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DEFICIT IRRIGATION EFFECTS ON WATERMELON (*CITRULLUS VULGARIS*) IN A SUB HUMID ENVIRONMENT

H. Kuşçu[1*], A. Turhan[1], N. Özmen[2], P. Aydınol[2], H. Büyükcangaz[3] and A. O. Demir[3]

[1] Department of Plant and Animal Production, Mustafakemalpaşa Vocational School, University of Uludag, 16500 Bursa, Turkey.
[2] Department of Food Processing, Mustafakemalpaşa Vocational School, University of Uludag, 16500 Bursa, Turkey.
[3] Department of Biosystems Engineering, Faculty of Agriculture, University of Uludag, 16059 Gorukle, Bursa, Turkey.
[*]Corresponding author e-mail: kuscu@uludag.edu.tr

ABSTRACT

In sub-humid environments where summer drought is intense, the efficient use of water is important for sustainable crop production. Watermelon has high water requirements. The application of deficit irrigation (DI) strategies to this crop may greatly contribute to save irrigation water. A two-year study was conducted with the aim to evaluate the effects of DI on water productivity, yield and some quality properties of watermelon in a sub-humid environment in western Turkey. Five irrigation treatments [FI-Full, DI1-deficit=100% and 50% crop evapotranspiration (ETc) restoration during whole growing season, respectively; DI2= 100% ETc up to flowering, then 50% ETc restoration; DI3=100% ETc up to yield formation, then 50% ETc restoration; DI4= 100% ETc up to ripening stage, then 50% ETc restoration] were arranged in randomized complete block design with 3 replications in both experimental years. The maximum marketable fruit yield was determined from full irrigation level. Results showed that marketable yield significantly decreased by reduction in irrigation. In spite of the yield loses up to averagely 31% under DI1 conditions, saved 50% of water as compared to treatment of full irrigation. The highest values of total soluble solids and total sugar were found in treatments of DI1 and DI2. Higher values of vitamin C and lycopene were observed in DI3 treatment. Water productivity was positively affected by reduction in irrigation. Yield response factor (ky), which indicates the level of tolerance of a crop to water stress, was 1.01 for marketable yield, indicating that the reduction in crop productivity is proportionally equal to the relative ET deficit. The study revealed that the best compromise among water productivity, quantity and quality for watermelon was achieved with DI4 that 100% ETc up to ripening, then 50% ETc restoration.

Key words: Watermelon, Water stress, Water use efficiency, Yield, Antioxidants.

INTRODUCTION

Watermelon (*Citrullus vulgaris*) is an important vegetable, widely cultivated throughout the world and its worldwide harvested area is 22% of that of all vegetables. The leading watermelon-producing countries are the China, Turkey, Iran and Brazil (FAO, 2014). According to the literature, watermelon has high water requirement (Şimşek *et al*., 2004; Özmen *et al*., 2015). In all the regions of Turkey, rainfall is low in the summer which is the cropping season for watermelon (average seasonal rainfall for 1960-2012 is 65 mm). The total precipitation does not meet the water needs of watermelon crop. For high yields, the seasonal water requirements of watermelon vary from 520 to 660 mm, depending on the climate and the total length of the growing period (Kirnak and Dogan, 2009; Çamoğlu *et al*., 2010; Özmen *et al*., 2015). Therefore, irrigation is necessary for optimal vegetative and reproductive development in the periods of insufficient precipitation during the plant production season in Turkey (Sahin *et al*., 2015). On the other hand, there is no reliable water resource for irrigation in the region. Hence, the efficient use of water for agriculture has become a top priority research and development area (Topcu *et al*., 2007).

