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Water use efficiency of red kidneybean affected by mulch and irrigation treatments

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Abstract

A factorial experiment (using RCB design) with three replications was conducted at the Research Farm of the Faculty of Agriculture, University of Tabriz, Iran, in 2012. The effects of irrigation (I_1 and I_2: irrigation after 60 and 120 mm evaporation from class A pan, respectively) and mulch (0 (control) and 2 ton/ha wheat straw mulch) was evaluated on water use efficiency and grain yield of red kidneybean (*Phaseolus vulgaris* L.) cultivars (Akhtar and Naz). The results indicated that the effects of irrigation and mulch on grain and biological yield of red kidney bean cultivars were significant. The highest grain yield (3135.2Kg /ha) and biological yield (8087.6 Kg /ha) were obtained in well-watered (I_1) treatment and application of 2 ton/ha mulch for cultivar Akhtar. Grain water use efficiency (WUE_G) and biological water use (WUE_B) efficiency were significantly affected by irrigation, mulch and cultivar. The highest WUE_G (0.538 kg/m3) was obtained in well-watered (I_1) treatment and application of 2 ton/ha mulch for cultivar Akhtar. It was concluded that the highest WUE_G was obtained under mulch condition, indicating that cultivar Akhtar can produce acceptable yield with low water consumption by using straw mulch.

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Introduction

In recent years, with the rapid development of agriculture and industry, the severity of water shortage is increasing. Although water resources are limited, inefficient use of water is quite common. Water use in agricultural production as one of the most important environmental factors affecting plant growth and development, especially in arid and semi-arid climatic conditions of Iran is of special importance (Mirzae *et al.*, 2005). One of the ways of alleviating water scarcity is by enhancing its use efficiency or productivity. Water use efficiency (WUE) is a broad concept that can be defined in many ways. For farmers and farm managers, water use efficiency is the yield of harvested crop produce achieved from the available water to the crop from rainfall, irrigation and soil water storage (Singh *et al.*, 2010). Water use efficiency is often considered an important determinant of yield under stress and even as a component of crop drought resistance. It has been used to imply that rainfed plant production can be increased per unit water used, resulting in "more crop per drop" (Kijne *et al.*, 2003).

Improving water use efficiency in arid and semi-arid areas depends on effective conservation of moisture and efficient use of limited water. Among the management practices for increasing water use efficiency (WUE) one of them is mulching. Any material spread on the surface of soil to protect it from raindrops, solar radiation or evaporation is called mulch. Straw is commonly used as mulch. Straw mulching has potential for increasing soil water storage (Shanging and Unger, 2001). Zaongo *et al.*, (1997) reported 27% increase in WUE with mulch treatments. Huang *et al.* (2005) reported that straw mulch decreased evapo-transpiration and increased water use efficiency. Mulches modify the microclimate and growing conditions of crops (Albright *et al.*, 1989), conserve more water and increase water use efficiency (Zhao *et al.*, 1996). Mulches increase WUE as these reduce the soil water evaporation by reducing soil temperature, impeding water vapor diffusion, absorbing water vapor onto mulch tissue and reduce wind speed gradient at the soil atmosphere interface (Sauer *et al.*, 1996). The ability of mulch to enhance WUE in a soil-plant system could encourage mulching practice for the enhancement of crop production.

Red kidney bean (*Phaseolus vulgaris* L.) is the most important food legume (Broughton *et al.*, 2003) and is an important source of calories, proteins, dietary fiber and minerals (Singh *et al.*, 1999). The majority of red kidney bean production is under drought conditions, and thus yield reductions due to drought are very common (Teran and Singh, 2002). In Iran, as one of the developing countries of the arid and semiarid climates, this crop after peas and lentil, the most area of under cultivation for itself to be allocated. Thus, the use of water conserving systems for bean offers the possibility of increasing yields when water is limited. This research was carried out to evaluate the effect of straw mulch on water use efficiency and grain yield of red kidney bean cultivars under well and limited irrigation conditions.

Materials and methods

Site description and experimental design

A field experiment was conducted in 2012 at the Research Farm of the Faculty of Agriculture, University of Tabriz, Iran (latitude 38°05_N, longitude 46°17_E, altitude 1360 m above sea level). The climate of research area is characterized by mean annual precipitation of 285 mm, mean annual temperature of 10°C, mean annual maximum temperature of 16.6°C and mean annual minimum temperature of 4.2°C. The experiment was arranged as factorial, based on randomized complete block design with three replications. Treatments were two irrigation treatments including (I_1 and I_2: irrigation after 60 and 120 mm evaporation from class A pan, respectively), mulch treatments (0 (control) and 2 ton/ha wheat straw mulch) and two red kidney bean cultivars (Akhtar and Naz). The two cultivars (Aktar as a determinate and Naz as an indeterminate cultivar) were chosen to show any effect caused by growth habit of the canopy.

