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The Effect of Water Deficit on Yield and Yield Components of Sugar Beet

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Abstract: This study was conducted to determine the effect of different water levels on the sugar rate, sugar yield and root yield of sugar beet (*Beta vulgaris* L.) under Kahramanmaraş climatic conditions in the production season 1999-2000. A line source sprinkler irrigation system was used with 6 irrigation levels; I_1, I_2, I_3, I_4, I_5 and I_6. The sugar beet row adjacent to the lateral was denoted the most water applied level (I_1), and the most remote row from the lateral was denoted the least water applied level (I_6). The plant rows between levels I_1 and I_6 were taken as the deficit irrigation levels in variably decreasing amounts. In the first (1999) and second (2000) years of the experiment, the total amount of irrigation water applied in a season was 1232 mm in 1999 and 1331 mm in 2000, while the amounts of water consumed (Et) were 1446 mm and 1491 mm lively respect. For level I_1, sugar rates were 17.2% and 15.1%, sugar yields were 9870 kg ha^{-1} and 9420 kg ha^{-1}, and root yields were 57 360 kg ha^{-1} and 62 350 kg ha^{-1} in 1999 and 2000, respectively. Reductions in applied irrigation water increased sugar rates and reduced Et and root yield. For level I_6, the amount of irrigation water applied in a season was 298 mm and 429 mm, Et levels were 495 mm and 587 mm, sugar rates were 18.9% and 18.3%, sugar yields were 1820 kg ha^{-1} and 2050 kg ha^{-1}, and root yields were 9630 kg ha^{-1} and 11 210 kg ha^{-1} in 1999 and 2000, respectively. Irrigation water use efficiency (IWUE) and water use efficiency (WUE) levels for I_1 were 46.6 kg ha^{-1} mm^{-1} and 39.7 kg ha^{-1} mm^{-1} in 1999 and 46.8 kg ha^{-1} mm^{-1} and 418 kg ha^{-1} mm^{-1} in the 2000, respectively. Both IWUE and WUE values varied with the amount of applied irrigation water. The root yield increased as the applied irrigation water increased, and a linear relationship was found between these 2 parameters.

Key Words: Sugar beet, deficit irrigation, water consumption, line source sprinkler system

Su Kısıntısının Şeker Pancarı Verim ve Verim Bileşenlerine Etkisi

Özet: Bu çalışma Kahramanmaraş iklim koşulları altında 1999-2000 yıllarında oluşturulan farklı su seviyelerinin, şekerpancarı (*Beta vulgaris* L.) kök verimine, şeker verimine ve şeker oranına olan etkilerini araştırmak amacıyla yürütülmüştür. Bu nedenle, çizi kaynaklı (tekil lateral) yağmurlama sulama sistemi kullanılarak altı farklı sulama konusu oluşturulmuştur. Bunlar sırasıyla I_1, I_2, I_3, I_4, I_5 ve I_6 dır. Bu konulardan ıslatılan alan içerisinde laterale en yakın olan konu en çok su uygulanan (I_1), lateralden en uzak olan konu ise en az su uygulanan (I_6) konu olarak adlandırılmıştır. I_1 ve I_6 konuları arasında kalan diğer konular ise değişken olarak azalan miktarlarda kısıtlı sulama uygulanan konular olarak belirlenmiştir. Denemenin ilk yılı (1999) ve ikinci yılında (2000) sırasıyla uygulanan toplam sulama suyu miktarları 1232 mm ve 1331 mm, bitki su tüketimi (Et) 1446 mm ve 1491 mm, şeker oranı %17.2 ve %15.1, şeker verimi 9870 kg ha^{-1} ve 9420 kg ha^{-1} ve kök verimi ise 57 360 kg ha^{-1} ve 62 350 kg ha^{-1} olarak bulunmuştur. Uygulanan sulama suyu miktarındaki azalmalara bağlı olarak Et ve kök verimi azalırken şeker oranı artmıştır. Ciddi su kısıntısı olan konuda (I_6) yıllara göre uygulanan dönemsel sulama suyu miktarları 298 mm ve 429 mm, Et 495 mm ve 587 mm, şeker oranı %18.9 ve %18.3, şeker verimi 1820 kg ha^{-1} ve 2050 kg ha^{-1} ve kök verimi ise 9630 kg ha^{-1} ve 11 210 kg ha^{-1} olarak bulunmuştur. Maksimum sulama suyu kullanım etkinliği (IWUE) ve su kullanım etkinliği (WUE) değerleri sırasıyla I_1 konusunda 1999 yılında 46.6 kg ha^{-1} mm^{-1} 39.7 kg ha^{-1} mm^{-1}, 2000 yılında ise 46.8 kg ha^{-1} mm^{-1} ve 41.8 kg ha^{-1} mm^{-1} olarak bulunmuştur. IWUE ve WUE değerleri sulama suyu miktarına bağlı olarak değişmiştir. Uygulanan sulama suyu miktarı artarken kök miktarının arttığı ve bu iki parametre arasında önemli doğrusal bir ilişki olduğu belirlenmiştir.