Particularly in water-shortage regions, deficit irrigation (DI) strategies have become important tool to attain higher water use efficiency (Fereres and Soriano, 2007; Al-Ghobari *et al*., 2013). DI is a water conservation strategy under which crops are subjected to a precise level of soil water stress either during one or more phenological growth stage or during the entire growing season (Pereira *et al*., 2002). It is believed that DI can help us to better understand the crop yield response to water (Steduto *et al*., 2012). Irrigation experiments have proved that watermelon is sensitive to DI (Orta *et al*., 2003; Rouphael *et al*., 2008). In previous studies, it is reported that yield of watermelon decreases at DI conditions (Wang *et al*., 2004; Erdem *et al*., 2005; Ghawi and Battikhi, 2008). Bang *et al*. (2004) stated that TSS increased with DI 0.5 ET rate in triploid watermelon cultivars, but not in diploids. Erdem *et al*. (2001) reported that total sugar content of watermelon relatively increased at DI conditions. Leskovar *et al*. (2003) reported that lycopene and vitamin C content did not change with DI at 0.75 ET and full irrigation. Proietti *et al*. (2008) determined that yield of mini-grafted watermelon was not significantly affected by moderate deficit drip irrigation. Before adoption of DI as a management tool, its effect on fruit yield and quality should be investigated at different ecological environments (Kirda, 2002).

It is understandable that effective use of scarce water resources is crucial to achieving improved watermelon yield, quality, and the crop water productivity. However, present information on the response of watermelon yield and quality to DI remains limited, particularly about the results of restricted water distributions in sub-humid environments. Consequently, the present research was carried out to study the yield, quality and water productivity response of watermelon grown under the different DI strategies in a sub-humid environment.

MATERIALS AND METHODS

Experimental site and its climate: Field experiments were carried out at the research area of Mustafakemalpaşa Vocational School of Uludağ University located in Bursa province, Turkey (22 m a.s.l., latitude: 40°02′ N, longitude: 28°23′ E) during the years 2011 and 2012. The soil was classified as a clay-loam Entisol soil (USDA, 1999). Over the 1975 to 2010 period, the annual mean temperature, precipitation and relative humidity were 14°C, 681 mm and 68%, respectively. According to the Thornthwaite climate classification system, the study area is classified as sub-humid (Feddema, 2005). Average air temperature, air relative humidity, rainfall and class-A pan evaporation were observed at the automated weather observing station located approximately 1 km east of the experimental area. In the growing seasons (May–August), the mean temperature and total rainfall were actually 23.7 °C and 52.0 mm in 2011 and 22.4 °C and 103.0 mm in 2012, respectively. As expected, rainfall is sufficient for watermelon production. For this reason, irrigation is needed for acceptable yields of watermelon grown in the region. Table 1 presents the soil properties of the experimental site.

Treatments and experimental design: The experiments for both seasons were conducted using a completely randomized block design in three replications. The experimental design was based on the amount of irrigation in the crop growth stages that vegetative, flowering, yield formation and ripening (Doorenbos and Kassam, 1979). Five irrigation treatments [FI-Full, DI1-deficit=100% and 50% crop evapotranspiration (ETc) restoration during whole growing season, respectively; DI2= 100% ETc up to flowering, then 50% ETc restoration; DI3=100% ETc up to yield formation, then 50% ETc restoration; DI4= 100% ETc up to ripening stage, then 50% ETc restoration] were arranged in randomized complete block design with 3 replications in both experimental years. ETc was estimated using the soil water balance ($ETc = ET_0 \times kc$) as proposed by the Food and Agricultural Organization (FAO) as the most reliable method for estimating ETc around the world (Allen *et al*., 1998). Reference evapotranspiration (ET_0) was measured by means of a class-A evaporation pan and kc were used according to Doorenbos and Kassam (1979): between 0.40 and 0.65 from transplanting to vegetative; between 0.65 and 1.05 from vegetative stage including early and late vegetative to beginning of flowering; 1.05 from beginning of flowering to beginning of yield formation (fruit filling); between 1.05 and 0.90 from beginning of yield formation to ripening; between 0.90 and 0.65 from beginning of ripening to harvest (Orgaz *et al*., 2005; Shukla *et al*., 2014). Pan coefficient was assumed as 1. The irrigation water amount was that required to fill soil up to field capacity in the 0-90 cm of depth, where most of the roots are expected to develop in watermelon (Erdem and Yuksel, 2003).

