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The Effects of Deficit Irrigation on Watermelon Yield, Water Use and Quality Characteristics

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Abstract: The effects of drip irrigation application amounts on watermelon (*Citrullus vulgaris,* c.v. Crimson Sweet) were evaluated under Thrace conditions. Irrigation amount treatments ranged from zero to 100 % of soil water replenishment in 25 % increments for whole growing season. Treatment T_1 in which irrigation water was adequately applied during the total growing season required 116.02 mm, 186.88 mm and 293.81 mm of irrigation water in 1998, 1999 and 2000, respectively. The seasonal evapotranspiration and total yield at this treatment were determined as 362.13 mm and 103.69 t/ha in 1998, 400.02 mm and 89.84 t/ha in 1999, 408.03 mm and 75.42 t/ha in 2000, respectively. For each differential water treatment, the parameters of fruit morphology (size, height and rind thickness), total soluble solids, total sugar, pH and total yield were analyzed. As a result it was found that yield and some yield components such as fruit height, rind thickness were affected by irrigation water amounts. But treatments had little or no effect on fruit size, total soluble solids, total sugar and pH. Irrigation water use efficiency (IWUE) and water use efficiency ranged from 24.31 to 197.89 kg/da-mm and 17.17 to 30.30 kg/da-mm, respectively.

Key words: *Citrullus vulgaris*, deficit irrigation, evapotranspiration, yield components, water use efficiency.

Introduction

The watermelon is one of the major crops produced in Thrace region, Turkey. The present production in Turkey is about 3.9 million tons of fruit from 146 000 ha. In the province of Tekirdağ in Thrace, annual fruit production is about 162 646 tons (Anonymous, 1996). The crop is generally grown under non-irrigated conditions and average yield is about 1.5 t/ha in the region. But, it is possible to increase production by well-timed irrigation during the whole growing season.

Watermelon and other cucurbits are grown during the warm seasons of the year and the values of consumptive water use (ET) of watermelon vary ranging from 400 to 600 mm (Doorenboss and Kassam, 1979). The range in ET is attributable to the irrigation levels used, climatic regions involved and length of growing season.

The region where precipitation and the soil water supply are limited such as Thrace region, most crops, including watermelon, respond positively to irrigation with respect to growth and yield. For watermelon, the amount and timing of irrigation are important for efficient use of applied water and for maximizing crop yields (Unger, 1990). With limited irrigation which does not fully replace soil water lost by evapotranspiration, yields are generally lower than with full irrigation, but water use efficiency (WUE) can be higher with limited irrigation (Unger, 1983).

Many studies have been reported on the irrigation of watermelon (Clark *et al.*, 1996; Srinivas *et al.*, 1989a; Andrade-Junior *et al.*, 1997; Clark and Maynard, 1996; El-Beheidi *et al.*, 1990; Çetin ve Nacar, 1997; Hegde, 1987; Lee *et al.*, 1995; Nerson *et al.*, 1994; Oliveira, 1992; Pascale *et al.*, 1998; Seo *et al.*, 1997; Sezgin *et al.*, 1997; Şenyiğit, 1998; Yadav *et al.*, 1989). The available information shows that fruit yield response to water is usually highest when watermelon is adequately irrigated.

The objective of this study was to determine the effect of irrigations on crop growth watermelon yield, the parameters of fruit morphology (size, height and rind thickness), total soluble solids, total sugar, and pH for drip-irrigated production. Also total water use, water use efficiency and relationships between water use and fruit yield were determined.

Materials and Methods

Field experiments on drip-irrigated watermelon were conducted in 1998 and 1999 at the research field of the Viticultural Research Institute of Tekirdağ, Turkey at 40-o59′ N latitude, 27°29′ E longitude and 4 m altitude.

Research field take part in semi-arid climatic region. The averages of annual temperature, relative humidity, wind speed, sunshine duration and total annual precipitation are 13.8 °C, 76 %, 3.1 m/s, 6.5 h and 575.4 mm, respectively (Anonymous, 1974).

The soils in the research fields are generally deep, heavy textured and well drained. There were no salinity and alkalinity problems. Irrigation water quality was analyzed as C_2S_1. Some physical characteristics of soils as field capacity, wilting point, available water holding capacity at the experimental site are presented in Table 1.

