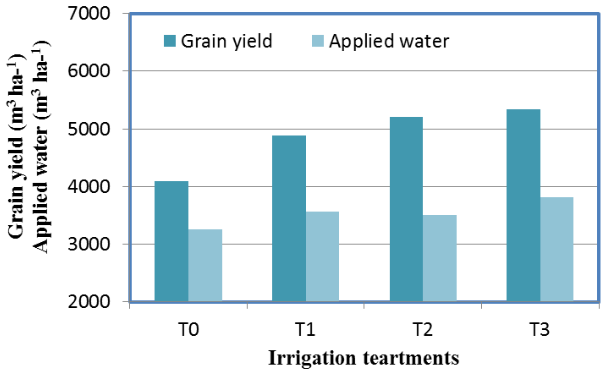

Fig. 3. Applied water and wheat grain yield for different irrigation treatments

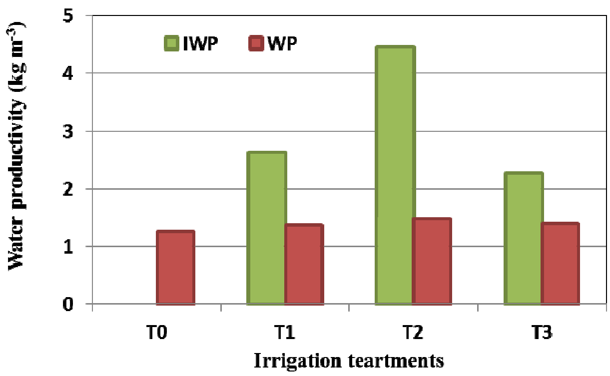

Fig. 4. Water productivity (red bar) and irrigation water productivity (green bar) of wheat from different irrigation treatments

Table 1. Treatment description for investigating rainfall and irrigation water productivity of wheat with single and double irrigations

Treatment abbreviation	Irrigation treatment	Irrigation water (W_{irr}) (m^3)	Rainfall (m^3)
T0	Rainfed	000	3,260
T1	Single irrigation at the flowering stage	300	3,260
T2	Single irrigation at the grain filling stage	250	3,260
T3	double irrigation at the flowering and grain filling stages	550	3,260

Overall, WP ranged from 1.3 to 1.5 kg m^{-3} (red bar in Fig. 4). This range is in agreement with that reported by Musick *et al.* (1984), Aggarwal *et al.* (1986), Aggarwal *et al.* (1986), Ehling and Le Mert (1976), Zwart *et al.* (2010), Zhang *et al.* (1998), Nasseri (1999), Wang *et al.* (2001), Mrabet (2002), Bandyopadhyay and Mallick (2003), Sharma *et al.* (2001). Note that the highest and the lowest water productivity were respectively obtained from irrigation at the grain filling stage and rainfed conditions. This finding is in consistence with McMaster *et al.* (1984) which reported that irrigation at grain filling caused an increase in grain weight. Since grain, weight is one of the main components of yield. Therefore, irrigation at the grain filling increased grain yield. Here, WP has three components of grain yield, rainfall and irrigation water. Since rainfall was similar for all the applied treatments. Consequently, differences in WP originated from grain yields and irrigation water amounts. In general, with increasing grain yields and/or irrigation water cause an increase in water productivity. However, produced grain yield and WP (1.48 kg m^{-3}) from T2 (with irrigation water of 25 mm) was more than that produced by T1 (1.37 kg m^{-3}) with IW of 30 mm. This result may be originated from relative sensitivity of grain filling stage to flowering stage of cultivated wheat.

The highest (4.5 kg m^{-3}) and the lowest (2.3 kg m^{-3}) IWP respectively were acquired from single irrigation at the grain filling and double irrigation at the flowering and grain filling stages (Fig. 3). Note that, IWP has three components of irrigation water (component 1) and grain yields from irrigation (component 2) and yields from rainfed conditions (component 3). The produced grain yield (5,336 kg ha^{-1}) by double irrigation was more than the yield from other irrigation treatments. Due to irrigation water of 550 m^3 ha^{-1}, acquired IWP (2.26 kg m^{-3}) was less than IWP produced by the other treatments.

Results showed that irrigation ratio for T1, T2 and T3 averaged respectively 1.9, 3.6 and 1.6. Therefore, all IR values obtained were more than 1, thus indicating that irrigation had a high compensation effect on yield loss from water stress. The highest value was from plots irrigated at the grain filling stage. As a result, it can be said that to have the highest WP, IWP and irrigation ratio, rainfed wheat may be irrigated at the grain filling stage with irrigation water of 25 mm. Therefore, the farm receives irrigation water of 250 m^3 ha^{-1} and rainfall of 3,260 m^3 ha^{-1} and total water of 3,510 m^3 ha^{-1} from both of rainfall and irrigation practice.

Rainfall averaged 3,614 and ranged from 1,920 (2008-2009) to 6,080 (2005-2006) m^3 ha^{-1}; and grain yield averaged 1,970 and varied from 820 (2010-2011) to 3,611 (2015-2016) kg ha^{-1}. Rainfall and irrigation water ranged from 2,218 (2008-2009) to 6,379 (2005-2006) m^3 ha^{-1} with an average of 3,914 m^3 ha^{-1}.

Water productivity of wheat was estimated based on rainfall and grain yield (Fig. 5). Resuls showed that water productivity of rainfed wheat averaged 0.63 and was from 0.26 (2010-2011) to 1.53 (2015-2016) kg m^{-3}. An increasing trend was observed in water productivity from 20140-2011 to 2015-2016 (Fig. 5).

