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Effects of Deficit Irrigation on Water Productivity and Maize Yields in Arid Regions of Iran

Hamidreza Salemi[1], Mohd. Amin Mohd. Soom[2], Teang Shui Lee[1*], Mohd Kamil Yusoff[3] and Desa Ahmad[1]

[1]Department of Biological and Agricultural Engineering, Faculty of Engineering,
[2]Smart Farming Technology Laboratory,
ITMA and Department of Biological and Agricultural Engineering,
[3]Department of Environmental Sciences, Faculty of Environmental Studies,
Universiti Putra Malaysia,
43400 UPM, Serdang, Selangor, Malaysia
[*]E-mail: tslee@eng.upm.edu.my

ABSTRACT

Deficit irrigation in the Gavkhuni River Basin (GRB), Iran, is an effective method for alleviation of drought impacts on crop yields. Whilst it saves considerable amounts of water, it has little effect on crop yields. The effects of deficit irrigation on grain yield and yield components of maize were studied using two factors [namely, the variety at two levels (704 maize variety with 9354 kg ha^{-1} yield, and 647 maize variety with 8822 kg ha^{-1} yield) and irrigation at four levels (control, 100, 80, and 60% of water level use)] for three consecutive years. Significant differences ($P \leq 0.05$) were noticeable in grain yield, as well as depth and column of kernel among the irrigation treatments. In addition, the effects of cultivars on grain yield, 1000 kernel weight, number of kernel per ear row, number of kernel per column, and depth of kernels were insignificant. Nevertheless, the effects of irrigation treatments on 1000 kernel weight and number of kernel per ear row were not significant. Based on the results and considering the quantitative characteristics of the crop, it was established that for the deficit irrigating of maize, the 80% irrigation level (i.e. 80% of crop evapotranspiration) is the most advantageous treatment when water is not limited. However, when higher water productivity and the possibility of using the water saved are taken into consideration during severe drought conditions, 60% irrigation level treatment is recommended.

Keywords: Deficit irrigation, maize, yield components, water productivity

INTRODUCTION

The limited and/or expensive available water supply makes it impractical to irrigate the entire irrigable land area. Therefore, irrigators must decide between fully irrigating a small area for maximum production and reducing the depth of water applied per unit area in order to increase the area put under irrigation. The latter strategy is called deficit irrigation (DI), which will reduce reasonable crop yield per unit of land but increases the net return for the water applied. DI maximizes water productivity (WP), which is the main limiting factor (English, 1990). The determination and analysis of the agricultural WP index in Iran are essential to find suitable methods for better and economical use of water for agriculture. Thus, field data such as crop yield, different levels of water use, and irrigation

[*]Corresponding Author

management practices are necessary and pertinent to the formulating of water resources policies for optimal agricultural production and advancement in Iran.

It is important to note that maize is one of the important and strategic crops in Iran and its average yield in the country is 8.57 ton ha^{-1} while this is about 8 ton ha^{-1} across the study area (Anonymous, 2007). Tavakoli (1999) has shown that the yield reduction in Iran is much lower than the water reduction under the DI. Thus, the selection of a method for DI by farmers is important. Aghdaii & Sattar (2000) revealed a significant (direct) effect of the levels of irrigation water on maize yield ($P \leq 0.05$) and 100% irrigation level gave the maximum yield. Meanwhile, Emam & Ranjbar (2000) studied the effects of plant density and water stress on grain yield (GY) and water use efficiency of the maize hybrid, SC704. The results of their study showed that water use efficiency had increased in water stress and high crop density treatments. Oktem (2008) demonstrated that the relationships between fresh ear yield and irrigation level treatments were statistically significant ($P \leq 0.05$), and the yield decreased with increasing DI. However, the study showed that the number of marketable ears at 10% water deficiency was still high and acceptable for sweet corn in south-eastern Turkey. Chen *et al*. (2009) revealed that increase of irrigation amount resulted in more crop yields, but the water amount required to gain maximum WP was much less than that required for obtaining the maximum crop yield. Payero *et al*. (2008) showed that the differences in seasonal water requirements among irrigation depth treatments significantly ($P \leq 0.05$) affected dry matter production and yield components of maize. Moreover, water use efficiency was more sensitive to irrigation water and decreased explicitly with irrigation.