Seeds of red kidneybean (cultivar Akhtar and Naz) were obtained from were obtained from National Bean Research Institute in Arak, Iran. Seeds were inoculated with *Rhizobium* and treated with 2 g/kg Benomyl and then were sown with a density of 50 plant/m^2. Each plot was included 5 rows of 4 m long, 50 cm apart. All plots were irrigated immediately after sowing. Irrigation treatments were applied after seedling establishment. The amount of water needed for each plot was calculated by the following equation (Mahluji *et al.*, 1379):

$$V = (\Theta_{FC} - \Theta_{SM}).\ \rho b.A.d \quad (1)$$

Where V is volume of used water (Lit), Θ_{FC} the soil humidity in the field capacity level (%), Θ_{SM} the soil humidity before exerting treatment (%), ρb soil bulk density (g/m^3), A plot area (m^2), d root penetrate depth (m).

Hand weeding of the experimental plots was performed as required. Mulch was wheat straw spread uniformly between the crop rows one week after germination. Finally, plants of 4.5 m^2 in the middle part of each plot were harvested and biological yield, grain yield and harvest index were measured.

Measurement of water use efficiency

Water use efficiency was calculated as (Hussain and Al-Jaloud, 1995):

$$WUE_G = \text{Grain Yield/Used Water} \quad (2)$$

$$WUE_B = \text{Biological Yield/Used Water} \quad (3)$$

where WUEG is water-use efficiency for the grain yield (kg/m^3), WUEB the water-use efficiency for the biomass yield (kg/m^3).

Harvest index (HI) was calculated by the following equation:

$$HI = (\text{Grain yield/Biological yield}) \times 100 \quad (4)$$

Statistical analysis

All the data were analyzed on the basis of randomized complete block design, using SAS. The means of treatments were compared according to Duncan multiple range test at $P<0.05$. Excel software was used to prepare the figures.

Result and discussion

Grain and biological yield

The effects of cultivar, irrigation and mulch on grain and biological yield were significant (Table 1). Interaction of cultivar × irrigation × mulch was also significant on grain and biological yield. The mean data showed that the highest grain yield (3135.2 Kg /ha) and biological yield (8087.6 Kg /ha) were obtained in well-watered (I_1) treatment and application of 2 ton/ha mulch for cultivar Akhtar (Table 3). Increasing of grain yield under well-watered treatment was mainly due to availability of adequate water for bean. Bean grain yield reduction due to drought stress are attributed to adverse effects of the stress on individual yield components (number of pods per plant, number of seeds per pod, seed weight and harvest index) which was in agreement with the results of Boutraa and Sanders (2001). Emam *et al.*, (2010) also reported that biological yield of bean under drought stress significantly decreased. The results of previous study (Rudy *et al.*, 2003) have also shown that drought stress reduces the grain and biological yield of soybean.

Table1. Analysis of variance (Mean squares) for the effects of irrigation and mulch on the grain yield, biological yield, harvest index, WUE_G and WUE_B of red kidneybean cultivars. Yield increase as a result of mulch conditions was due to the fact that water conservation improved physical and chemical properties of soil and enhanced biological activities (Deng *et al.*, 2006; Ramakrishna *et al.*, 2006). Surface mulching reduces evaporation and increases infiltration which result into more water availability for crop growth.

In the case of the effect of cultivar on yield the results showed that the maximum grain yield was recorded in cultivar Akhtar with 2530.6 Kg /ha (Table 2). Drought resistant cultivars that display high yield under stress are more efficient in photoassimilate remobilization (Samper and Adams, 1985; Rosales-Serna *et al.*, 2000; Acosta-Díaz *et al.*, 2004; Rosales-Serna *et al.*, 2004).

Table 1. Analysis of variance (Mean squares) for the effects of irrigation and mulch on the grain yield, biological yield, harvest index, WUE_G and WUE_B of red kidneybean cultivars.

S.O.V	df	Grain yield	Biological yield	Harvest Index	WUE_G	WUE_B
Replication	2	935.49	9751.1	2.43	0.000	0.000
Mulch	1	1138445.1**	4754967.3**	0.115	0.105**	0.620**
Irrigation	1	2845715.1**	5403265.4**	169.49**	0.042 **	0.026**
Mulch × Irrigation	1	6527.1	533.187	0.882	0.000 *	0.001
Cultivar	1	2236939.2**	17719452.6**	36.015**	0.061 **	0.517 **
Mulch × Cultivar	1	139097.1**	1558927.7**	0.115	0.006 **	0.068**
Irrigation × Cultivar	1	53750.8**	1531109.6**	0.322	0.002 **	0.052**
Mulch × Irrig. × Cul.	1	21853.3**	192736.9*	0.882	0.001**	0.002
Error	14	1773.7	37168.7	0.688	0.000	0.001

* and ** , Significant at 5% and 1% probability level, respectively.

Table 2. The mean comparison of some agronomic traits of red kidney bean cultivars as affected by irrigation and mulch.