The relationship developed by Doorenbos and Kassam (1979) between Ya/Ym and ETa/ETm, was modified as:

$$(1\text{-}Ya/5336) = 1.05(1\text{- }Eta\ (1593) \qquad (6)$$

In this relation, crop yield response factor (Ky) was 1.05 and Ym = 5,336 kg ha^{-1} and ETm = 1,593 m^3 ha^{-1} for wheat production in this study. Therefore, applying single irrigation with water volume of 300 m^3 ha^{-1} (for example) at the grain filling stage in wheat production increased about 20% in grain yield in Mediterranean environment.

Water productivity (WP) and irrigation water productivity (IWP) of wheat was estimated during 11 years (2005-2016) based on rainfall, irrigation water at grain filling stage and grain yield (Fig. 6). Results showed that irrigation water productivity of rainfed wheat averaged 1.31 and was from 0.55 (2010-2011) to 2.41 (2015-2016) kg m^{-3}. Also, water productivity of wheat averaged 0.68 and was from 0.28 (2010-2011) to 1.63 (2015-2016) kg m^{-3}. The present finding is similar to those reported by Musick *et al.* (1984), Aggarwal *et al.* (1986), Aggarwal *et al.* (1986), Ehling and Le Mert (1976), Zwart *et al.* (2010), Zhang *et al.* (1998), Nasseri (1999), Wang *et al.* (2001), Mrabet (2002), Bandyopadhyay and Mallick (2003), Sharma *et al.* (2001). In addition, as shown in Fig. 7, irrigation ratio with an average of 2.2, ranged from 1.23 (2008-2009) to 3.54 (2005-2006).

Water productivity of rainfed wheat by single irrigation at grain filling stage increased with an average of 10% during 11 years. Increase in water productivity ranged from 3.8 (2008-2009) to 14.4% (2005-2006).

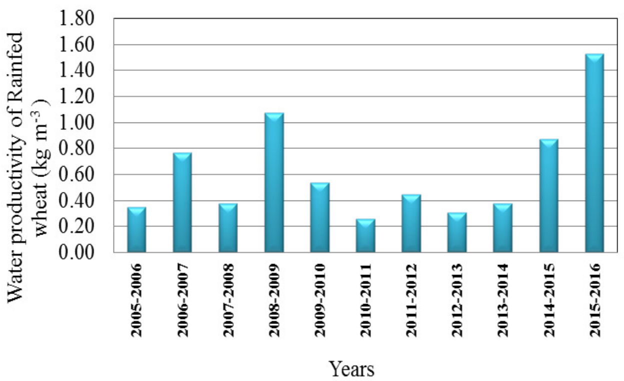

Fig. 5. Water productivity of rainfed wheat

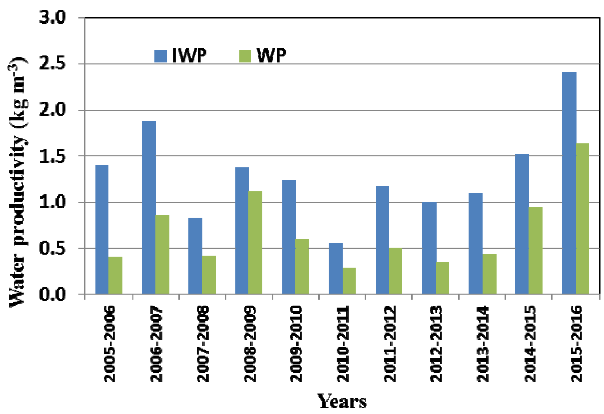

Fig. 6. Water productivity of rainfed wheat

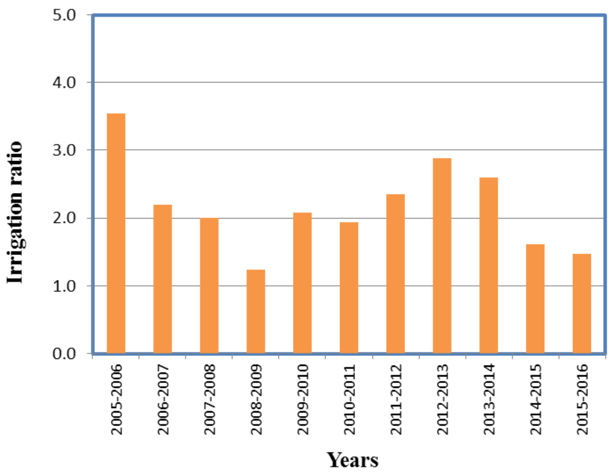

Fig. 7. Irrigation ratio applied to wheat

Conclusions

Rainfall, wheat grain yield and water productivity variability during 11 years (2005-2006 to 2015-2016) was analyzed under a Mediterranean environment. Results revealed that the highest water productivity and optimum yield was acquired with single irrigation at the grain filling stage. The average of irrigation water productivity (1.31 kg m^{-3}), water productivity (0.68 kg m^{-3}) and irrigation ratio (2.2) indices determined for 11 years. Applying single irrigation at grain filling stage of rainfed wheat increased grain yield (average 20%) and water productivity (average 10%) relative to full rainfed conditions during 11 years. Therefore, irrigating at this stage is recommended to have the optimum yield and the highest water productivity. Supplementary studies are necessary to investigate the interaction effect of single irrigation and fertilizers on yield and water productivity of wheat in Mediterranean environment.

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Conflicts of interest

The authors declare that there are no conflicts of interest related to this article.

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