Soil water regimen of sugarbeet in reduced irrigation

S. DRAGOVIC, M. Cicmil, L. Radonjic, V. Radojevic
Institute of Field and Vegetable Crops, M. Gorkog 30, Novi Sad, Serbia and Montenegro
Tel. 381-21 4898170, Fax. 381-21 621212, E-mail: dragovic@ifvcns.ns.ac.yu

Abstract

In the main agricultural regions of Serbia and Montenegro, where the sum and distribution of rainfall are highly variable within a single year and from one year to another, irrigation is a supplementary practice. The average annual rainfall is 600 mm, with variations from 400-800 mm. Variations are also large during the growing season, especially in July and August, from 0 to 150 mm. In 70-90% of the years the rainfall in July and August does not meet sugarbeet requirement for water and irrigation becomes necessary.

A study has been conducted on a loamy soil which had favorable water-physical and chemical properties. The content of total nitrogen in soil layer 0-30 cm was 0.185%, i.e., below the sugarbeet requirement.

Sprinkling irrigation was scheduled on the basis of soil moisture measurements made with a neutron probe. The irrigation variants included: A_5 - 60 mm at soil moisture of 60-65% FWC, and variants with reduced amounts of water: A_4 - 45 mm (75% of the full rate), A_3 - 30 mm (50%) and A_2 - 15 mm (25%). Variant A_1, the control, was not irrigated.

Sugarbeet root yields varied with the amount and distribution of rainfall and air temperatures during growing season.

In irrigation, the highest average yield was obtained in variant A_3 - 112.96 t/ha. This yield was higher than those in variants A_1 (90.58 t/ha), A_2 (108.47 t/ha), A_4 (108.74 t/ha) and A_5 (102.57 t/ha) by 25.0%, 4.1%, 3.9% and 10.2%, respectively. The relatively low effects of irrigation were due to the relatively favorable rainfalls in the experiment years, resulting in high yields without irrigation. The highest yield in the experiment (137.94 t/ha) was obtained in 1996, in the variant with irrigation rate of 50%. This yield was higher by 46% than the yield obtained in the non-irrigated variant.

Key words: soil moisture, irrigation rate, weather conditions, sugarbeet yield, sugar content

Introduction

In the agricultural parts of Serbia and Montenegro, the amount of rainfall during growing season is often insufficient and unfavorably distributed for high yields and intensive crop production. Droughts of various intensities occur almost every year, and they are a limiting factor for achieving high yields.

Insufficient rainfall is particularly detrimental for sugarbeet, which is grown in Serbia and Montenegro at 70-80,000 ha for the country's 11 sugarbeet refineries. The sugarbeet is capable of synthesizing and accumulating considerable amounts of sugar. Under favorable conditions of soil moisture and fertility, it develops large leaf mass and a large storage root with a high percentage of sugar. The sugarbeet has a high water requirement because of its high production of organic matter per unit area. At the same time, it is a thrifty consumer of water. The well-developed root system takes up water from the depth of two meters. The sugarbeet has a high coefficient of soil water utilization, higher than most field crops (Dragovic and Panic, 1981). Depending on the conditions of growing, cultural practices applied, properties of genotype and yield level, sugarbeet water requirement ranges in Serbia and Montenegro from 500 mm to 600 mm (550 mm on average). Sugarbeet needs irrigation in order to achieve high yields, since its water requirement cannot be met solely by the rainfall during growing season and winter soil moisture reserves. The most critical period for water supply includes July and August - this period accounts for 40% to 50% of the total sugarbeet requirement for water. As the amount of rainfall during growing season is 350 to 450 mm, there regularly occurs a deficit of 100-200 mm, which may reach 300 mm in some years.

Because sugarbeet acreages in different regions are limited to suit the processing capacity of the nearest refinery, it is desirable to minimize yield variation and maximize yield level. In semihumid and semiarid conditions, only irrigation may ensure such production. The increase of sugarbeet yield by irrigation will depend on the weather conditions and the amount and distribution of rainfall during growing season. According to Maksimovic and Dragovic (2000), the average yield in a series of long-term field trials on irrigated chernozem was 76.7 t/ha, while the average yield without irrigation reached 59.8 t/ha. According to Panic and Dragovic, (1991) irrigation affected sugarbeet yield by 32.3% (17.8 t/ha), ranging between 5% (3 t/ha) and 98% (51.0 t/ha) in various years of the study.

Material and Method

Experiments with different irrigation norms were conducted on the loamy chernozem soil of favorable water-physical and chemical properties in the period 1996-1999 at the experiment field of Institute of Field and Vegetable Crops in Novi Sad.

