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Effects of deficit irrigation on the yield, yield components, water and irrigation water use efficiency of spring canola

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Key words: Rapeseed, irrigation, water use efficiency, yield, yield response factor.

Abstract

Rapeseed is the third most important edible oil source after soybean and palm in the world and is the most widely cultivated oilseed crop in Iran. Because of oil and many other usages of rapeseed this experiment was conducted to evaluate the effects of water stress on yield and yield components, total biomass, evapotranspiration, yield response factor to water stress, water use efficiency (WUE) and irrigation water use efficiency (IWUE) of spring canola (*Brassica napus* L.) in Agricultural Research Station of Tabriz University, Iran. Spring type of canola was planted in furrows and irrigated during the growing season. In this research four irrigation treatments (applied water at the ratios of 1.0, 0.8, 0.65, and 0.5 of canola potential water requirements as I1, I2, I3, and I4 treatments, respectively) were tested. Results showed the evapotranspiration, *WUE* and *IWUE* of canola were all affected by controlled volumes of irrigation water. The highest amount of daily evapotranspiration was observed as 9.84 mm d^{-1} in mid July at the treatment I1. The *WUE* reached its maximum value at a seasonal evapotranspiration of 483 mm, and then started to decrease with increasing evapotranspiration. The values of *WUE* and *IWUE* were between 2.97 - 3.13 and 3.57-4.29 kg $ha^{-1}mm^{-1}$, respectively. The amount of yield response factor (K_y) was found smaller than 1 in the canola growing season. It was concluded that canola was a water stress tolerant crop and could be cultivated in arid and semi arid regions such as Iran.

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Introduction

Water scarcity is the most important limiting factor for crop production in arid and semi-arid regions, so water should be used more efficiently in irrigated agriculture to increase and sustain productivity. In crop production, instead of reaching maximum yield per unit area by full irrigation, water productivity can be optimized within the concept of deficit irrigation (*Fereres and Soriano* 2007*, Geerts and Raes* 2009*, Pereira et al.* 2002).

Because of increasing food requirements, limited water resources, and continuous droughts, deficit irrigation merits consideration in Iran. Rapeseed, subsidized by the government because of its good characteristics such as suitable placement in crop rotation, desirable quality, high value of oil and protein (*Ghassemi–Golezani et al.* 2010), has become an increasingly popular part of the crop rotation and so production of spring and winter types of it has been expanded recently throughout the country.

Oilseed rape, as a member of the mustard (*Brassicaceae*) family, is one of the main sources of vegetable oil in the world. It has also a great potential in developing biodiesel market (*Economic Research Service*, 1996). In addition to oil production, the leaves and stems of oilseed rape provide high quality forage suitable for animal feeding because of their low fibre and high protein contents (*Wiedenhoeft and Bharton* 1994, *Banuelos et al.* 2002).

Because of limited annual precipitation, many regions of Iran suffer from water deficit. Water deficit more than other stresses, like salinity and heat, limits growth and crop production. Therefore, understanding of the effects of irrigation scheduling and water use efficiency on canola production under deficit irrigation condition is becoming increasingly important.

Identifying a relationship between water use efficiency and seed yield under deficit irrigation condition has been a major concern of agricultural research in semi-arid regions (*Nielsen* 1997, *Johnston et al.* 2002, *Condon et al.* 2002, *Fan et al.* 2005, *Sun et al.* 2006, *Sinaki et al.* 2007, *Faraji et al.* 2009). However, one of the greatest challenges for agriculture is to develop technological or agronomic options to improve *WUE* (*Turner* 2004).

The main objective of this research is to investigate the effects of deficit irrigation on evapotranspiration, soil water content, irrigation water requirement, crop water production functions, water and irrigation water use efficiency, yield and growth components of canola during its growing season.

Materials and methods

Study area

This study was done in the agricultural research station of Tabriz University (Karkaj), Iran, during the growing season of 2011. The latitude, longitude and elevation above mean sea level of the station are 37° 03´ north, 46° 37´east and 1567.3 m, respectively. The long-term average annual precipitation of the area is 288.9 mm (Table 1).

The climate in the experimental area is terrestrial, summers are mild and dry, and winters are cold and snowy.

Table 1. Some meteorological characteristics of Tabriz Weather Station.