Zwart & Bastiaanssen (2004) reported that the range of crop WP of maize, based on a review of 84 literature sources, is very large (1.1–2.7 kg m^{-3}) and it thus offers new water management practices for increasing crop production with 20–40% less water resources. They concluded that in order to achieve optimum crop WP in water short regions, it would be wise to irrigate maize and wheat with less water. Geerts & Raes (2009), who had reviewed many research from around the world, confirmed that DI is successful in increasing WP for various crops without causing severe yield reductions. They further suggested that in regions where the available water supply limits agricultural production, farmers must select crops and irrigation strategies to maximize their crop yields and livestock production activities. Although a perception of WP is required to develop improved water management strategies, little is known about its application at the irrigation field level at the GRB. The vulnerability amongst farmers, at the tail-end of the GRB (Rudasht East and West networks) [*Fig. 1*] in spite of their larger farm possession, demands that an improved water management program is necessary at the head of irrigation networks (of the study area), in order to increase water equity. Furthermore, with an effective DI management in the study area, it is believed that it can contribute to improve the livelihood of the farmers.

The objectives of this study were:

- To determine the effect of water deficit (as quantified by different irrigation levels) on maize yields and yield components.
- To establish optimal water management strategies for maize in the GRB for the purpose of achieving more WP in limited water or water stressed environments.

MATERIALS AND METHODS

Research Location and Condition

The GRB (41,500 km^2) is a closed basin with no outlet to the sea (see *Fig. 1*). The research was conducted in the Nekuabad district of Isfahan state, which is located in the central part of the GRB. The Agricultural Research Centre (32°, 38’ N, 51°, 22’ E) is located at the altitude of 1649 m above the sea level. A large part of the

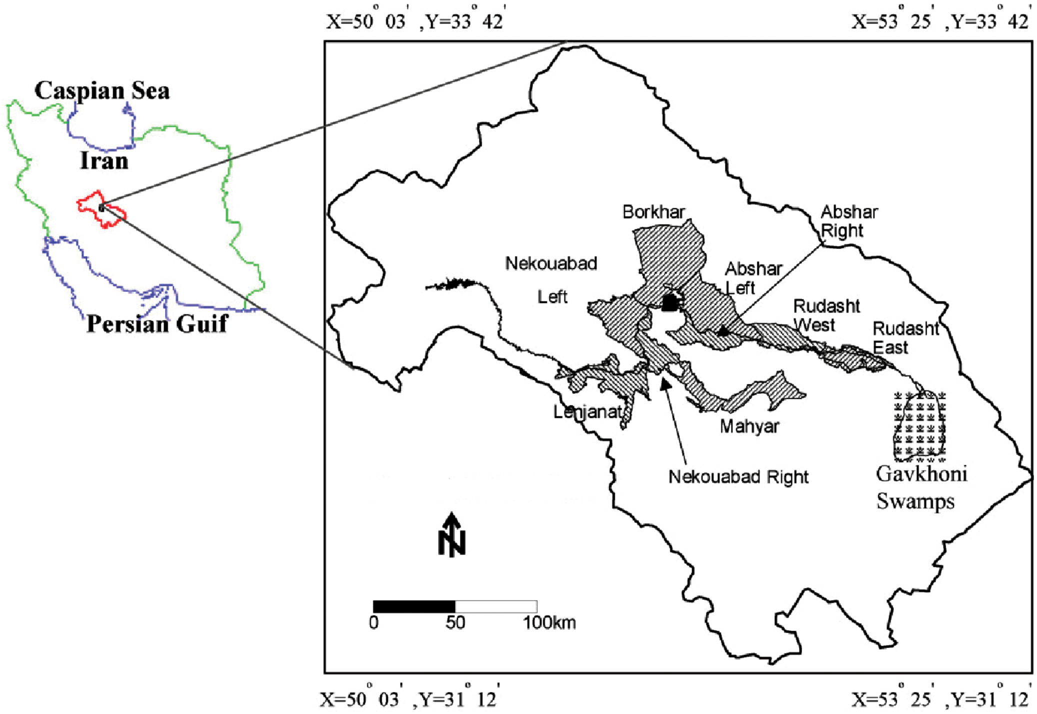

Fig. 1: Location of the study area and major irrigation networks in the GRB, Isfahan, Iran

basin has typical arid and semiarid climate with an average rainfall of 165 mm concentrated over the months of December to May, and whence it is almost impossible to have any economic form of agriculture without reliable irrigation. During the experimentation, there was a severe drought in the region and as well as throughout the whole country, i.e. when average rainfall declined to 48 and 70 mm in the years 2000-2001 and 2002-2003, respectively. The soil of the experimental area, according to USDA Soil Taxonomy 1994 (Anonymous, 1998), is of fine loamy, mixed, thermic, typiccalcigypside. At the soil depth of 1m, soil salinity (1.1-3.7 dS m^{-1}), water salinity (2.2 dS m^{-1}), pH of irrigation water (7.2), soil moisture at saturation (47%), and saturated hydraulic conductivity (Ksat= 300 mm/day) at the field site were measured or experimentally obtained in the Isfahan Soil and Water Laboratory. Table 1 shows some properties of the soil.