The experiments included the following variants of soil water regimen:
A_1 - Non-irrigated control - 0 mm (0%)
A_2 - Irrigation rate 15 mm (25%)
A_3 - Irrigation rate 30 mm (50%)
A_4 - Irrigation rate 45 mm (75%)
A_5 - Irrigation rate 60 mm (100%)

Irrigation dates were scheduled after soil moisture analysis by a Troxler neutron probe - Model 4300. The probe was previously calibrated by the gravimetric method. The calibration curve was plotted on the basis of a large number of analyses (Figure 1). The curve had the form of linear regression and a high correlation coefficient (r = 0.99). Similar curves were plotted in previous studies of Dragovic (1983), with coefficient correlation r = 0.735, and Djorovic and Maksimovic (1993).

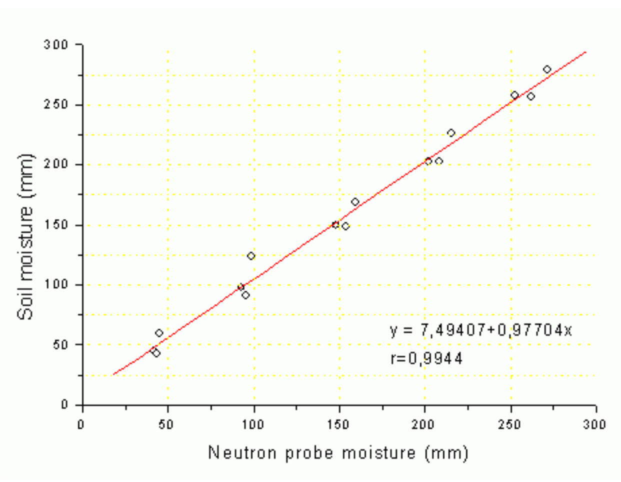

Figure 1 - Calibration curve for neutron probe measurements of soil moisture

The scheduling was done in the variant of 100% irrigation norm, at soil moisture of 60-65% of field water capacity (FWC). All variants were irrigated on the same dates. Sprinkling irrigation was used.

Calculation of nitrogen requirement to achieve the desired yield level took into account the content of NO_3-N in the soil, determined each spring at the beginning of sugarbeet growing season by the N-min method, and the rate of mineralization during growing season. The missing portion was added by nitrogen fertilization. Since the experiment was rotated each year, there were different contents of NO_3-N in the soil of the experiment plots and different amounts of nitrogen had to be added to achieve the target root yield of 120 t/ha. The following amounts of nitrogen were added: 175 kg/ha in 1996, 267 kg/ha in 1997, 170 kg/ha in 1998, 257 kg/ha in 1999.

The experiment included the sugarbeet variety NS-Dana developed at the Institute of Field and Vegetable Crops in Novi Sad. The sowing was performed in late March or early April, in the plant arrangement of 50 cm between rows and 20 cm in the row, with about 100,000 plants per hectare. Harvesting was performed in late October. Vegetation period was about 180 days.

Results

Weather conditions and water requirement of sugarbeet. Because of relatively favorable rainfall sums and distribution in all four years of the experiment, the effects of irrigation were not as high as they usually are in dry years. The high rainfalls and their favorable distribution were responsible for the negative effects of the high irrigation rates, regardless of the high sugarbeet requirement for water. This confirmed an earlier finding Vucic (1991), later corroborated by Dragovic (1994), that in conditions of high soil moisture sugarbeet plants tend to spend water unproductively, above the actual requirement.

The average rainfall sum for the four growing seasons (April-September) was 473 mm (from 416 to 521 mm), the average rainfall sum for July was 130 mm (from 85 to 192 mm) and for August 86 mm (from 28 to 124 mm). On the other hand, the long-term average rainfall for the growing season is 356 mm, the long-term average rainfall for July is 64 mm and for August 59 mm. Clearly, the four experiment years had the rainfalls above the average (Figure 2).