Anahtar Sözcükler: Şeker pancarı, kısıtlı sulama, su tüketimi, çizi kaynaklı yağmurlama sistemi

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Introduction

Sugar beet is one of the most important crops in the Kahramanmaraş region of Turkey. The rate of sugar beet among all other crops in the region was about 30% in 1998, and the average sugar beet yield was 45 000 kg ha^{-1} (TÜRKŞEKER, 2001). Common irrigation methods practiced for sugar beet production are wild flooding, furrow and basin. In general, farmers overirrigate, resulting in high losses of water and low irrigation efficiencies, and thus creating drainage and salinity problems. The highest benefit per unit of applied water depends upon the effective use of water by preventing water losses. These can partly be prevented by using new irrigation techniques and by reduction of evapotranspiration. New irrigation techniques are the cutback furrow, surge furrow, and alternate furrow in surface irrigation, and the use of very precise techniques in pressured irrigation. Evapotranspiration can be reduced either by agricultural practices such as tillage and mulching or by changing irrigation programs. The reduction of evapotranspiration by changing irrigation programs can be managed by the application of deficit irrigation (Köksal et al., 2001). In this approach, plants were exposed to water deficit in an entire growing season or in some part of the season. The potential benefits of deficit irrigation derived from 3 factors: increased irrigation efficiency, and reduced irrigation costs and water opportunity costs (English et al., 1996)

Sucrose production from sugar beet depends on maximizing storage root growth over a long growing season. As root growth proceeds, there is a constant partitioning of sucrose to the roots, and thus the sucrose yield also increases throughout the season. To obtain a high yield and sugar rate in sugar beet (*Beta vulgaris* L.) production it is necessary to apply a suitable irrigation program together with appropriate agricultural measures. The sugar beet yield in particularly arid regions is closely related to the amount of water given to the crop and the rain received in a growing season (Scott and Jaggard, 1993). The increase in the sucrose concentration of fresh-weight root is due to a slower accumulation of water. The yields of sugar beet root and sucrose are closely related to crop Et (Dunham, 1995). Excess irrigation increased sugar beet yield, but quality and sugar rates decreased (Bilgin, 1992).

The objectives of the study were to investigate the effects of deficit irrigation on the sugar rate, sugar yield, and root yield of sugar beet and to suggest a suitable irrigation program to farmers in the region using the sprinkler irrigation system.

Materials and Methods

The experiment was conducted under semi-arid climatic conditions at the Ferhus Agricultural Experimental Station, Kahramanmaraş Sütçü Imam University, in 1999-2000. The physical and chemical properties of the soil in the research area are given in Table 1.

The soils in the region are heavily textured (C or CL) and structured. On the site, soil field capacity, wilting point, bulk density, salinity and pH were determined using methods given by Tüzüner (1990).

In 1999, the annual average temperature, total rainfall and relative humidity were 17.2 °C, 442.7 mm, and 56.5% the while in 2000 they were 17.0 °C, 680.3 mm and 61.5%, respectively. A large part of the total rainfall in these 2 years about 74% was received out of the growing season, and the rest in the growing season. Therefore, sugar beet was heavily dependent upon

Table 1. The physical and chemical properties of the soil.

Depth (cm)	Field capacity (Pw*)	Wilting point (Pw*)	Bulk density (g cm^{-3})	Texture	Salinity (ds m^{-1})	pH**	$CaCO_3$ (%)	P_2O_5 (kg ha^{-1})	K_2O (kg ha^{-1})
0-30	33.57	22.66	1.426	Clay-loam	1.015	8.03	1.50	41	648
30-60	36.28	26.23	1.568	Clay	1.015	7.90	12.1	26	475
60-90	26.00	16.38	1.785	Sandy-loam	0.984	7.94	19.0	11	291

*Pw: % water by volume, ** pH: in paste

irrigation in the growing season. Irrigation water was taken from the main channel of the Kahramanmaraş Kartalkaya Irrigation Scheme. Irrigation water quality was C_2S_1, which was appropriate for irrigation.