Seeds of watermelon (*Citrullus vulgaris,* c.v. Crimson Sweet) were planted 10-15 days prior to transplanting. Watermelon were transplanted on 30 May 1998, 12 May 1999 and 17 May 2000, and ripe fruits were harvested on 5 - 28 August 1998, 27 July - 11 August 1999 and 1 – 8 August 2000.

The experiment was arranged in a randomized complete block design with three replications. Each experimental plot took up an area of 19.2 m^2 and included 16 plants with 1.20 x 1.00 m^2 plant spacing. There is a blank of 3 m between the plots. Five irrigation treatments differing in irrigation rate were evaluated. Irrigation was applied when approximately 50 % of available soil moisture was consumed in the root zone at the control treatment (T_1). The measured soil moisture levels at T_1 treatment were used to initiate irrigation during the season. In treatments T_2, T_3, T_4 and T_5, irrigation was applied at rates of 75, 50, 25 and 0 % of T_1, respectively.

Soil water level was monitored in each plot by neutron probe (CPN, 503 DR Hydro probe) in 30-60 cm and 60-90 cm soil

Table 1: Some physical characteristics of soils at the experimental site

Year	Soil depth (cm)	Soil texture	Bulk density (g/cm^3)	Field Capacity (%)	Field Capacity (mm)	Wilting (%)	Wilting (mm)	Available water holding capacity (%)	Available water holding capacity (mm)
1998	0-30	C*	1.48	27.13	120.46	17.92	79.56	9.21	40.90
	30-60	C	1.51	27.57	124.89	18.10	81.99	9.47	42.90
	60-90	C	1.55	27.10	126.02	20.01	93.05	7.09	32.97
	90-120	C	1.58	27.90	132.25	21.02	99.64	6.88	32.61
	0-90				371.37		254.60		
	0-120				503.62		354.24		
1999 and 2000	0-30	C	1.60	27.07	129.94	16.34	78.43	10.73	51.51
	30-60	C	1.64	24.17	118.92	15.31	75.33	8.86	43.59
	60-90	C	1.58	23.62	111.96	15.97	75.70	7.65	36.26
	90-120	C	1.61	23.90	115.44	13.76	66.46	10.14	48.98
	0-90				360.82		229.46		131.36
	0-120				476.26		295.92		180.34

*Clay

Table 2: Water use factors of watermelon at different treatments and years

Year	Irrigation treatment (mm)	Soil water depletion (mm)	Rainfall (mm)	Irrigation water use (mm)	Seasonal ET (mm)	Water use efficiency (kg/da-mm)	Irrigation water use efficiency (kg/da-mm)
1998	T_1	179		116	362	28.65ab**	89.40b**
	T_2	174		88	329	27.75ab	103.70b
	T_3	165	67	61	293	30.32a	145.60ab
	T_4	179		33	279	23.24ab	196.50a
	T_5	153		-	220	21.28b	-
1999	T_1	153		187	400	22.46NS	48.04**
	T_2	146		140	346	22.11	54.64bc
	T_3	161	60.0	94	315	22.47	75.29b
	T_4	175		47	282	18.88	113.30a
	T_5	158		-	218	19.09	-
2000	T_1	63		294	409	18.44b**	25.65b**
	T_2	83		220	355	18.52	29.89b
	T_3	114	52	147	313	17.60	37.48b
	T_4	134		74	260	17.10	60.07a
	T_5	111		-	163	26.63	-

- ** Significant at 0.01 level. NS = Non significant

Table 3: Vegetative growth parameters, yield, and yield components data of watermelon at different treatments and year