Years	Jan	Feb	March	April	May	June	July	Aug	Sep	Oct	Nov	Dec	Average
Temperature (° C)													
2011	-0.5	1.6	6	14.4	20.5	22.5	28.2	26.1	21.7	13.4	2.4	-0.5	13.02
Long-term -average	-1.7	0.3	5.4	11.4	16.6	21.9	26	25.8	21.3	14.4	7	1.1	12.5
Relative humidity (%)													
2011	71	65	50	58	40	45	29	36	40	46	67	68	51
Long-term -average	70	61	52	44	33	27	28	31	34	45	58	70	46
Rainfall (mm)													Total
2011	7.8	18.3	42.4	80.7	47.5	7.8	0	4.8	16	13.7	26.7	7.9	273.6
Long-term -average	22.3	24.2	40.6	52.7	42.6	16.9	5.8	3.2	7.6	21.9	27.9	23.2	288.9

Soil properties

The soil of the research area has a sandy-loam texture with 0.98% organic matter content and rich in calcium carbonate. The average values of the soil pH, field capacity, permanent wilting point, and bulk density in the depth of 0-30 cm were measured as 7.65, 0.28 (m^3m^{-3}), 0.125 (m^3m^{-3}) and 1.58 g cm^{-3}, respectively. The water retention capacity of the soil was determined as 140 mm in its 0-90 cm profile.

Experimental design

The experimental design was based on a randomized complete block with four replicates. The planted cultivar was RGS003, spring type of canola. Seeds were sown on 23th April 2011with 5 cm spacing on the ridge of furrows having a length of 5 m and a width of 0.25 m. The plot size was 20 (4×5) m^2.

The application of fertilizers was based on the soil analysis. Phosphorus in the form of ammonium phosphate was applied at a rate of 100 kg /ha before planting and nitrogen as urea form was added to the soil at a rate of 200 kg N/ ha. The 70% portion of urea was applied at 21 and 22 days after planting and the rest was applied at the beginning of the flowering period. During the experiment, the necessary cultivation practices such as maintenance, fertilization, and agricultural protection were carried out.

Four irrigation levels at a seven-day interval were applied. The irrigation treatments of canola were based on the soil water depletion/replenishment. The control treatment (full irrigation-I1) was designated to compensate 100% of soil water depletion during the seven-day period. For the remaining treatments (I2, I3 and I4), the amounts of irrigation water were 20%, 35% and 50% of the total water volume applied at the full irrigation treatment (I1).

Soil water content and evapotranspiration

Volumetric soil water contents were measured by PR2 (Profile Probe Delta-T) at the depths of 0.1, 0.2, 0.3, 0.4, 0.6 and 1 m at different treatments before each irrigation. The pumped water was conveyed by a PE pipeline and delivered to the experimental plots by taking advantage of a flow meter. A perforated pipe was used to ensure uniform delivery of water to each blocked-end furrow in plots. The crop was harvested on 8^{th}August and then the total top dry matter production, grain yield, and some other yield components were measured for the all treatments.

Crop evapotranspiration (*ET*) of each treatment was determined using the soil water balance equation (*Jensen et al.,* 1990). In the water balance equation runoff/runon was considered to be zero because the experimental plots were surrounded with dikes. Soil water depletion was calculated as the difference between soil water contents at the beginning and the end of each irrigation for the 0-90 cm soil profile. Drainage below the root zone was assumed to be zero, since the maximum water applied with each irrigation was equal to the soil moisture deficit in the root zone for the fully irrigated treatment (I1).

Crop water production functions

The Stewart model, which is frequently used to define relationship between yield and *ET,* has been used to determine the yield response factor as follow (*Stewart et al.* 1976, *Doorenbos and Kassam* 1979):

$$\left(1-\frac{Y_a}{Y_m}\right)=K_y\left(1-\frac{ET_a}{ET_m}\right)$$

where Y_a is the actual yield under water deficit conditions, Y_m is the maximum yield under full irrigation regime, ET_a is the actual *ET* under water deficit condition, ET_m is the maximum *ET* related to the full irrigation treatment and K_y is the yield response factor to water stress.

Water use efficiency (*WUE*) was calculated from ratio of grain yield and seasonal evapotranspiration. In addition, irrigation water use efficiency (*IWUE*) was calculated from ratio of grain yield and total irrigation water depth (*Fereres and Soriano* 2007, *Unger et al.* 2006). The data were evaluated by SPSS software to determine any statistically significant differences.

Results and discussion

Irrigation water and evapotranspiration

Because of the rainfall occurrence at the beginning of the growing seasons, desirable levels of water stress were not easily achieved. In the experimental year, the total rainfall during April and May was measured 128 mm while the months. June, July and August were almost dry. The total number of irrigations during the experiment was 12. Accumulated irrigation water amounts for the treatments I1, I2, I3 and I4 were 501, 410, 340 and 274 mm, respectively (Fig. 1).