An experimental field with an area of 30 m x 28.8 m was planted with a 4 row planting machine at a 45 cm row spacing at 3 cm depth. Plants were thinned to 20 cm in rows on May 7, 1999, and May 30, 2000. Irrigation water was given to increase soil moisture content in the root depth up to the field capacity following thinning, and then the level irrigations were started. The first row on each side of the lateral and the fifth rows in each level were not used in the experimental analyses due to a consideration that the levels were affected by each other. A variety of seed, Fiona 98 (monogerm), grown widely in the region was planted on March 17 of the first year and on April 5 of the second year. Monogerm is the closed-capsule that contains a single seed has germination capability (İncekara, 1973). Fertilizer applications were based on the soil analysis recommendations. All level plots received the same amount of fertilizer. Fertilizer of 20-20-0 was applied (50 kg ha^{-1} N and 50 kg ha^{-1} P_2O_5 as pure matter) at a rate of 250 kg ha^{-1} at planting. At the first irrigation, the rest of the N was applied to the experimental plots in the form of urea $(CO(NH_2))_2$ at a level of 250 kg ha^{-1} added to the soil by a lister on June 17 of the first year and May 5 of the second year. Weeds were controlled manually and hoed whenever they appeared.

Irrigation water was applied by using a line-source sprinkler system, in which sprinkler heads with nozzle sizes of 4.5 x 4.8 mm were located 6.0 m apart on the lateral. The system was operated at 3 atm pressures in order to obtain an approximately linearly decreasing water distribution from the lateral to the wetted perimeter (Hanks et al., 1976). Six irrigation levels were considered in the experiment with 4 replications. The layout of the sugar beet irrigation experiment is shown schematically in Figure 1.

The effective root depth of sugar beet was taken as 90 cm (Güngör and Yıldırım, 1989). Soil water content in the root depth for every irrigation level was measured at 30 cm increments by the gravimetric sampling method, applied before each irrigation event on the plant row. Water was applied at 7 day intervals and the available soil water at a 90 cm depth of the adjacent plots (I) to the lateral was replenished to the field capacity. Other plots received irrigation water at the same frequency but in decreasing amounts.

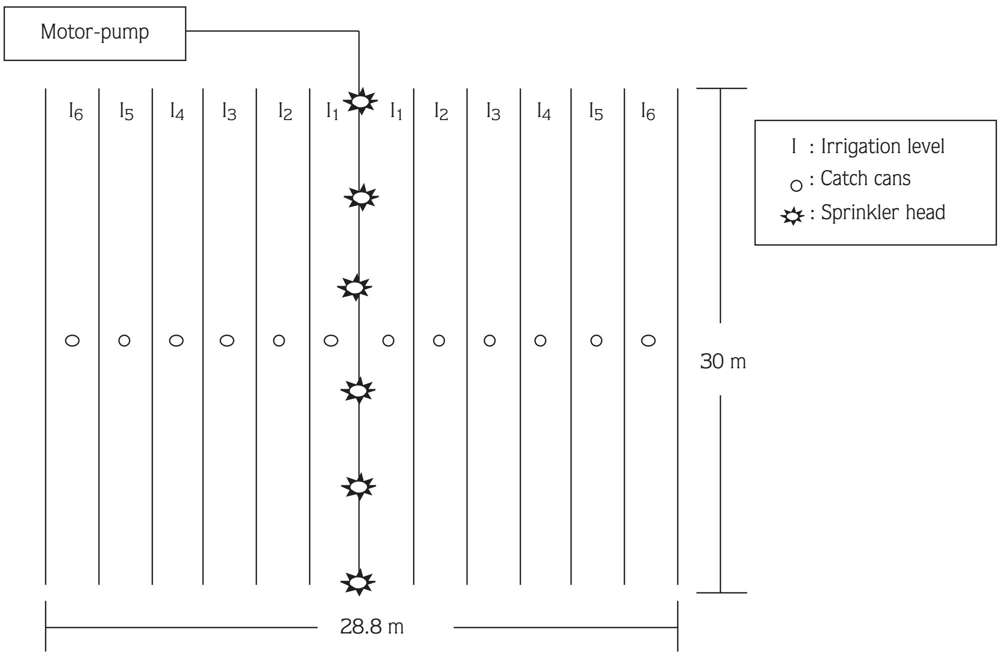

Figure 1. The layout of the sugar beet irrigation experiment.