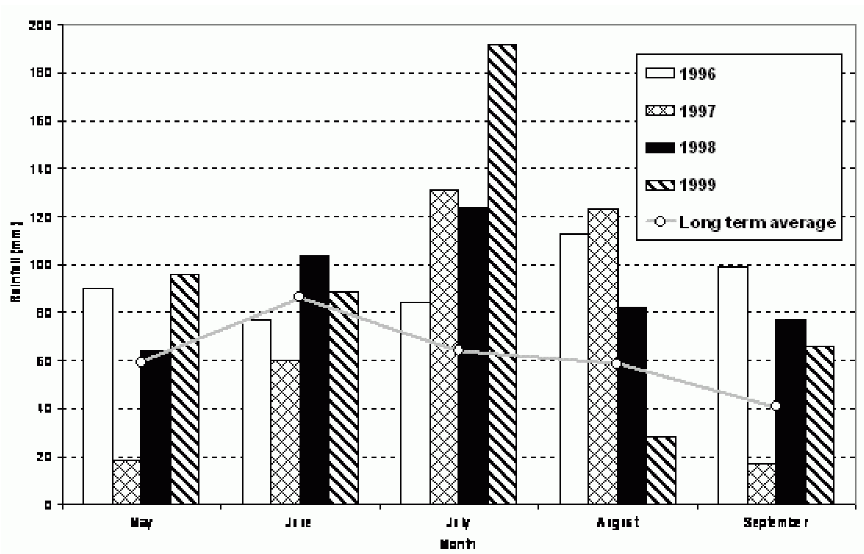

Figure 2 - Monthly and long-term average rainfall sums in the growing seasons

Table 1 shows the distribution of rainfall per month and per 10-day periods during the four growing seasons. Irrigations were performed in the periods with low rainfall (Table 2). In 1996, there were 11 mm of rain in the first 20 days of June and only 2 mm of rain in the first half of July, two irrigations were performed in these two months. In 1997, a period without rainfall occurred only in the second half of June and only one irrigation was needed. In 1998, low rainfalls occurred in the last 20 days of July and in the first half of August so that two irrigations had to be performed. In 1999, there were only 11 mm of rain in the last ten days of June and there were no rain at all at the beginning of July and one irrigation was needed. However, 74 mm of rain fell around the end of the first 10-day period of July and 106 mm in the third 10-period. After that, soil moisture to the depth of 60 cm remained well above 65% FWC and supplementary irrigation was not needed.

Table 1 –Total monthly and 10-day rainfall sums (mm) at Rimski Šančevi experiment field

Month	10-day period	Year				Long-term average (1964-1996)
		1996	1997	1998	1999	
Outside of the growing season		210	321	292	250	246
April	I	5	13	11	15	12
	II	15	4	23	7	19
	III	5	51	5	28	16
	Σ	25	68	39	50	47
May	I	16	10	36	26	18
	II	39	0	6	42	16
	III	35	7	20	28	25
	Σ	90	17	62	96	59
June	I	0	13	31	4	32
	II	11	47	47	74	30
	III	66	2	14	11	24
	Σ	77	62	92	89	86
July	I	2	50	53	74	24
	II	34	57	27	12	17
	III	49	21	34	106	23
	Σ	85	128	116	192	64
August	I	26	105	1	10	15
	II	58	3	12	15	17
	III	29	16	68	3	27
	Σ	113	124	81	28	59
September	I	51	1	24	33	14
	II	30	16	29	0	15
	III	18	0	23	33	11
	Σ	99	17	76	66	40
Growing season		489	416	466	521	356
Hydrologic year		699	737	758	771	602

Table 2 - Irrigation schedule and rates

Year	Date of irrigation	Variant			
		100%	75%	50%	25%
1996	15 June	60	45	30	15
	24 July	60	45	30	15
	Total	120	90	60	30
1997	05 July	60	45	30	15
1998	24 July	60	45	30	15
	13 August	60	45	30	15
	Total	120	90	60	30
1999	07 July	60	45	30	15

Root yield. Effects of irrigation on sugarbeet yield varied in dependence of weather conditions during growing season, soil moisture, cultural practices applied, etc.

The highest average yield in the experiment was obtained in variant A_3 (50% of the full rate) - 112.96 t/ha. This yield was significantly higher, by 22.38 t/ha or 25%, than the yield in the non-irrigated control. Further increases in irrigation rate caused gradual yield reductions. The yield obtained in variant A_4 (75% of the full rate) was 4% lower than that in variant A_3. The variant with the highest irrigation rate (A_5) yielded 10% less than variant A_3 (Table 3). This difference was highly significant. Marinkovic (1996) warned that application of large amounts of water might depress sugarbeet yield, especially in wet conditions.

Effect of irrigation differed in independence of rainfall and its distribution during growing season. The highest effect of irrigation on sugarbeet root yield was obtained in 1996 year with 50% irrigation rate (A_3), 137.94 t/ha. This yield was higher by 43.56 t/ha or 46% that the yield obtained in the non-irrigated variant. The difference was highly significant. The other irrigation variants (A_2, A_4 and A_5) had lower yields than variant A_3 by 1.7%, 1.3% and 14.2% respectively.