Year	Irrigation treatment (mm)	Total yield (t/ha)	Fruit weight (kg)	Fruit Size (cm)	Fruit height (cm)	Rind thickness (cm)	Total soluble solids (%)	Total sugar (%)	pH
1998	T_1	103.7a**	6.22a**	68.05NS	39.60a**	1.36NS	9.40NS	8.19NS	5.92NS
	T_2	91.29ab	5.48ab	63.97	36.18a	1.43	9.60	8.89	5.93
	T_3	88.83ab	5.33ab	64.30	33.95ab	1.61	10.83	8.80	5.88
	T_4	64.83bc	3.89bc	65.46	26.78bc	1.45	9.67	8.64	5.70
	T_5	46.82c	2.81c	65.76	23.90c	1.70	10.23	9.07	5.82
1999	T_1	89.84a**	5.39a**	57.37b*	31.39a**	1.44ab**	9.79NS	7.51NS	5.37NS
	T_2	76.50ab	4.59ab	56.92b	27.71ab	1.19b	8.10	7.34	5.32
	T_3	70.77ab	4.24ab	60.22ab	26.74ab	1.50a	9.17	8.56	5.36
	T_4	53.25bc	3.20bc	62.10a	24.62ab	1.19ab	8.43	7.74	5.28
	T_5	41.62c	2.50c	59.73ab	22.55b	1.50a	9.00	8.21	5.34
2000	T_1	75.42a**	9.43a**	54.83NS	30.50NS	1.46a**	7.80b**	7.20b*	5.14NS
	T_2	65.76ab	8.22ab	56.00	31.52	1.44a	9.10ab	8.90a	5.30
	T_3	55.10abc	6.89abc	54.92	29.75	1.27a	9.10ab	8.30ab	5.31
	T_4	44.45bc	5.56bc	54.33	28.22	1.29a	9.60a	8.80a	5.46
	T_5	43.41c	5.43c	53.50	27.44	0.95b	10.00a	9.10a	5.44

*, ** Significant at 0.05 and 0.01 level, respectively. NS= Non-significant

layers during the whole growing season. Although calibration equations were obtained to every 15 cm soil layers, one equation was used, because there were no significant differences between them. Soil moisture content of the first 30 cm was measured gravimetrically (Evett *et al.*, 1993). The amount of soil moisture in 0.90 m depth was used to initiate irrigation, however, the values within 1.20 m depth were used to obtain the evapotranspiration of the crop. Evapotranspiration for ten - days periods were calculated according to the water balance method (Heerman, 1985).

The plots were irrigated by drip irrigation. The control unit was constituted of a screen filter with 10 L/s capacity, a pressure regulator to control and regulate the pressure in the system and manometers mounted inlet and outlet of each unit. Polythene tube was used for 63 mm (nominal diameter) main and 20 mm manifolds of the irrigation system. The laterals diameter were 20 mm PE and each lateral irrigated one plant row. Pressure compensating drippers were used to supply uniform water distribution. Dripper discharge rate was 4 L/h above 10 m operating pressure. Dripper and lateral spacing were chosen as 0.50 m and 1.20 m.

Watermelon fruits were harvested at marketable maturity and were then counted and individually weighed. Also, the parameters of fruit morphology (size, height and rind thickness) were measured. Two fruits were selected randomly for quality analysis from each replicate plot for all treatments on every harvest date. Those fruits were cut in half and piece of the core was used for soluble solids determinations with a hand-held refractometer. Total sugar in watermelon juice was determined by the Lane-Eynon method and pH was determined with pH meter (Anonymous, 1989). Water use efficiency was calculated by dividing fruit yield by water used. Data were analyzed seasonally with a regression analysis using yield and quality data and amount of irrigation input. Differences among means were established through use of the Duncan's multiple range test (MSTAT 3.0, Michigan State University, Michigan).

Results and Discussion

Total number of irrigations, total amount of irrigation water, the rainfall during whole growing periods and seasonal evapotranspiration for each treatment are presented in Table 2. Most of the irrigation water was applied in T_1, suggesting that the irrigation water applied was adequate to meet the full crop water requirements, as 116.02 mm (in 5 applications), 186.88 mm (in 7 applications) and 293.81 mm (in 10 applications) in 1998, 1999 and 2000, respectively. The number of irrigations and the amount of irrigation water applied in 1998 and 1999 were lower than those in 2000 because of different climatic conditions and residual water contents in the soil profile. Rainfall during the total growing period ranged from 52 - 67 mm in these years. The seasonal evapotranspiration in T_1 was maximum in three years, (362 mm in 1998, 400 mm in 1999 and 409 mm in 2000). Other treatments underwent water deficits and gave lower seasonal ET. The lowest ET occurred in treatment T_5, 220 mm in 1998, 218 mm in 1999 and 163 mm in 2000, because there was no irrigation and maximum water deficit in the root zone.