The amount of irrigation water applied to each plot was determined by measuring the amount of water collected in the catch cans located at the center of each plot on both sides of the line source (Hanks et al., 1976). Crop evapotranspiration was estimated for each irrigation level by the following equation (Garrity et al., 1982):

$$Et = I + P - R \pm \Delta s - Dp$$

where Et is the crop evapotranspiration (mm), I is the irrigation water (mm), P is the rainfall (mm), R is the runoff (mm), Δs is the change of soil water content in the root depth, and Dp is the deep percolation. The runoff and deep percolation were assumed to be zero because water was applied in short durations to make the intensity of the sprinkler lower than or equal to the infiltration rate. Dikes were constructed between and around the plots to prevent runoff.

Water use efficiency (WUE) and irrigation water use efficiency (IWUE) were determined in order to gauge the effect of irrigation programs (Tanner and Sinclair, 1983). The equations are as follows:

$$WUE = Ey/Et$$

$$IWUE = Ey/I$$

where Ey is the economical root yield (kg ha^{-1}), Et is the seasonal evapotranspiration (mm), and I is the amount of irrigation water (mm).

The relationship between relative evapotranspiration deficit (1-Eta/Etm) and relative root yield reduction (1-Ya/Ym) was determined using the method given by Doorenbos and Kassam (1979):

$$1-(Ya/Ym)=ky(1-(Et/Etm))$$

where Ya is the actual sugar beet yield in kg ha^{-1}, Ym is the maximum sugar beet yield in kg ha^{-1}, ky is the crop response factor, Et is actual evapotranspiration and Etm is maximum evapotranspiration.

Two samples were taken from the second row of each plot in all levels every 15 days before irrigation to calculate the Leaf Area Index (LAI). A leaf area was determined by drawing the leaf shape on a piece of paper and measuring the area of that shape by digital planimeter. The LAI was determined by dividing the total leaf area of a plant into the area covered by that plant in the field (Güngör and Öğretir, 1980).

The sugar concentration was determined in the laboratory by polarimetry from the Elbistan Sugar Factory. The variance analysis of the yield was evaluated based on the randomized-block design (Efe et al., 2000).

Results and Discussion

The total irrigation water and seasonal Et are given in Table 2. Evaporation was higher in the second year of the experiment than in the first year because of higher air temperatures in the second year (Table 2).

Two pre-irrigations with 137 mm amount of water in the first year, and 5, pre-irrigations with 271 mm

Table 2. Amounts of irrigation water and seasonal Et.

	Months	May		June				July				August				Total irrig. water (mm)	Seasonal Et (mm)
	Irrigation levels	1	2	3	4	5	6	7	8	9	10	11	12	13	14		
1999	I_1	61	76	64	129	64	89	81	123	152	121	155	116	-	-	1232	1446
	I_2	61	76	70	95	52	85	62	101	74	116	139	87	-	-	1023	1236
	I_3	61	76	60	83	48	79	45	78	62	92	112	80	-	-	881	1093
	I_4	61	76	21	57	37	66	31	53	46	69	72	61	-	-	674	882
	I_5	61	76	23	24	16	44	29	49	42	43	45	41	-	-	493	698
	I_6	61	76	14	7	11	13	22	28	23	22	7	14	-	-	298	495
2000	I_1	59	46	61	59	46	85	89	96	115	125	129	135	134	132	1331	1491
	I_2	59	46	61	59	46	80	82	88	108	119	118	125	135	125	1241	1406
	I_3	59	46	61	59	46	76	64	75	88	96	101	108	115	114	1108	1278
	I_4	59	46	61	59	46	48	45	61	65	68	69	76	91	98	892	1056
	I_5	59	46	61	59	46	34	37	38	43	47	45	48	53	52	668	841
	I_6	59	46	61	59	46	18	10	15	16	18	17	19	22	21	429	587