The lowest average yield as well as the lowest effect of irrigation were registered in 1999, when the total sum of rainfall during growing season (April-September) was 521 mm, 192 mm of that occurring in July alone. Furthermore, the sum of temperatures was 10 to 20% lower than in the other years. Compared against 1996, the 1999 average yield was lower by 42% and the effect of irrigation was lower by 2.5 times.

In May and June of 1997, the rainfall was below the sugarbeet requirement. The single irrigation that was performed still increased the root yield by 20%. The highest yields were achieved with irrigation rates of 75% and 100% (variants A_4 and A_5). These yields were similar and only marginally higher than that in variant A_3, without significant differences.

In 1998, the sum of rainfall met the sugarbeet requirement but the distribution of rainfall in July and August necessitated two irrigations to be performed. The average yield was 94.90 t/ha, which was lower by 32 and 16% than the average yields obtained in 1996 and 1997, respectively. The highest yield was obtained in variant A_3, 105.07 t/ha, the higher irrigation rates causing significant yield reductions. Variant A_3 outyielded the control variant A_1 by 23%.

Table 3 – Effect of soil water regimen on sugarbeet yields (t/ha)

Irrigation variant	1996	1997	1998	1999	Average
A_1 – Ø	94.38	96.67	85.22	86.06	90.58
A_2 – 25%	135.69	108.80	101.30	88.08	108.47
A_3 – 50%	137.94	114.59	105.07	94.25	112.96
A_4 – 75%	136.18	116.32	95.19	87.28	108.74
A_5 –100%	120.81	116.14	87.67	85.57	102.57
Average	125.00	110.50	94.90	88.27	104.66

LSD	0.05	7.75	4.59	4.06	5.24	5.41
	0.01	10.33	6.13	5.41	6.98	7.21

Numerous studies, conducted in Serbia and Montenegro and elsewhere in the world, have shown high effects of irrigation. Analyzing the effect in irrigation on sugarbeet yield on the basis of long-term data (1966-1995), Maksimovic and Dragovic (1996) found that the minimum and maximum yields were 39.9 and 74.1 t/ha, respectively, under rainfed conditions and 58.2 and 114.8 t/ha, respectively, under irrigated conditions. The average yield increase in irrigation was 29%, the actual increases varying in dependence of weather conditions from 4 to 98%. Other authors too have reported high effects of irrigation on sugarbeet yield. Jaggard and Glover (1996) reported an increase by 37%, Winter (1980) by 50%.

In extremely dry years, however, Dragovic (1994) has found increases of 64% in experiments and 76% in commercial production. On the other hand, the maintenance of high soil moisture throughout the growing season does not bring a proportional increase of sugarbeet yield, as reported in earlier studies (Panic et al., 1992; Maksimovic and Dragovic, 1994). Figure 3 shows that root yield increases to the irrigation rate of 50% of the full rate and after that it gradually goes down.

Yield variations among years are also due to sugarbeet diseases, which tend to intensify in rainy years, and low temperatures. Clover et al. (1998) stated that yields of sugarbeet vary from 85 t/ha (15 t of sugar) to 45-50 t/ha (7.5-8.0 t of sugar). A major reason for the difference is that the crops experience stress most commonly caused by disease or drought. In different growing regions in California, according to Hills et al. (1986), root yield averaged from 49 to 77 Mg·ha^{-1}, and sucrose contents from 14.1 to16.4%.

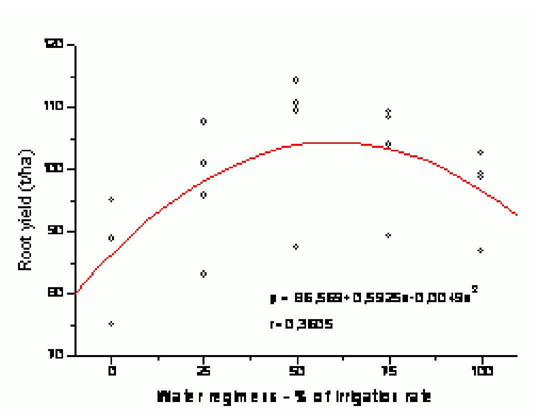

Figure 3 - Dependence of sugarbeet root yield on irrigation schedule and rate

Soil moisture determination. According to the research plan, soil moisture in the variant of 100% irrigation rate was maintained above the level of readily available water for plants (60-65% FWC). In the variants with reduced irrigation rates, soil moisture was supposed to be maintained below the level of available water (technical minimum). However, the favorable rainfalls in all experiment years made the values of soil moisture similar in all irrigation variants and in all years. Therefore, we shall present here only the 1998 results (Figure 4).