The seasonal *ET* of each treatment was computed by using soil water content, applied irrigation water amount, and precipitation. The seasonal *ET* increased with increasing number and amount of irrigations. The highest seasonal *ET* occurred at the full irrigation treatment obviously owing to an adequate soil water supply during the entire growing season. The lowest *ET* occurred at the continuous stress treatment for which the seasonal *ET* varied between 602 and 368.5 mm, as expected. Canola *ET* values under similar climatic conditions were reported by several researchers. *Niyazi and Fuladvand* (2007) report winter canola potential evapotranspiration as 740, 709 and 700 mm in three years experiment in the south west of Iran. *Zarei et al.* (2010) obtain the highest seed yield for irrigation water of 675 mm in the experimental farm of Karaj, Iran. *Istanbulluoglu et al.* (2010) find *ET* of oilseed rape in the range of 465-715 mm at different deficit irrigation regimes in Turkey. They report that the seasonal *ET* of different oilseed rape varieties under different climatic and soil conditions vary from 300 to 1150 mm.

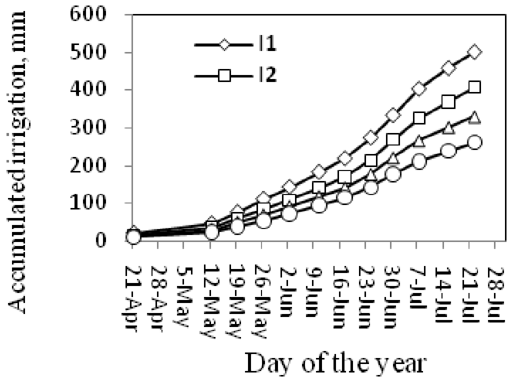

Fig. 1. Accumulated irrigation water amounts in different irrigation treatments in Karkaj.

In accordance with crop development and increase of leaf area, the amounts of evapotranspiration increased. The highest amount of daily evapotranspiration was observed as 9.84 mm/d in mid July 2011 (Fig. 2). This high evapotranspiration might be caused by some local conditions such as advection phenomenon (*Majnooni-Heris et al.* 2009, 2011). The highest water consumption was in July, when the ripening stage started. The daily average *ET* of this month was 6.73 mm. Furthermore, the mean daily *ET* in June was 6.33 mm which was in agreement with the results obtained by *Nielsen* (1997), *Banuelos et al.* (2002), *Rahnema and Bakhshandeh* (2006), Sinaki *et al.* (2007), and *Istanbulluoglu et al.* (2010).

Crops were not affected by water stress at the beginning of the growing season (Fig. 2). In the remaining period, all evapotranspiration rates followed the irrigation water amounts and showed decreasing trends from the treatment I1 toward I4.

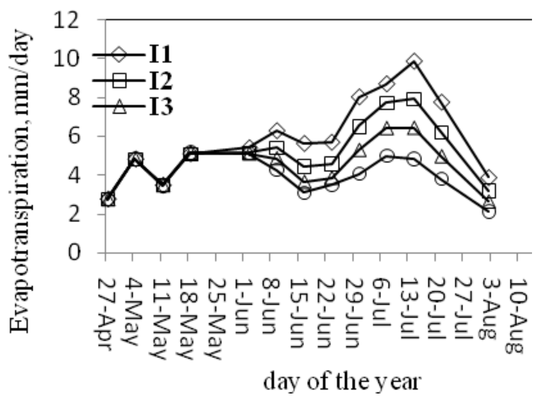

Fig. 2. Daily evapotranspiration rate of different treatments in the growing season of spring canola in Karkaj.

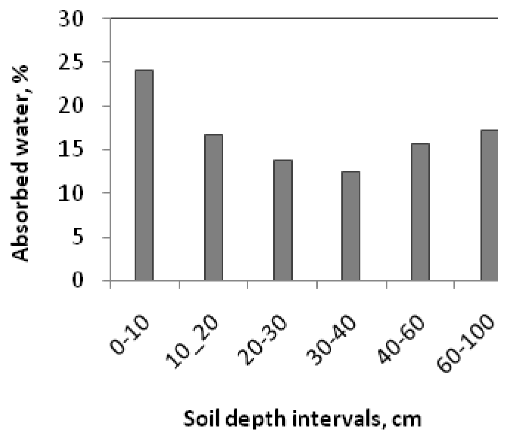

Fig. 3. Variations of absorbed soil water percentage in different soil depths.