I_1, I_2, I_3, I_4, I_5 and I_6: Irrigation water levels applied amount of water in the second year were applied in the whole field. Then the irrigation program was initiated. In this program, 10 irrigations with 1095 mm amount of water in the first year, and 9 irrigations with 1060 mm amount of water in the second year were applied. The highest (1232-1331 mm) and lowest (298-429 mm) levels of water were applied to levels of I_1 and I_6, respectively. Weeden (2000) noted that irrigation water was applied levels of between 500 and 1000 mm for production of sugar beet in areas like the USA, Egypt and Pakistan. Ehlig and LeMert (1979) reported that the amount of total seasonal irrigation water was 1195 mm in the wettest plot and 900 mm in the driest plot. The amount of irrigation water in our study was close to the amounts cited by the other researchers above.

Average seasonal evapotranspiration was 1469 mm for level I_1 and 541 mm for level I_6 in the experimental years. Seasonal water consumption of the irrigation levels varied according to the applied irrigation water depth. Jensen and Erie (1971) found that seasonal Et of sugar beet was between 450 and 1000 mm in semiarid regions. The sugar beet growing season is short in cold regions and seasonal water use is about 400 mm, whereas it is long in hot regions, and irrigated sugar beet can use up to 1500 mm of water (Dunham, 1995).

Sugar beet is a crop, which is affected by water deficit. Fluctuation in the yield showed itself to be related to the amount of water given. The sugar beet yields were the highest in irrigation level I_1 at 57 360 kg ha^{-1} and 62 350 kg ha^{-1}, and the lowest in level I_6 at 9630 kg ha^{-1} and 11 210 kg ha^{-1} in the corresponding years, respectively (Table 3). Tukey's test results showed that the root and sugar yields were significantly different ($P<0.05$) among the irrigation levels. The sugar rate was the opposite of the sugar beet root yields, increased with irrigation. Haddock (1959) has shown that water stress or irrigation levels may affect the sucrose content of sugar beet roots; however, this effect cannot be easily separated from the effect of nitrogen. Sucrose content may be improved, and yield reduced, where excess water leaches N from the soil early in the growing season (Hills et al., 1990).

The sugar rate varied between 17.2% and 18.9% in 1999 and between 15.1% and 18.3% in 2000 with regard to deficit irrigation. In earlier studies for Kahramanmaraş region, the sugar rate was 13.52% in 1999, and 13.07% in 2000 (TÜRKŞEKER, 2001). Hang and Miller (1986) found that sugar concentration in well watered crops rises steadily through the growing season, often leveling off before the harvest between 15 and 18% (g sugar per 100 g fresh roots). In water stressed crops it rises more quickly, and under severe stress conditions it can be 5% higher than in unstressed crops. In similar studies published by different researchers it has been postulated that irrigation increases the sugar rate. The same researchers have emphasized that the necessary conditions must be established for the development of the sugar industry (Weeden, 2000).

The relationships between the seasonal Et and root yield are shown in Figures 2 and 3. There were statistically significant relationships at the 0.05 probability level for the 2 years. Stewart and Hagan (1973) reported that there was a significant relationship between Et and yield, and that this relationship is linear. However, the relationship between the yield and applied water is not linear, but concave. In addition, Tekinel and

Table 3. Root yield, sugar rate, and sugar yield in levels.

Irrigation levels	1999			2000		
	Root yield (kg ha^{-1})	Sugar rate (%)	Sugar yield (kg ha^{-1})	Root yield (kg ha^{-1})	Sugar rate (%)	Sugar yield (kg ha^{-1})
I_1	57360a	17.2	9870a	62350a	15.1	9420a
I_2	45760a	16.7	7640ab	54320a	16.0	8690ab
I_3	39,420ab	17.8	7020ab	42,150ab	17.1	7210ab
I_4	34,420ab	18.6	6400ab	32150ab	17.4	5600ab
I_5	14,580ab	18.4	2680ab	18,150ab	18.0	3270ab
I_6	9630b	18.9	1820b	11,201b	18.3	2050b