Agronomy and measurements: The previous crop was corn. In order to prepare the soil for watermelon cultivation, the experimental site was ploughed at the depth of 30 cm in the autumn preceding to the both experimental years. In the month of May in both years, secondary plough was performed at the depth of 25 cm for soil pulverization and clogs were broken into small pieces using disk method. The cultivar ‘Crimson Sweet’ of watermelon (*Citrullus vulgaris*) was used for the trials. Watermelon seedlings were transplanted at the 4-5 true leaf period on 23 May 2011 and 16 May 2012. In the experiments, a single plot size was 24 m^2 (4.8 m × 5.0 m) with 4 rows per plot; row spacing was 1.2 m; plant-plant spacing was 1.0 m. A buffer zone spacing of 3.0 m was supplied between the plots. All recommended agronomic practices were applied for cultivation and plant protection at the experimental site. A total of 120 kg N ha^{-1} and 42 kg P_2O_5 ha^{-1} fertilizer was applied according to recommendations based on the results of the soil productivity analysis. Since the soil analysis results indicated that there was a sufficient level of the potassium in the soil, no additional fertilizer was applied on the experimental site. The crop was harvested by hand on 22-30 August 2011 and 15-22 August 2012.

The soil water content was monitored in 0.3 m depth increments to 1.2 m from each plot in all blocks throughout the growing season. Soil moisture was estimated by the gravimetric method based on oven dry basis. Crop seasonal evapotranspiration was estimated for each plot using the soil water balance equation (Yıldırım *et al*., 2009).

Marketable yield (t ha^{-1}) was measured considering fruits free of disorders and available for local markets (Turhan *et al*., 2012). Ripened fruits (5 fruits per plot) were sampled for laboratory analyses at harvest.

The watermelons were sliced with rinds and seeds eliminated, afterwards the fleshy mesocarps, which is the edible portion of the fruit, were analyzed for total soluble solids, pH, total sugar, vitamin C and lycopene. Total soluble solids (TSS, °Brix) were measured with an abbe-type refractometer (Model 60, Direct Reading, Bellingham & Stanley Inc., Kent, UK) at 20 °C (Yetisir *et al*., 2003); pH was measured with a pH meter; vitamin C (mg 100 g^{-1} FW, as ascorbic acid) was determined by titration of homogenate watermelon samples (AOAC, 1990); total sugar (TS, % FW) was determined by the Luff-Schoorl method (Gormley and Maher, 1990). Finally, lycopene content (mg 100 g^{-1} FW) was determined by extraction method. Extraction was performed with petroleum ether-acetone and the measurements were made with a spectrophotometer (Shimadzu UV-1208, Japan) at 472 nm.

Water productivity: Water use efficiency based on ET (WUE, kg m^{-3}) was calculated as marketable yield (kg ha^{-1}) obtained per unit volume of seasonal ETc (m^3 ha^{-1}). Also, irrigation water use efficiency (IWUE, kg m^{-3}) for in each experimental treatment was estimated as marketable yield (kg ha^{-1}) obtained per unit amount of seasonal irrigation water applied (SIWA, m^3 ha^{-1}), respectively (Howell *et al*., 1990).

Yield response factor: The yield response factor (ky) for total growing season was determined by following approach (Doorenbos and Kassam, 1979):

$$[1 - Y_a\, Y_m^{-1}] = k_y\, [1 - SET_a\, SET_m^{-1}]$$

where, Y_a (kg ha^{-1}) and Y_m (kg ha^{-1}) are actual and maximum crop yields, related to SET_a (mm) and SET_m (mm), seasonal actual and maximum evapotranspiration, respectively.