Description of the experimental treatments

The effects of various levels of consumptive water on GY and yield components of maize were determined using randomized complete blocks design as a split plot layout with three replicates and four treatments for 3 years (2000-2003). The levels of irrigation water which included control, 100%, 80%, and 60% level of water requirement were considered as the main plots and 2 varieties (single cross 704 and 647) as the sub-plots in the research station. The control was the conventional irrigation of the maize in the region. In the conventional irrigation treatment, the irrigation method, water amounts, timing and interval, as well as other irrigation criteria were considered based on the tradition of several years of local farmers. In this treatment, water losses during conveyance would usually result in lower irrigation efficiency. The irrigation amounts refers to the approximate historical average water applied by local farmers.

TABLE 1
Results of the soil samples analysis

Soil depth (cm)	EC (dS/m)	OC (%)	P (ppm)	K (ppm)	N (%)	FC (m^3/m^3)	WP (m^3/m^3)	BD (g/cm^3)	Texture
0-20	3.7	1.06	17.3	335	0.106	0.32	0.16	1.45	SiCl
20-40	1.2	0.78	5.1	250	0.078	0.36	0.17	1.42	SiCl
40-60	1.4	0.67	4.1	250	0.067	0.34	0.15	1.41	SiCl
60-80	1.1	0.15	2.3	260	0.051	0.35	0.16	1.43	CL
80-100	1.2	0.44	2.0	240	0.044	0.36	0.16	1.43	CL

EC, Electrical Conductivity; OC, Organic carbon; FC, field capacity; WP, wilting point; BD: Bulk density; SiCl, silty clay loam; CL, clay loam

The treatments were compared based on GY and yield components, which included 1000 Kernels Weight (1000 KW), kernel depth (KD), Kernel Number per Ear Row (KNER), and Kernel Number per Column (KNC) as means of GY improvement. GY was determined by grain weight for maize. This required a total of 24 plots (eight treatments with three replications). The maize was sown by hand at the end of May, at depths of 5-6 cm. The row spacing and crop distances on each row were 75 cm and 20 cm, respectively, giving a plant density of 90000 plant ha^{-1}. The length of each row was 30 m and there were four rows in each plot. The type and amount of the required fertilizers were determined from the analysis of the soil samples based on the instruction of the Soil and Water Research Institute (Malakouti, 1999). The N application used in this study was 500 kg ha^{-1} of N (urea at 46% N), which was divided into 3 applications (10 days before planting, 30 days after planting, every 15 days until 22 of July). The P (Amonium Phosphate) application added to the soil was 250 kg ha^{-1}. The K (potassium sulphate) application added to the soil was 350 kg ha^{-1}. Pests and weeds were controlled following the recommendations given by the Isfahan Pest Management Department. At harvest, the final total GY per plot was determined. At the end of September, the treatments were compared based on GY and yield components. The volume of water required for each treatment, taking into consideration an irrigation efficiency of 80%, was calculated based on the area cultivated and the depth of water. Irrigation intervals were seven days, which were based on the existing water rights in the region, and in accordance with irrigation scheduling. The different levels of irrigation water were applied based on the volumetric basis using siphons (2.54 cm diameter). The first irrigation by furrow irrigation method was implemented one day after seeding, with observed emergence about 6 days later. The source of water supply is an irrigation canal with EC equivalent to 1.2 dS m^{-1}. WP was calculated as the ratio of GY and the volume of applied water.