I_1, I_2, I_3, I_4, I_5 and I_6: Irrigation water levels applied

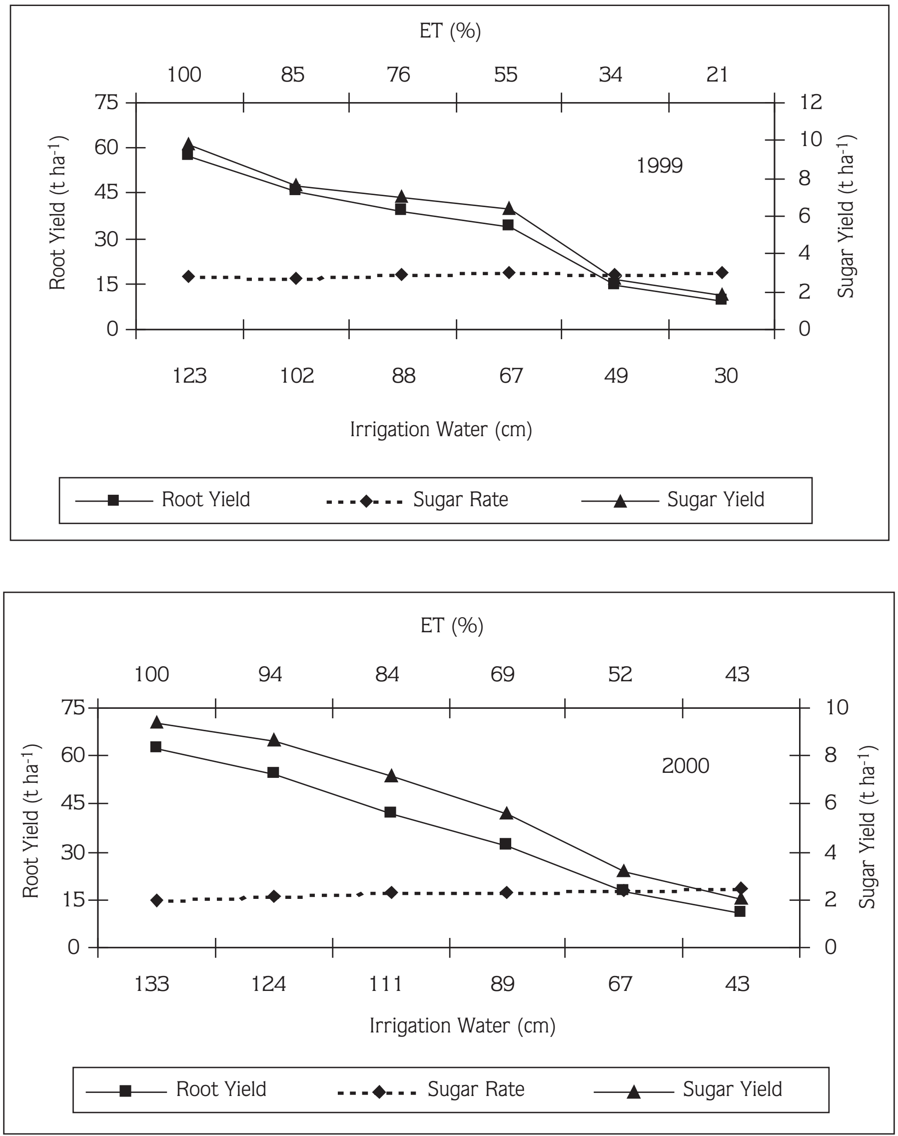

Figure 2. The root yield, sugar yield, and sugar rate as a function of water applied.

Kanber (1979) reported this relation to be curvy, and even sigmoidal. The results of our study (Figures 2 and 3) support the findings of other researchers as mentioned above.

In the experiment plots, water use efficiency (WUE) and irrigation water use efficiency (IWUE) are shown in Table 4. IWUE was higher than WUE in all levels and years because crop water consumption was higher than the irrigation water amount. The values of IWUE and WUE decreased in the levels from I_1 to I_6 in 1999 and 2000 because of the decrease in the applied water and yield.

Sepaskhah and Kamgar-Haghighi (1997) reported values for WUE of 19.1 and 52.1 kg ha^{-1} mm^{-1} using the every-other-furrow system in Iran. In a study conducted by Winter (1980) in Texas, the values for WUE and IWUE were 51.4 and 58.7 kg ha^{-1} mm^{-1}, and 44.0 and 63.0 kg ha^{-1} mm^{-1} for basin irrigation with different amounts of applied water.