Data analyses: All data were subjected to analyses of variance using IBM® SPSS® Statistics, Version 20, Copyright 1989, 2011 SPSS Inc. Analyses of variance over the experimental years showed a significant ($P<0.05$) year by treatment interaction for the data. Therefore, data were analyzed and presented separately for each year. Treatment means were compared using F-test. Duncan's multiple range test was used to group the means of irrigation treatments. Regression analysis was performed on the relationship between the marketable yield and crop evapotranspiration.

RESULTS AND DISCUSSION

Irrigation water applied, soil water content, and evapotranspiration: The values of seasonal irrigation water applied and ETc for the different irrigation strategies are presented in Table 2. The amount of irrigation water applied remained in the range of 243 to 486 mm during 2011, while varied between 215 to 429 mm during 2012. The rainfall during the crop growing season has an effect on volume of the irrigation water applied in the treatments. The total precipitation amount during the season was 52.2 mm in 2011 and 103.0 mm in 2012. In 2012, the amount of irrigation water applied decreased for all of the treatments because of higher rainfall.

The soil moisture content fluctuated greatly in response to irrigation amounts and rainfall (Fig. 1). The soil moisture increased with irrigation and then decreased with ETc, and showed fluctuations owing to precipitation at vegetative stage of the cropduring 2012. Therefore, there was no substantial variation in soil water status amongst the treatments up to the beginning of flowering during 2012. Soil water level was almost stable in between DI1 and DI2 treatments throughout the whole season during 2012 due to availability of sufficient rainfall amounts up to beginning of flowering stage. Variation observed in soil water status amongst the treatments during 2011 may be attributed to the less and infrequent rainfall. Soil moisture contents declined rapidly from the flowering stage to the yield formation in this area of high evaporation and high crop water requirements.

The seasonal ETc values for the different irrigation treatments ranged from 367.3 to 563.3 mm during 2011 and from 370.5 to 535.1 mm during 2012. The highest seasonal ETc was estimated in treatment FI owing to favourable soil moisture, whereas the lowest ETc was obtained from treatment DI1 with a water deficit (50% of ETc) during the whole growth stage (Table 2). The second highest seasonal ETc was attained in DI4 treatment for both experimental years. The outcome indicated that the watermelon utilized the soil water sufficiently, despite soil water stress as 50% applied at ripening stage. In one of the parallel study, Çamoğlu *et al*. (2010) found out that the seasonal ETc of full and deficit irrigated watermelon varied from 169 to 516 mm in Canakkale, Turkey. Özmen *et al*. (2015) indicated that seasonal ETc of grafted and non-grafted watermelon irrigated by drip system ranged between 433-521 mm in the Cukurova region of Turkey. The ETc values obtained by those field studies were in agreement with the ETc values of our study.

Fruit yield and quality: Soil water stress timing had a significant effect ($p \leq 0.001$) on marketable yield during both years of the experiment (Table 3). The DI strategies adversely affected marketable yield, hence in agreement with the findings of Erdem and Yuksel (2003). As expected, the highest yield throughout the whole irrigation season was attained at FI treatment which maintained the soil water level high for both experimental years and the DI4 treatment followed FI treatment in terms of yield level. Yield decrease occurred as 1.5 and 2.0% at DI4 treatment in comparison to FI treatment, whereas the save in irrigation water amount of DI4 treatment was as high as 8.4 and 12.3% in 2011 and 2012, respectively (Table 4). In previous studies, the highest yield of watermelon was attained at full irrigation conditions (Erdem *et al*., 2005; Ghawi and Battikhi, 2008). The lowest yield was observed at treatment DI2 in 2011, treatments of DI1 and DI2 in 2012 (no statistical difference at $p<0.05$ level). Variations of fruit yield between years may be associated with low rainfall amounts up to flowering stage during 2012 (Fig. 1). Yield loss with 29.5-33.5% at treatment with 50% DI level (50% of ETc) throughout the whole cropping season (Table 4). In similar studies, yield was found as 6.9-38.2 t ha^{-1} (Kirnak and Dogan, 2009) and 7.0-64.8 t ha^{-1} (Çamoğlu *et al*., 2010). The differences in yield in reported studies may be attributed to the difference of varieties, irrigation and fertilization practices, soil, and climate factors. For instance, Leskovar *et al*. (2003) reported that the yield was considerably changed in different varieties depend upon the applied irrigation water amount.