Irrigation Scheduling

The amount of evapotranspiration for irrigation scheduling was determined by using a crop coefficient (KC), ET_{pan} from measured daily open Class A pan evaporation data, and pan coefficient values from FAO 24 (Doorenbos & Pruitt, 1977). Irrigation water requirement was calculated as the difference between ETc (=KC times ET0) and the effective rainfall amount. In this study, pan evaporation and rainfall amount data collected from the Kabutarabad meteorological station located at the agricultural research centre were used for calculating irrigation water application quantities. The irrigation schedule was timed to meet the crop water requirement. The depth of irrigation water and consequently the volume of water were applied weekly and irrigation amounts equalled the previous week's evapotranspiration (ETc) from the crop. Then, taking into consideration the discharge of the irrigation siphons, the relevant irrigation duration for each treatment was also determined. The data on the water requirement during the growing season for each period are shown in Table 2. Regardless of the difference between pan-evaporation and the evapotranspiration of vegetative surfaces, the use of pans to calculate ETo for the periods of 10 days or longer may be warranted (Doorenbos & Pruitt, 1977). Thus, to calculate ET0, 10-day periods were used in this study. The amounts of water to be used in the different irrigation level treatments were evaluated and these are shown in Table 3.

TABLE 2
Calculated irrigation water requirement of the maize in the region

	Period*	ET_c (mm/day)	ET_c (mm/ Period)	Net irrigation requirement (mm/ Period)
May	3rd	2.65	26.5	23.6
June	1st	2.82	31.0	29.0
	2nd	3.03	30.3	29.4
	3rd	3.76	37.6	37.6
July	1st	4.94	49.4	49.2
	2nd	6.24	62.4	61.8
	3rd	7.54	75.4	74.6
August	1st	7.82	86.0	85.5
	2nd	7.55	75.5	75.4
	3rd	7.36	73.6	73.6
September	1st	6.90	75.9	75.9
	2nd	6.29	62.9	62.9
	3rd	5.22	52.2	52.2
October	1st	3.77	37.3	37.6
	2nd	2.55	17.8	17.5
Total			794.3	785.8

* Each period is a 10 day in a month

TABLE 3
Amount of water (m^3 ha^{-1}) applied for different irrigation level treatments

Treatment/Month	Control	Irrigation level (100%)	Irrigation level (80%)	Irrigation level (60%)
June	1045	950	760	570
July	2769	2517	2014	1510
August	3357	3052	2442	1632
September	273	2482	1986	1489
October	935	850	680	510
Total	10836	9851	7881	5911

Statistical Analyses

The results were subjected to an ANOVA to analyze the effects of the treatments and their interactions. In order to determine the effects of year in different years of study, the data obtained were analyzed using the compound variance analysis and the averages of different treatments were separated using the Duncan multiple range test using the statistical software (SAS Institute, Inc., Cary, NC). The probability level of 0.05 (5%) was selected.

RESULTS AND DISCUSSION

Data Analysis

There is no interaction between irrigation and year, Irrigation × Variety, Variety × Year and Irrigation × Variety × Year (Table 4) for GY, 1000KW, KNER, KNC, and KD. The effect of irrigation levels on GY, KNC, and KD were found to be significant ($P \leq 0.05$) (Table 4). On the contrary, the effects of the irrigation level treatments on the 1000 KW and KNER were not significant. The effects of variety on GY and yield components were not significantly ($P \geq 0.05$) detected. The 60% irrigation level gave the lowest GY (8377 kg ha^{-1}) compared to the control, 100%, and 80% full irrigation (9250-9450 kg ha^{-1}) [Table 5]. KD and KNC at the 60% irrigation level were respectively reduced by 8% and 5.1% compared to the control treatments. The GY at the 60% irrigation level was reduced by 11.4% as compared the 100% treatments. The treatments of the control, 100%, 80% levels used for the GY, KD, and KNC were not significant. Thus, the 80% treatment can be utilized without any yield crop reduction when water is not limited, whereas the 60% treatment can be adopted when water availability is a limiting factor.

As indicated by the results, the 3-year average WP ranged between 0.83 and 1.42 kg m^{-3}. The WP was 0.835, 0.935, 1.167, and 1.422 kg m^{-3} respectively for the treatment control, 100, 80 and 60% levels of water use (*Fig. 2*). The highest WP was 1.43 kg m^{-3}, as calculated for the 60% treatment (means ± standard error). The effects of the control and full irrigation treatments on the WP were found to be higher than those under severe water stress such as the 60% treatment. On average, the increase in WP relative to that of the control treatment was 66% for the 60% treatment, 37.2% for the 80% treatment, and 12.8% for

TABLE 4
The variance analysis of different levels of irrigation on Maize GY, 1000 KW, KNER, KNC and KD indicators in the three years of the study period