The seasonal evapotranspiration of watermelon was obtained by Eylen and Tok (1988) as 226 mm and by Şenyiğit (1998) as 361 mm in Çukurova, by Gündüz *et al.* (1997) as 560 mm and by Çetin and Nacar (1997) as 217-679 mm in Harran, by Sezgin *et al.* (1997) as 247-417 mm in Aydýn conditions. The results observed in this research are consistent with the ones given above.

Total fruit yields obtained from the experimental plots and their classification according to Duncan's Multiple Range Test is presented in Table 3 for the three respective years average. The variations between treatments were significantly different at 1 % ($p < 0.01$). At this confidence level, fruit yields are statistically classified into 4 groups in 1998 and 1999, and 5 groups in 2000. The highest fruit yield was obtained from T_1 treatment with 100 % irrigation as 103.7 t/ha, 89.84 t/ha, 75.42 t/ha and the lowest fruit yield was obtained from T_5 treatment with no irrigation as 46.82 t/ha, 41.62, 43.41 t/ha in 1998, 1999 and 2000, respectively. For the other treatments, they varied between these two. The drip irrigated watermelon fruit yields in this study are similar to others reported in the previous studies by Srinivas *et al.* (1989b); Srinivas *et al.* (1991); Clark and Maynard (1996); Pier and Doerge (1995); Lee *et al.* (1995); Clark and Maynard (1996); Andrade-Junior *et al.* (1997); Şenyiğit (1998).

While the deficit rates were 25 % (T_2), 50 % (T_3), 75 % (T_4) and 100 % (T_5) of T_1, the rates of decreases in average fruit yield for three years were found to be 13.2, 20, 39.6 and 51% of the T_1, respectively. Therefore, it was observed that the ratio of decreases in fruit yield for each percent of deficit rate was not constant.

Water use efficiency (fruit yield/seasonal evapotranspiration) and irrigation water use efficiency (fruit yield/total amount of irrigation water) for the growing season was calculated for all treatments (Table 2). The highest water use efficiency was found to be 30.32 kg/da-mm and 22.47 kg/da-mm in 1998 and 1999, respectively, in T_3 treatment and 26.63 kg/da-mm in 2000 in T_5. The difference between the treatments was not statistically significant in 1999. In 1998 and 2000, no significant difference was observed except water use efficiency value in T_5. This is probably because a great decrease in yield was seen in the first year of the experiment in T_5.

The irrigation water use efficiency (IWUE) in treatment T_4 was the maximum, as 196.50 kg/da-mm, 113.30 kg/da-mm and 60.07 kg/da-mm in 1998, 1999, 2000, respectively. Irrigation water use efficiencies were significantly different for the irrigation amounts ($p < 0.01$). A certain decrease in IWUE with increases in the amount of applied irrigation water was recorded as 89.40, 48.04 and 25.65 kg/da-mm in 1998, 1999 and 2000, respectively for T_1. Similar relationships were also obtained in other studies (Sirinivas *et al.*, 1989; Çetin and Nacar, 1997; Şenyiğit, 1998).

Fruit yield as a function of applied irrigation water and ET for the treatments are plotted in Fig. 1 and 2, respectively. Based on multiple regression analyses, fruit yield was best correlated with applied irrigation water and ET and the regression coefficients for the treatments were highly significant ($p < 0.01$). Evapotranspiration and total yield increased significantly with each increase in irrigation amount and the data are similar to that summarized by Senyiğit (1998) for watermelon under Çukurova conditions.

Watermelon quality parameters, namely were fruit yield, fruit size, fruit height and rind thickness, total soluble solids, total sugar and pH and results of variance analyses on the parameters are presented in Table 3 for each treatment in 1998, 1999 and 2000, respectively. It can be seen that, the highest and shortest fruit heights were obtained in treatments T_1 and T_5, respectively. In the first two years of the experiment, significant differences were observed between the treatments.

The deviation is attributed to different rates of limited irrigation water application.