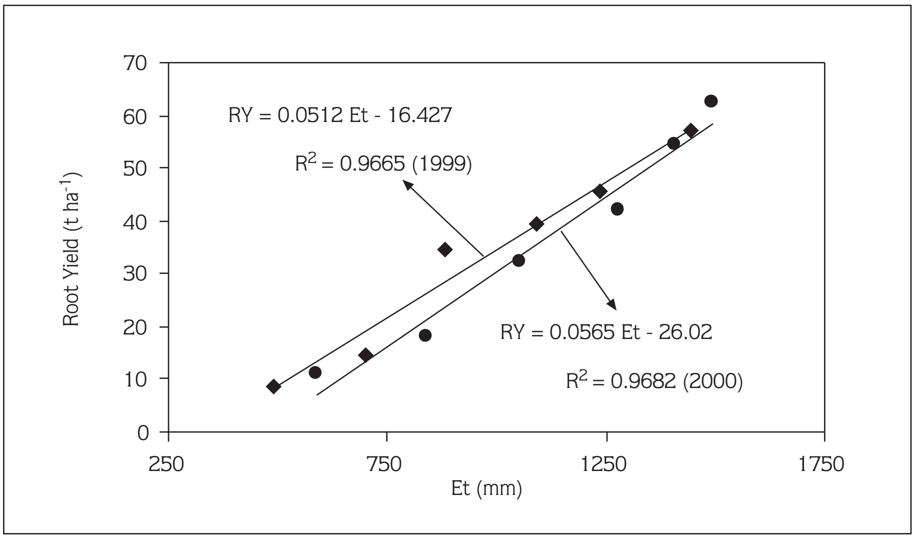

Figure 3. Relationship between irrigation water and yield.

Table 4. Water use efficiency (kg ha^{-1} mm^{-1})

Irrigation levels	1999		2000	
	WUE*	IWUE**	WUE*	IWUE**
I_1	39.7	46.6	41.8	46.8
I_2	37.0	44.7	38.6	43.8
I_3	36.1	44.8	33.0	38.0
I_4	27.7	36.2	30.4	36.1
I_5	20.9	29.6	21.6	27.2
I_6	19.5	32.3	19.1	26.1

*WUE: Water use efficiency, **IWUE: Irrigation water use efficiency

The results of our and other studies have shown that water use efficiencies in sugar beet varied due to the irrigation program, cultural applications, and regional conditions such as soil and climate. The greatest values for WUE and IWUE were observed in the levels with the highest yields, depending upon the irrigation water.

The crop response factor (ky), which is the slope of the relationship, was determined as 0.73 and 1.32 for the 2 years, respectively (Figure 4).

Application of the yield response factor (ky) for the planning, design and operation of irrigation projects allows quantifications of water supply and water use in terms of crop yield and total production for the project area. In different areas irrigated with furrows seasonal ky values were between 0.7 and 1.1 (Kodal, 1994). The ky was determined by Gençoğlan (1996), Doorenbos and Kassam (1979), and Yıldırım et al. (1995) as 1.23 (1.08 and 1.61), 1.25, and 0.94, respectively. Some differences in the ky of the response factor might be due to climatic changes, cultural practices, and irrigation methods and programs.

Periodic leaf area index (LAI) values were determined for the irrigation levels (Figure 5). The highest LAI value (average 1.7) was measured in level I_1, followed by the other irrigation levels. LAI values increased with increasing water use. Sugar beet plants reached their maximum LAI on July 7 in 1999 and on July 15 in 2000 for full irrigation levels (level I_1). Maximum leaf area for the stressed levels occurred approximately 1 or 2 weeks earlier compared to the full irrigation levels. Vegetative growth declined severely as water deficit increased.

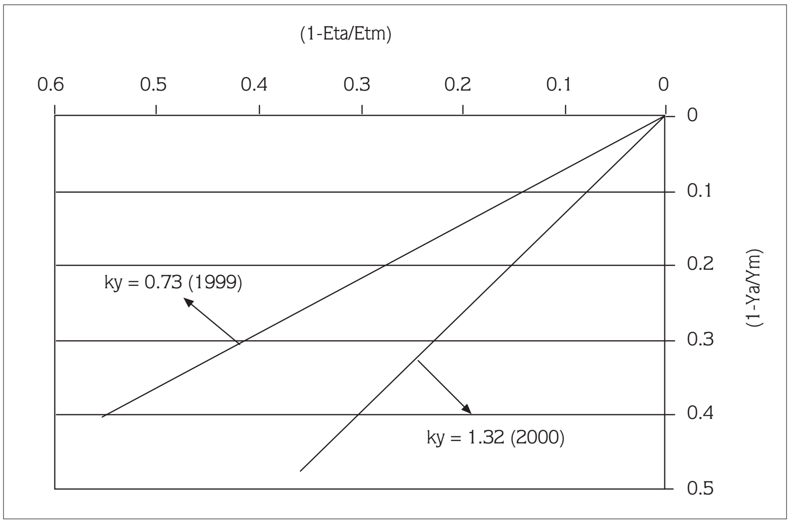

Figure 4. Relative yield reduction and relative Et deficit relationships.