TSS was significantly ($p<0.001$) affected by soil water deficit (Table 3). The TSS was higher in the water-stressed plants. Relatively high TSS values were determined by DI1 and DI2 treatments for both experimental years. On the other hand, the lowest TSS values were obtained under full irrigation treatments during whole cropping season for both years. Erdem *et al*. (2001) reported that DI had generally little effect on the increase in TSS content of watermelon fruits because of cut-off irrigation about 20 days before picking of watermelon. Rouphael *et al*. (2008) who reported for grafted and ungrafted watermelon cultivars that DI based on ET rate did not significantly change the TSS. Wang *et al*. (2004) who reported the effects of supplemental irrigation on watermelon grown with and without surface mulch that there were no significant differences in the TSS among different irrigation levels while for the trials without mulch, TSS of the 45 and 68 mm irrigation applications was significantly lower than those of the 0 and 23mm. TSS values in this study is consistent with the values reported (7.3-10.7 ºBriks) in previous studies for watermelon (Çamoğlu *et al*., 2010; Turhan *et al*., 2012). Kaya *et al*. (2003) has defined relatively higher TSS values (10.5-12.6 ºBriks) in watermelon in a semi-arid environment of Turkey. This difference may be explained with the differences in variety and ecological conditions. Wang *et al*. (2004) found out that water soluble dry matter content increased with the increase at total sugar in fruit. Findings of our study justified that conclusion. In this study, the highest total sugar values were obtained from treatments of DI1 and DI2 for both experimental years (Table 3). The second highest total sugar content was observed at DI3 treatment and DI4 treatment followed it. The lowest total sugar values were seen under full irrigation treatment. In a parallel study; Erdem *et al*. (2001) have found similar results with our study in total sugar content (7.20-9.07%) for Crimson Sweet watermelon variety and they also defined that total sugar relatively increased at DI conditions.

Different irrigation treatments have had no effect on pH values of watermelon and the pH values varied from 5.27 to 5.47 for both experimental years (Table 3). Earlier watermelon studies also reported that pH was not affected by irrigation (Erdem and Yuksel, 2003; Proietti *et al*., 2008).

Watermelon is a natural source of lycopene and Vitamin C for its antioxidant properties. In this study, Vitamin C values were relatively changed during years (Table 3). The highest Vitamin C values were obtained from DI2 and DI3 treatments, whereas the full irrigation treatment (FI) produced the lowest Vitamin C. When the highest Vitamin C was found at DI3 treatment, the lowest value was realized at full irrigation treatment during 2012. There was no significant change statistically amongst Vitamin C values of DI1, DI2, and DI4 treatments during 2012. Lycopene contents were not affected by irrigation treatments during 2011 and the values were defined as 6.19-6.34 mg 100 g^{-1} in 2011 (Table 3). Relatively higher lycopene contents were observed at DI3, DI4, and FI treatments during 2012. In a similar field study, Proietti *et al*. (2008) have emphasized that the limitation with irrigation water has no significant effect on Vitamin C and lycopene content for mini-watermelon cultivars. Leskovar *et al*. (2003) reported that lycopene and vitamin C content did not change with DI at 0.75 ET and full irrigation. Since we have considered the different crop growth stages in determining the DI treatments, as light difference in Vitamin C and lycopene content compared to previous studies.