Variance analyses for fruit size showed that, while there was no difference in 1998 and 2000, significant differences were found in 1999 between the treatments at 0.05 confidence

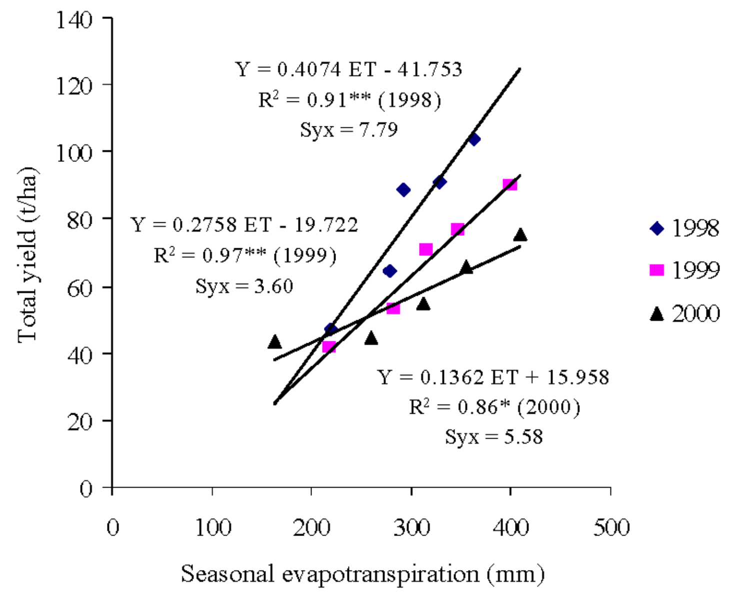

Fig. 1: Watermelon total fruit yield as related to irrigation water use

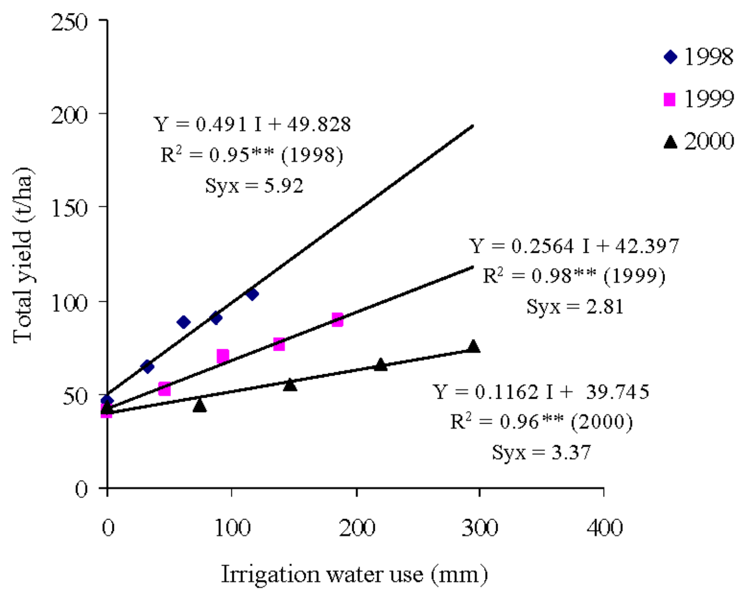

Fig. 2: Watermelon total fruit yield as related to seasonal evapotranspiration

level. In general, fruit size of Crimson Sweet (Starburst F1) variety does not vary significantly with different treatments since it grows into length with an oval shape rather than into size.

As for the rind thickness, statistically significant differences were found at 0.01 confidence level, between the treatments in the last two years. But the distribution was irregular according to Duncan's multiple range test. Therefore, the differences between the treatments are attributed to the soil, plant and environmental conditions, not to different water applications.

There was a significant difference between treatments ($P<0.0$) and ($P<0.05$) in 2000, for total soluble solids and total sugar contents, respectively. Irrigation amount generally did not affect total soluble solids and sugar contents of fruits except for 2000. These results can be attributed to stop irrigation about 20 days before picking of watermelon. Also, there was no significant difference in pH.

Results indicate that highly acceptable watermelon fruit yields and quality under drip irrigated conditions may be acquired in

Thrace region. Seasonal evapotranspiration and total fruit yield was consistent each year and averaged 390 mm and 89.65 t/ha with suggested treatment (T_1), respectively. Seasonally applied irrigation for T_1 treatment average 199 mm of three years. Fruit quality as measured by fruit size, total sugar content, total soluble solids and pH was generally not affected by irrigation treatment.

In addition, statistically significant differences and a linear relationship was determined between the fruit yield and applied irrigation water and measured crop water consumption. WUE, an index of efficient use of ET, was variable between treatments, whereas, IWUE, an index of efficient use of irrigation water, was highest with deficit irrigation.

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