Source of variation	df	GY	1000 KW	KNER	KNC	KD
Year	2	54.64^{**}	14131.92^{**}	15.71^{ns}	1287.27^{**}	31.8^{**}
Error (a)	6	0.87	462.17	5.09	22.36	0.44
Irrigation	3	0.91^{**}	298.34^{ns}	5.03^{ns}	24.14^{*}	4.99^{**}
Irrigation × Year	6	0.41^{ns}	243.99^{ns}	9.31^{ns}	16.09^{ns}	2.48^{**}
Error (b)	18	0.479	547.77	6.13	18.07	1.36
Variety	1	0.318^{ns}	33230.4^{ns}	256.74^{ns}	71.76^{ns}	22.680^{ns}
Irrigation × Variety	3	0.145^{ns}	496.44^{ns}	8.85^{ns}	2.266^{ns}	0.47^{ns}
Variety × Year	2	0.452^{ns}	146.03^{ns}	0.532^{ns}	5.07^{ns}	0.713^{ns}
Irrigation × Variety × Year	6	0.157^{ns}	214.67^{ns}	7.14^{ns}	5.99^{ns}	0.614^{ns}
Error (c)	24	0.359	248.29	5.4	6.97	0.505
%CV		9.8	5.2	13.5	6.3	5.9

** Significant at 1% level, * Significant at 5% level and ns Not significant

TABLE 5
The effects of different levels of irrigation on the quantitative indicators of the maize during the three years of research period (comparison of the mean of the treatments*)

Irrigation treatment	GY (kg/ha)	1000 KW (gr)	KNER -	KNC -	KD (mm)
Control	9271a	301.3a	16.7a	42.8a	12.4a
Irrigation level (100%)	9450a	308.8a	17.1a	43.1a	12.2a
Irrigation level (80%)	9250a	301.4a	18a	41.6a	12.6a
Irrigation level (60%)	8377b	299.8a	17.2a	40.6b	11.4b

* Comparison of the mean was done using Duncan test at 5% level. Mean with common letter is not statistically significant

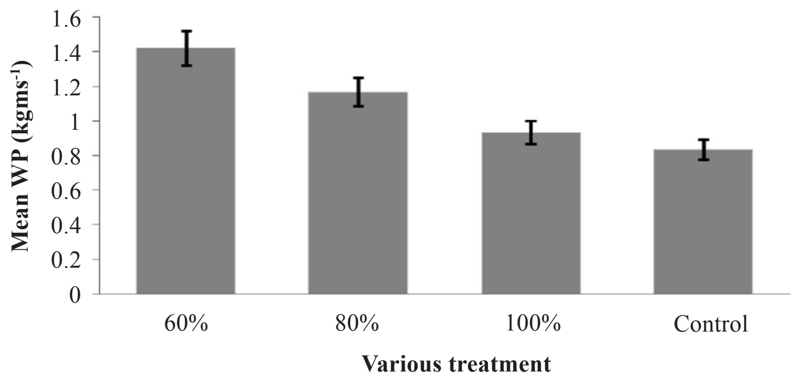

Fig. 2: Water productivity for different treatments (Bars represented standard error)

the full treatment cases, respectively. In *Fig. 3*, WP is plotted against irrigation water. This figure demonstrates how WP can be increased while simultaneously achieving water saving through reduced irrigations. WP was shown to be strongly affected by water deficit. The coefficient of determination of the regressed equation (R^2) index is 0.97, which shows high correlations between these two parameters for the three years of experimentation. Li *et al.* (2005) demonstrated that irrigation water use efficiency was negatively correlated with irrigated water volume.

Meanwhile, the regression analyses showed that the relationships between irrigated water volume and water use efficiency could be described by linear functions. Research conducted by Tavakoli (1999), Aghdaii & Sattar (2000), Cakir (2004), Payero *et al*. (2008) and Chen *et al*. (2009) revealed that the maize crop yield reduced with decreasing irrigation amounts, while maximum values of yield crop were obtained under fully irrigated treatments. Similarly, Oktem (2008) also found that water deficiency, together with hot and dry climate such as the GRB's summers, resulted in ear yield reduction. Most of the above stated studies have shown that maize yield is mostly affected by water stress. Payero *et al*. (2008), however, showed that the reported yield crop reduction for maize varied with location with differences in temperature and rainfall pattern, soil and crop characteristics, management practices, as well as weather conditions. However Kijne *et al*. (2003) believe that yield reduction is much lower than water reduction under the DI, whereas there is still potential for reducing crop water requirements to adopt more severe DI treatments and achieve the target of producing more crop yield per unit of water.