Water-yield relationship: The water-yield relationship is crucial for a successful water management and economic assessment. Figure 2 shows the relationship between the total water consumed by crop (SET) and marketable yield. The relationship was linear, showing that the yield increased with evapotranspiration. The linear equation ($MY = 0.198 [SET] + 3.709$) implies that a yield approximately 21 t ha^{-1} of marketable watermelon fruit will be obtained for every increment of 100 mm SET (Fig. 2). Several previous studies have also shown a linear relationship between MY and ET (Erdem *et al*., 2001; Kirnak and Dogan, 2009).

Water productivity: WUE and IWUE are key indicators that reveal the optimal use of water for plant production. The values of water use efficiency and irrigation water use efficiency are presented in Table 5. DI increased both WUE and IWUE. The highest values of WUE and IWUE were obtained from treatment DI2 during both years. These results are also comparable with the findings of Kirnak *et al*. (2009), who showed that limited irrigation in the ripening period considerably improved WUE. Although the WUE values (17.10-30.32 kg m^{-3}) reported by Erdem *et al*. (2001) were higher than the values of our study. Higher values obtained at aforementioned study may be attributed to the differences in yield values depending upon soil and climatic conditions.

Yield response factor: Figure 3 shows the crop yield response factor to water (ky), which relates relative yield decrease to relative evapotranspiration deficit. The ky was 1.01 for the total crop growing period (the pooled data from the two years), in agreement with the 1.10 reported for watermelon by Doorenbos and Kassam (1979), the 1.15 obtained by Şimşek *et al*. (2004) and the 1.00 recorded by Kirnak *et al*. (2009). The value of ky found in this study reveals that the relative yield decrease was nearly equal to the rate of evapotranspiration deficit.

Table 1. Characteristics of the upper soil layer (0–60 cm) of the experimental site.

Characteristic	Value
Sand (%)	23.70
Silt (%)	44.40
Clay (%)	31.90
pH (saturation)	7.80
Total N	0.18
Available P (P_2O_5 – kg ha^{-1})	85.00
Exchangeable K (K_2O – kg ha^{-1})	1280.00
Total calcareous (%)	7.50
Organic matter (%)	2.15
EC (1:2.5 – dS m^{-1})	0.45
Bulk density (g cm^{-3})	1.40
Field capacity at -0.03 MPa (g g^{-1} dry weight)	0.32
Permanent wilting point at -1.5 MPa (g g^{-1} dry weight)	0.20

Table 2. Irrigation water applied (IWA) and seasonal evapotranspiration (SETc) during two years of experiment.

Treatments	Description	IWA (mm)		SETc (mm)	
		2011	2012	2011	2012
FI	Irrigation at 100% Etc	486.1	429.0	563.3	535.1
DI1	Irrigation at 50% Etc	243.1	214.5	367.3	370.5
DI2	Irrigation at 100% ETc up to beginning of flowering then 50% ETc restoration	279.6	216.6	398.8	375.5
DI3	Irrigation at 100% ETcrop up to beginning of yield formation then 50% ETc restoration	370.9	298.3	489.1	451.2
DI4	Irrigation at 100% ETc up to beginning of ripening then 50% ETc restoration	445.1	376.1	552.3	514.0

Table 3. Marketable yield, total soluble solids, pH, total sugar, vitamin C and lycopene for the irrigation treatments in the experimental years.

Treatments	Marketable yield (t ha^{-1})	Total soluble solids (ºBrix)	pH	Total sugar (%)	Vitamin C (mg 100 g^{-1})	Lycopene (mg 100 g^{-1})
2011 year						
FI	86.2 a	8.85 d	5.43	7.84 d	7.21 d	6.22
DI1	57.3 e	11.37 a	5.47	8.94 a	7.65 b	6.19
DI2	61.1 d	11.43 a	5.33	8.74 ab	8.17 a	6.34
DI3	70.2 c	10.85 b	5.27	8.54 b	8.21 a	6.34
DI4	84.9 b	9.93 c	5.37	8.11 c	7.46 c	6.27
Significance	***	***	ns	***	***	ns
2012 year						
FI	86.9 a	8.82 d	5.47	7.75 d	7.30 c	6.27 ab
DI1	61.3 d	11.25 a	5.40	8.78 a	7.74 b	6.17 b
DI2	61.5 d	11.20 a	5.41	8.76 a	7.68 b	6.16 b
DI3	69.4 c	10.41 b	5.30	8.48 b	8.02 a	6.35 a
DI4	85.2 b	9.50 c	5.35	8.05 c	7.63 b	6.30 ab
Significance	***	***	ns	***	**	*

*, **, *** significant at $p \leq 0.05$, 0.01 and 0.001 level, respectively. ns: not significant at $p \leq 0.05$.