Soil water contents

Except the case of the first few weeks, average water contents of the stressed treatments were lower compared to the induced stress. Also except the surface layer of 0-10 cm the amounts of soil water content never reached below the permanent wilting point (12.5%) during the growing season at all treatments. Also, the soil water contents went beyond the field capacity limit because of excessive precipitation at the first week of the spring canola growing season. Considering soil water contents at the all treatments, it was found that the maximum percentage of water was absorbed from the first 10 cm of the soil depth (Fig. 3) in the growing season.

Yield, yield components and biomass

In this study grain yield of spring canola was found in the range of 1.12-1.78 t ha^{-1} (Table 2). In comparison with the winter type of canola, grain yield of spring type decreased in response to the short-term growing season. *Rahnema and Bakhshandeh* (2006) and *Hamzei et al.* (2007) found grain yield in the range of 1.0–5.3 t ha^{-1}. *Zarei et al.* (2010) found grain yield of three winter species of canola in the range of 2.09-3.95 t ha^{-1} in Yazd, E. Azarbaijan (Tabriz), and Khuzestan provinces of Iran. *Sinaki et al.* (2007) reported grain yield of three winter types of canola under normal and water stress conditions in the range of 0.97-3.98 t ha^{-1} in Alborz (Karaj) province. *Safahani Langeroudi and Kamkar* (2009) reported grain yield of winter type of the same cultivar (RGS003) of canola equal to 2.60 t ha^{-1} at normal irrigation treatment for Golestan province of Iran.

Table 2. Mean comparison and standard deviation (*SD*) of irrigation treatment effects for some traits of spring canola in the combined ANOVA.

Treatments	Biomass (t ha^{-1})	Yield (kg ha^{-1})	Plant Height (cm)	*LAI* m^{2}m^{-2}	Pod number in main stem (no plant^{-1})	Pod length in main stem (cm)	Pod number in secondary stem (no plant^{-1})	Pod length in secondary stems (cm)
Mean (*SD*)	7.05(2.16)	1457.16(318.0)	75.00(16.68)	3.14(1.12)	24.27(9.99)	5.82(1.27)	73.21(47.49)	5.59(1.07)
*Treatments								
I1	9.87(0.35)a	1788.1(235.6)a	98.75(8.54)a	4.28(0.65)a	32.64(3.68)a	6.48(1.56)a	131.25(41.51)a	6.08(0.52)a
I2	7.91(0.50)b	1595.74(261.4)ab	78.25(5.38)b	3.51(1.16)ab	25.00(13.43)b	6.43(1.22)a	86.05(28.10)b	6.23(0.68)a
I3	5.82(1.14)c	1248.32(181.3)bc	62.17(2.06)bc	2.36(0.49)b	20.12(7.53)b	5.66(0.83)b	51.73(30.96)bc	5.66(0.73)ab
I4	4.60(0.90)d	1124.83(60.9)c	58.25(2.17)c	2.03(0.35)c	18.75(9.35)b	4.71(1.06)c	43.28(37.82)c	4.39(0.95)b

* Means in each column followed by the similar letter(s) are not significantly different at 5% probability level, using Duncan's Multiple Range Test.

There was significant difference in grain yield between the irrigation treatments at 0.05 probability level using Duncan's Multiple Range test (Table 2). The highest canola grain yield was obtained at the treatment I1 and the lowest at the continuous stress treatment. The treatments I1 (1788.1 kg/ha) and I2 (1595.74 kg/ha) produced significantly higher seed yields than the treatment I4 (1124.83 kg/ha) and were at the same statistical group. In comparison with I1, the yield reduction percentages in I4, I3 and I2 were 37, 26 and 11%, respectively. The obtained grain yields at different irrigation treatments were comparable with those reported by *Hassanzadeh et al.* (2005) and Leilah *et al.* (2003). In this research, there were significant differences between pod numbers per plant in the treatment I1 and the other treatments. *Zarei et al.* (2010) report that higher grain yield can be largely due to the greater number of pods per plant in a 7-day irrigation interval compared to long-term irrigation intervals. The analysis showed significant differences between *LAI* (when 80% of flowers are open) in the treatments I1, I3 and I4. The higher grain yield in oilseed rape may be associated with higher leaf area (*Nielson* 1994, *Wright et al.* 1988, *Howell,* 2000).