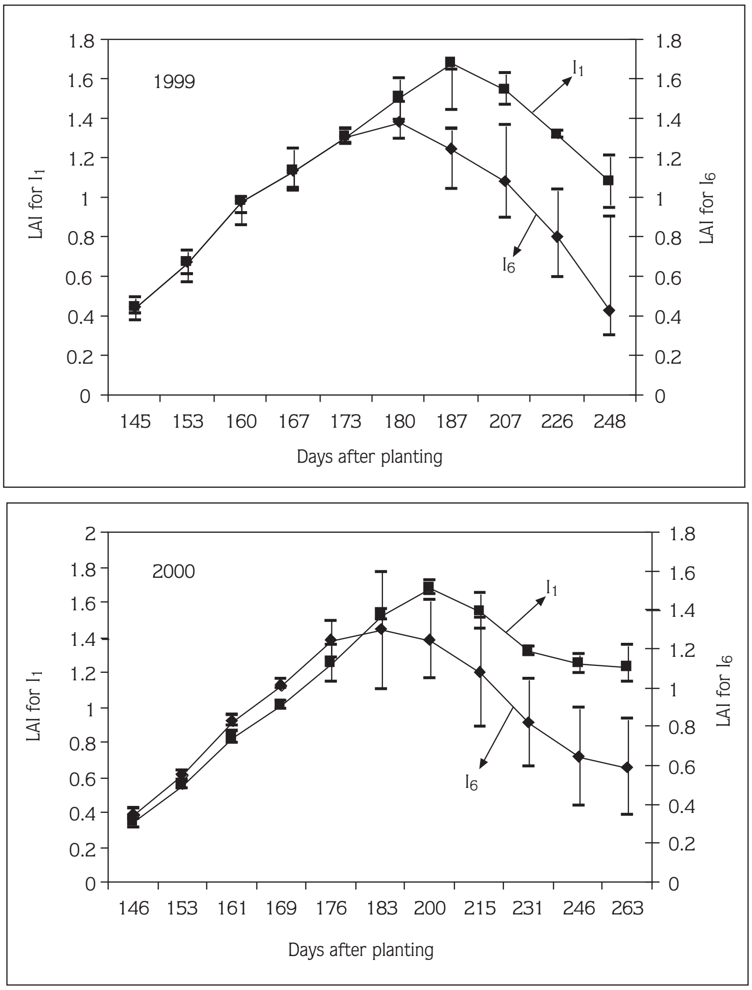

Figure 5. The leaf area index (LAI) development over time in 1999 and 2000 (The vertical lines refer to ±SE).

Conclusions

Variable amounts of water were applied to the sugar beet rows using a line source in the sprinkler irrigation method. The rows closer to the lateral received enough water, whereas the amount of applied water decreased as the distance from the lateral increased. The highest yield was obtained from level I, which was the closest to the lateral. The root yields in level I_1 increased by 30 and 38% when the yields of our study (57 360 and 62 350 kg ha^{-1}) were compared to the average yields (44 190 and 45 290 kg ha^{-1}) (TÜRKŞEKER, 2001) of the region for 1999 and 2000, respectively.

The sugar rates in level I_1 increased by 3.7 and 3.0% when the rates in our study (17.2 and 15.1%) were compared to the average rates (13.5 and 13.1) (TÜRKŞEKER, 2001) for the region. The sprinkler irrigation method can be recommended over the furrow and basin irrigation methods, which are commonly used for irrigation of sugar beet in the region.

The values for WUE (40.7 kg ha^{-1} mm^{-1}), IWUE (46.7 kg ha^{-1} mm^{-1}), and LAI (1.7) can be suggested for use in the planning of sprinkler irrigation for similar climate and soil conditions.

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