Table 4. Yield losses and irrigation water saving for the irrigation treatments during two years of experiment.

Irrigation treatment	Marketable yield losses (%)		Irrigation water saving (%)	
	2011	**2012**	**2011**	**2012**
FI	0	0	0	0
DI1	33.5	29.5	50.0	50.0
DI2	29.1	29.2	42.5	49.5
DI3	18.6	20.1	23.7	30.5
DI4	1.5	2.0	8.4	12.3

Table 5. Water use efficiency (WUE) and irrigation water use efficiency (IWUE) for the irrigation treatments in the two years of experiment.

Irrigation treatment	Water use efficiency (kg m^{-3})		Irrigation water use efficiency (kg m^{-3})	
	2011	2012	2011	2012
FI	15.33 b	16.24 b	17.73 d	20.23 d
DI1	15.38 b	16.58 a	19.07 c	22.67 c
DI2	15.59 a	16.55 a	23.53 a	28.57 a
DI3	14.35 c	15.38 c	18.93 c	23.27 b
DI4	15.32 b	16.37 b	21.83 b	28.40 a
Significance	***	***	***	***

*** significant at $p \leq 0.001$ level.

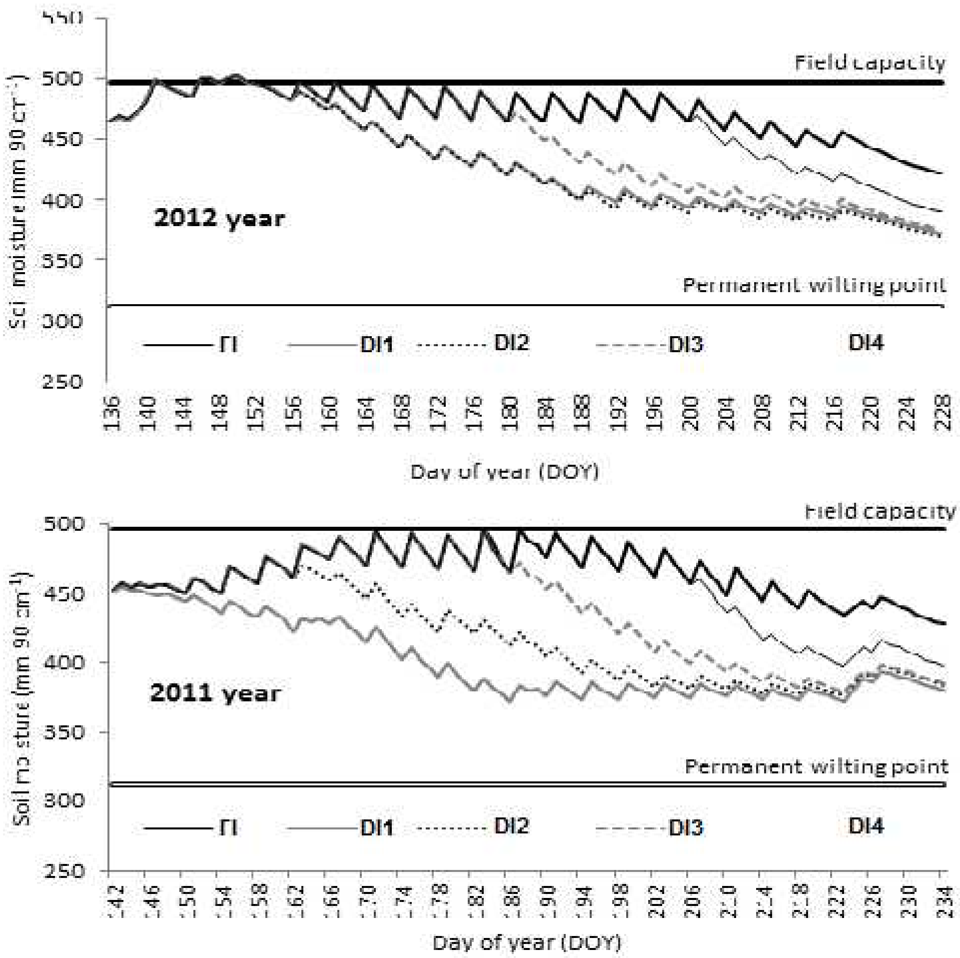

Figure 1. Seasonal variation of average soil water content in 0-0.9m depth for irrigation treatments (FI, DI1, DI2, DI3 and DI4).