Significant differences in the plant height and biomass observed amongst the different irrigation treatments. The plant height increased significantly with increasing irrigation water amounts. Treatments with limited water amounts and controlled soil water deficits caused biomass reductions compared to those with higher irrigation amounts and soil water contents.

The relation between grain yield and biomass was interpreted as a quadratic function (Fig. 4). It could be deduced from the developed equation that the highest grain yield could not be obtained at maximum biomass value. Further investigation showed that the maximum grain yield (2.01 t) was obtained from 9.43 t biomass, while the highest value of biomass was more than 10 t in some replication of the treatment I1.

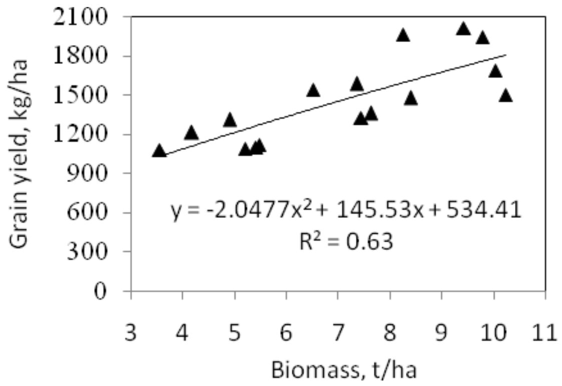

Fig. 4. Relationship between biomass and grain yield for spring canola in Karkaj.

Crop water production functions

The relationship resulting from the regression analysis of grain yield and seasonal evapotranspiration is best described by a quadratic equation with a determination coefficient of 0.99 (Fig. 5).

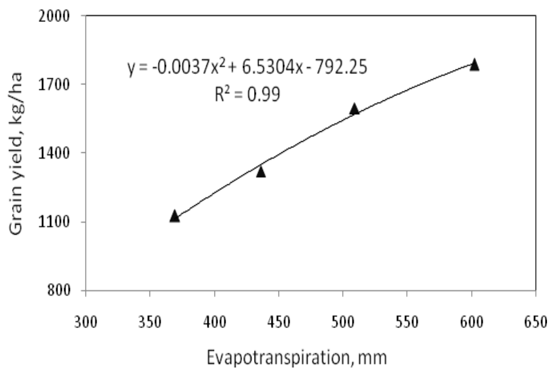

Fig. 5. Relationship between seasonal evapotranspiration and grain yield for spring canola in Karkaj.

The relationship between biomass and seasonal evapotranspiration was depicted as a logarithmic function (Fig. 6). At treatments with water deficit reductions of biomass and evapotranspiration were observed as compared to full irrigation treatment. Fig. 6 indicated a direct relationship between biomass and evapotranspiration at different treatments.

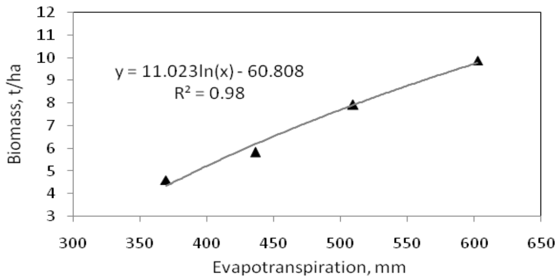

Fig. 6. Relationship between biomass and grain yield for spring canola in Karkaj.

Significant increase of biomass with application of more water is observed in various *Brassica* (*Banueles et al.* 2002, *Mingeau* 1974, *Clarke and Simpson* 1978, *Prihar et al.* 1981, *Singh et al.* 1991). Generally, canola and other *Brassica spp.* appear very responsive to soil water availability. For example, in Alberta, Canada, the canola cultivated for forage yields 19 t ha^{-1} dry weight during a wet year (*Henkes and Dietz* 1995).

The amount of yield response factor (K_y) in the whole growing period was 0.93 (Fig. 7). Considering the values of K_y being smaller than 1, it was concluded that Canola was a water stress tolerant crop and could be cultivated in arid and semi arid regions such as Iran. Results of the present study on canola were in agreement with the results reported by *Istanbulluoglu et al.* (2010). They found values of 0.56 and 0.99 for K_y in two-year experiments in Trakya region of Turkey. Also, the K_y value of the present study was close to the K_y values of some other oil crops such as sunflower. *Doorenbos and Kassam* (1979) report the value of 0.95 for K_y of sunflower in its total growing period.