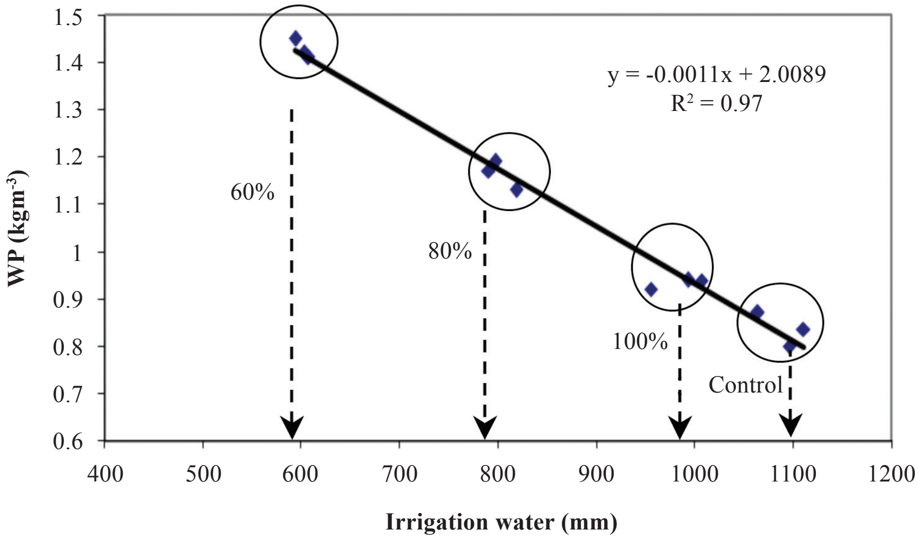

Fig. 3: The relationship between irrigation water and water productivity

Maize is the crop that is most sensitive to variations in plant density. The population for maize maximum economic GY varies from 30,000 to over 90,000 plant ha^{-1}, depending on water availability and nearly all environmental factors (Sangoi, 2001). Norwood (2000) and Emam & Ranjbar (2000) concluded that for maize, deficit-irrigation combined with proper fertility and plant population was a viable alternative to dryland in Kansas and Shiraz, where water resources are limited. In the present study, maize seeds were planted at the above plant density which might have resulted in a moderate reduction of maize yield under DI. Stone (2001) showed that water use efficiency (calculated the same as WP in this study) with water deficit increased as maize yield increased. The desire of most farmers is not to maximize WP, but to maximize profits. Therefore, there could be very good reasons for imposing deficit irrigation other than trying to maximize WP. Payero *et al*. (2006) demonstrated that trying to increase WP by applying deficit irrigation for maize might not be a beneficial strategy. Zwart & Bastiaanssen (2004) found that DI would probably increase WP only in situations where crops are being over-irrigated. The results suggested that if the crop was already deficitly irrigated, lowering irrigation inputs would only contribute to further reduction in yields and lower WP. Nonetheless, Oweis *et al*. (2004) have looked deeper into this issue and believe that there is a need to look for an optimum combination of production per hectare and production per m^3 volume of irrigation water to obtain "more food with less water". In other words, DI helps to stabilize crop yields and obtain maximum WP rather than maximum yields (Zhang *et al*., 2005). The above studies have also revealed that WP was strongly increased if crop water deficit was induced. These results are confirmed by the findings of the current study. A water deficiency level of 40% could therefore be acceptable for the maize (var. 704 and 647) in the central region of Iran and other similar arid and semi-arid ecological regions of the world.

CONCLUSION

During the three (3) years of the experiments with the four (4) irrigation treatments imposed on the crop, it was found that the grain yield and its components were mostly affected by the amount of irrigation water applied. The highest and lowest values of WP resulted from the treatment

60% level of water use and control, respectively. The highest magnitude of WP was calculated as 1.42 kg m^{-3} for the 60% treatment. Meanwhile, the general condition of the GRB is that there are many challenges involved in water shortage issues. Since demand for irrigation water far exceeded the supply in the years considered, the GRB succumbed to a severe deficit. In such a situation, the only way to keep supply and demand in balance is to reduce the allocation for agriculture. The good relationship obtained between WP and seasonal water consumption in this study can help and guide policy makers and planners come up with desirable solutions on how to manage water allocation for irrigated maize as the main summer crop in study area. This study has shown that with limiting water resources becoming a constant reality, deficit irrigation practices have become a priority for large irrigation networks. Considering the importance of water consumption optimization as the main scope in arid and semi-arid lands of Iran, a 60% level of water use is therefore highly recommended for agricultural maize production.

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