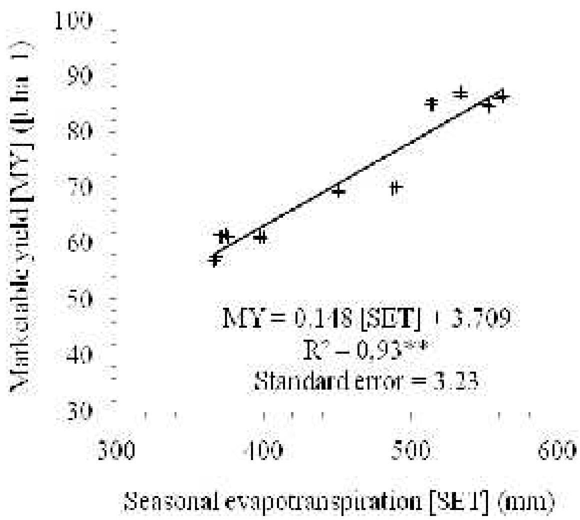

Figure 2. Marketable yield versus seasonal evapotranspiration for combined years (2011 and 2012). R^2: determination coefficient; **significance at the 1% probability level (P < 0.01).

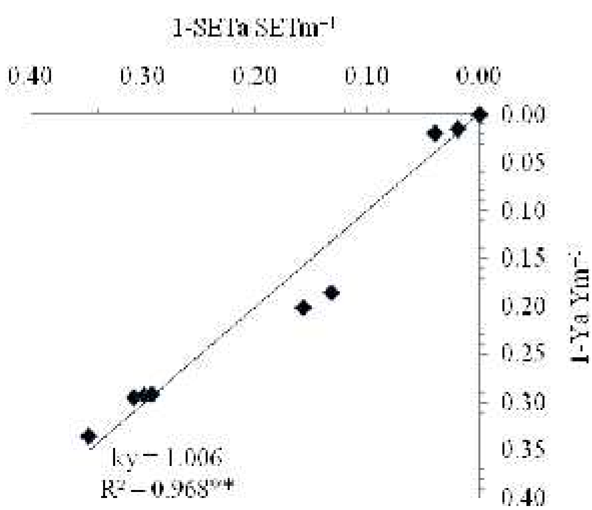

Figure 3. Relationship between relative yield decrease (1– Ya Ym^{-1}) and seasonal relative evapotranspiration deficit (1– SETa $SETm^{-1}$) for the two seasons' experiment data combined. R^2: determination coefficient; **significance at the 1% probability level.

Conclusion: The irrigation at 50% of evapotranspiration for the flowering or yield formation onwards could be recommended where water resources are scarce as savings up to 50% improved water productivity compared with full irrigation. The use of DI programs would be a useful tool in increasing quality parameters including total soluble solids, total sugar, and antioxidants (vitamin C and lycopene) of watermelon fruits.

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