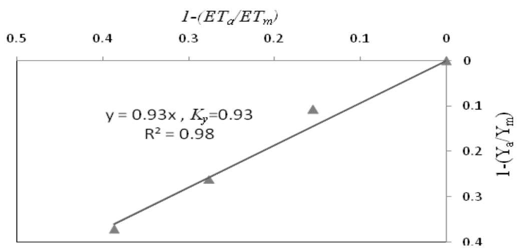

Fig. 7. Relationship between relative evapotranspiration deficit and relative yield decrease for spring canola in Karkaj.

Water use efficiency and irrigation water use efficiency of canola

The calculated irrigation water use efficiency values were greater than those for water use efficiency as presented in Table 3. This could be justified by the fact that the values of the seasonal irrigation water were smaller than the seasonal evapotranspiration.

Table 3. The mean and standard deviation (*SD*) of water use efficiency (*WUE*) and irrigation water use efficiency (*IWUE*) for different irrigation treatments in Karkaj.

Parameter	Irrigation Treatments			
kg/ha/mm	I1	I2	I3	I4
WUE (*SD*)	2.97 (0.39)	3.13 (0.51)	3.03 (0.42)	3.05 (0.16)
IWUE (*SD*)	3.57 (0.47)	3.92 (0.64)	3.88 (0.53)	4.11 (0.22)

According to Table 3, values of *WUE* and *IWUE* except for the treatment I2 followed water stress amounts and showed increasing trends at other treatments. Regression analyses indicated quadratic equations for *WUE*-seasonal evapotranspiration and *IWUE*- seasonal irrigation water relationships as shown in Fig. 8. *WUE* reached its maximum value at a seasonal evapotranspiration of 483 mm, and then started to decrease with increasing evapotranspiration. However, the maximum value of *WUE* did not correspond to the maximum grain yield because the evapotranspiration value was 602.6 mm when the maximum grain yield occurred. When evapotranspiration was relatively low, water availability was the limiting factor for grain yield and an increase in evapotranspiration resulted in significant increase in both grain yield and *WUE*. *IWUE* reached its maximum value at minimum applied irrigation water, i.e. 274 mm, and then started to decrease with increasing applied water.

Sinaki et al. (2007) reported that *WUE* values were significantly influenced by the irrigation programs. They obtained the highest grain yield at normal irrigation treatment and the highest *WUE* under stress conditions for three species of canola in Alborz province (Karaj), Iran. *Banuelos et al.* (2002) showed that *WUE* values of canola and Kenaf decreased as the level of irrigation increased from 25 to 150% of potential evapotranspiration in Frenso. *Istanbulluoglu et al.* (2010) reported the occurrence of the highest and lowest values of *IWUE* at minimum and maximum applied irrigation water respectively in Turkey.

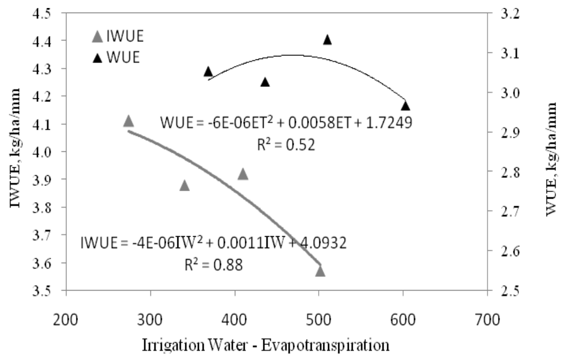

Fig. 8. Water use efficiency - seasonal evapotranspiration (*ET*) and irrigation water use efficiency-seasonal irrigation water (*IW*) relationships in Karkaj.

Conclusions

Present research was done to evaluate the effects of different irrigation treatments on canola growth in the northwest of Iran. Results showed that there were significant differences in biomass, plant height, *LAI*, yield and yield components between the irrigation treatments. Investigation showed Controlled volumes of irrigation water affected all *ET, WUE* and *IWUE* of spring canola. Grain yield response to irrigation varied considerably due to the differences in soil moisture contents and irrigation scheduling. Values of grain yield, evapotranspiration, and biomass followed decreasing trends from full irrigation toward maximum stress treatment for which the applied water volume was 0.5 of the canola potential water requirement. The relation between grain yield and biomass was interpreted as a quadratic function. It could be deduced from the developed equation that the highest grain yield could not be obtained at maximum biomass value. Maximum values of *WUE* and *IWUE* occurred at the treatments for which the applied water volumes were 0.2 and 0.5 of the canola potential water requirement, respectively. The amount of yield response factor (K_y) in the canola growing season was found as 0.93 and canola cultivation could be recommended in arid and semi arid regions such as Iran.

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