Treatment	Grain yield (Kg /ha)	Biological yield (Kg /ha)	Harvest Index (%)	WUE_G (Kg /m^3)	WUE_B (Kg /m^3)
Mulch					
No mulch	2007.5b	5767.002b	34.968b	0.298b	0.863b
2 Ton/ha	2443.1a	6657.223a	35.106a	0.430a	1.184a
Irrigation					
full irrigation (I_1)	2569.6a	6686.598a	37.694a	0.406a	1.056a
limited irrigation (I_2)	1881.0b	5737.627b	32.379b	0.323b	0.991b
Cultivar					
Akhtar	2530.593a	7071.363a	36.262a	0.415a	1.170a
Naz	1920.000b	5352.863b	33.812b	0.314b	0.887b

Different letters indicate significant difference at $p \leq 0.05$.

WUE_G and WUE_B

The effects of cultivar, irrigation and mulch on grain and biological water use efficiency were significant (Table 1). Interaction of cultivar × irrigation × mulch was also significant on WUE_G (Table 3). Mean data showed that the highest WUE_G (0.538 kg/m^3) was obtained in well-watered treatment with application of 2 ton/ha mulch for cultivar Akhtar (Figure 1).

Both WUE_G and WUE_B increased under well-watered treatment, which is consistent with the findings of Rudich *et al*., (1977) and Hedge (1987). The mulch gave higher WUE regardless to the irrigation treatments (Table 2). This could be attributed to the higher plant biomass and low evapotranspiration under mulching condition (Huang *et al*., 2005). Zaongo *et al*., (1997) reported 27% increase in WUE with mulch treatments. The mulches modify the microclimate and growing conditions of crops (Albright *et al*., 1989), conserve more water and increase water use efficiency (Zhao *et al*., 1996). The mulches increase WUE as these reduce the soil water evaporation by reducing soil temperature, impeding water vapour diffusion, absorbing water vapor onto mulch tissue and reduce wind speed gradient at the soil atmosphere interface (Sauer *et al*., 1996).

Table 3. The mean comparison of grain and biological yield and WUE_G of red kidney bean affected by interaction of cultivar × irrigation × mulch.

Treatments			Grain yield (Kg /ha)	Biological yield(Kg /ha)	WUEG (Kg /m³)
Mulch	Irrigation	Cultivar			
No Mulch	I_1	Akhtar	2520.00b	6498.96c	0.358cd
		Naz	2216.66e	5974.58e	0.315d
	I_2	Akhtar	1953.33e	6243.81d	0.308d
		Naz	1340.00g	4350.65g	0.211e
Mulch	I_1	Akhtar	3135.22a	8087.57a	0.538a
		Naz	2406.66d	6185.27d	0.412bc
	I_2	Akhtar	2513.81c	7455.10b	0.454b
		Naz	1716.66f	4900.94f	0.317d

The means with same letters in each column are not significantly different at $p \leq 0.05$.

Harvest index

The effects of cultivar and irrigation on harvest index were significant (Table 1). Results indicated that harvest index was significantly decreased under limited irrigation. Foster *et al*., (1995) also observed that the harvest index of red kidney bean was reduced in moisture stress condition.

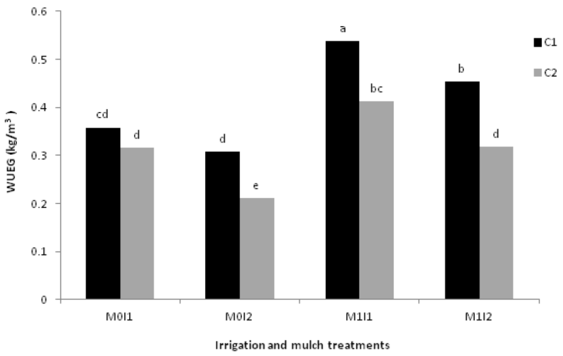

Fig. 1. Effect of irrigation (I_1, and I_2, irrigation after 60 and 120 mm evaporation from class A pan, respectively) and mulch treatments (M_0: control and M_1: 2 ton/ha) on grain WUE of red kidney bean cultivars (C_1: Akhtar and C_2: Naz). Different letters indicate significant difference at $P \leq 0.05$.

Conclusion

The results of the present study showed that cultivar Akhtar had higher grain water use efficiency and yield stability than cultivar Naz under mulch condition and its yield reduction under drought stress was lower than cultivar Naz. The highest grain water use efficiency was obtained under mulch condition, indicating that Akhtar cultivar can produce acceptable yield with low water consumption by using wheat straw mulch. The results indicated that red kidneybean cultivars with determinate growth habit, such as Akhtar might have potential as a dry-land rotation crop for most areas of Iran. Under drought and aridity conditions, field management practices such as selecting high-yielding cultivars and reducing soil evaporation by using of mulch can improve water use efficiency especially in water limitation condition. Investigating the response of other red kidneybean cultivars and other common bean types such as pinto bean and white bean to drought stress and mulch could be effective for identifying the common bean cultivars with high grain yield at drought stress condition with mulch application.

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