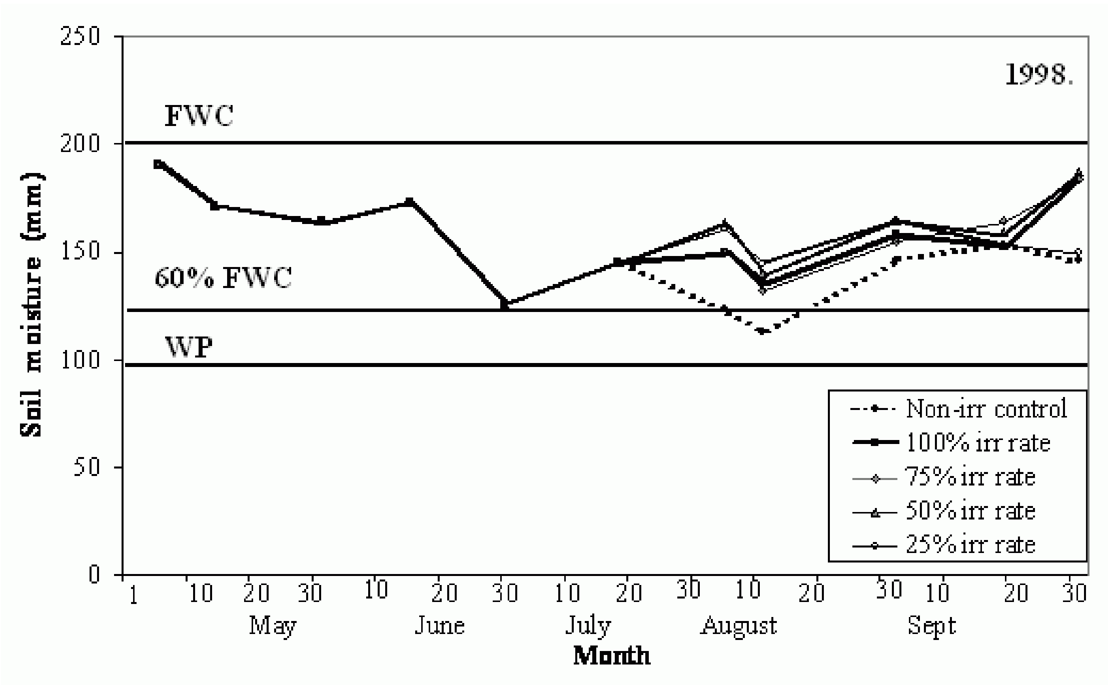

Figure 4 - Dynamics of soil moisture in the soil layer 0-60 cm in 1998

Sugar content. Sugar contents in sugarbeet roots differed per year and irrigation variant (Table 4). In 1999, the year with the highest rainfall sum and the lowest air temperature, sugar content was considerably lower than in the previous tree years, by 22.6; 24.4 and 4.9% respectively. Regarding the irrigation variants, the lowest sugar content was registered in the variant of 100% of irrigation rate. Sugar contents in the other irrigation variants were very similar.

Sugar content in the non-irrigated variant was higher than that in the variant of 100% of irrigation rate but it was similar to the contents in the other irrigation variants.

Table 4 - Sugar content in dependence of irrigation rate (%)

Irrigation variant	1996	1997	1998	1999	Average
A_1 – Ø	16.45	16.39	13.46	12.99	14.85
A_2 – 25%	15.00	14.94	14.08	12.60	14.15
A_3 – 50%	14.90	15.71	13.66	12.55	14.20
A_4 – 75%	16.02	16.01	12.26	12.57	14.21
A_5 –100%	14.77	15.33	12.66	12.31	13.77
Average	15.43	15.68	13.22	12.60	14.23

Conclusion

Under variable climatic conditions, with fluctuating rainfall, irrigation in experiments increased the yields of sugarbeet from 4 to 90%. In the years with relatively favorable sums and distributions of rainfall (1996-1999), the yields were 25% higher in the variant with the optimum soil water regimen than in the non-irrigated control.

The highest yield was obtained in variant A_3 (50%), 112.96 t/ha. The yield in the variant A_5 (100%) was lower by 10.39 t/ha or 10% than in A_3, and lower by 5.90 t/ha or 6% than in variant A_2 (25%). The root yield in the non-irrigated control, 90.58 t/ha, was below the yields obtained in the irrigated variants.

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