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Response of Sugarbeets to Irrigation Frequency and Cutoff on a Clay Loam Soil *

T. A. Howell [1], L. H. Ziska [2], R. L. McCormick [2], L. M. Burtch [3], and B. B. Fischer [4]

[1] USDA-ARS, Bushland, TX 79012, USA
[2] USDA-ARS, Bresno, CA 93747, USA
[3] Spreckles Sugar Division, Amstar Corp., Mendota, CA 93640, USA
[4] University of California Cooperative Extension Service, Fresno, CA 93721, USA

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Summary. Sugarbeets (*Beta vulgaris* L.) on a Panoche clay loam soil were subjected to 3 different irrigation frequencies and 3 irrigation cutoff dates prior to harvest to determine the effects on evapotranspiration, growth, and sucrose yield. Lengthening the irrigation interval from 1 to 3 weeks reduced evapotranspiration without a significant decline in sucrose production. Increased irrigation cutoff from 3 to 7 weeks prior to harvest significantly increased sucrose percentage within the root and resulted in similar total sucrose yields. Lengthening the irrigation interval only slightly reduced both fresh vegetative biomass and leaf area index (significant differences occurred only at one plant sampling date). The combination of less frequent irrigation and an early cutoff date increased the amount of soil water extracted by sugarbeets. The water use of sugarbeets can be reduced without a significant decline in sucrose production through optimizing irrigation frequency to about 14 to 20 days on this soil and cutting off irrigations about 40 to 45 days before harvest, provided irrigations replenish soil water depletions.

Increased costs of irrigation (water, energy, and labor) and other production inputs have reduced the economic return for sugarbeets grown under irrigated conditions in semi-arid environments. Irrigation management methods are required which maintain economic productivity while reducing the water use of sugarbeets. Irrigation techniques which increase water use efficiency while reducing yield may not be economically viable since savings in irrigation costs may not offset the reduced income of the harvested product. Since sugarbeets have certain characteristics which are favorable for drought tolerance (Winter 1980; Moraghan 1972; Erie and French 1968), the number of irrigations might be reduced over current irrigation practices while still maintaining a high sucrose production. In addition, withholding irrigation anywhere from 3 to 12 weeks prior to harvest while reducing

* Contribution from USDA, Agricultural Research Service, Water Management Res. Laboratory, 2021 S. Peach Avenue, Fresno, CA 93747, USA

root yield maintained sucrose production with a corresponding savings of irrigation water (Carter et al. 1980; Ferry et al. 1965; Loomis and Worker 1963). The combination of reduced number of irrigations with early irrigation cutoff prior to harvest may be an effective management technique. However, such a technique may result in reductions in yield if the induced water stress is too severe (Miller and Hang 1980).

The purpose of this study was to determine the effects of irrigation frequency and cutoff on sugarbeet growth, evapotranspiration, and sucrose accumulation on a clay loam soil for the semi-arid climate of California's San Joaquin Valley.

Materials and Methods

The experiment was conducted during the 1983 growing season at the University of California West Side Field Station, which is located on the western side of the San Joaquin Valley near Five Points, California. The soil is classified as Panoche clay loam, a member of the non-acidic family of Typic Torriorthents, which has a large available water holding capacity of 275 mm (for a 2.5 m profile) and minimal crop rooting interference. Specific soil physical characteristics of Panoche clay loam have been described previously by Grimes et al. (1975), Nielsen et al. (1973), and Nielsen et al. (1964).

Sugarbeet (*Beta vulgaris* L.) cultivar SS-E 1 (synonymous to US H-11) was planted on April 15. Following emergence on April 25, the plants were thinned to a population of 6.5 plants/m^2. Treflan* [2-6-dinitro-N, N-dipropyl-4-(trifluoromethyl)benzenamine] was incorporated into the soil 27 days after planting for weed control. Bayleton [1-(4-Chlorophenoxy)-3,3-dimethyl-2-(1H-1,2,4-dtriazol-1-yl)-2-butamone] was applied just prior to full cover to control powdery mildew. Ammonium nitrate was sidedress applied 28 days after planting at a rate of 112 kg of N/ha. Nitrogen fertilizer requirements were based on nitrogen prediction equations, as described by Carter et al. (1975), using preplant soil samples to a 0.9 m depth.

Since water stress during the early stages of growth may cause substantial yield decreases for sugarbeets (Martin 1983; Jensen and Erie 1971), the different irrigation frequencies were not imposed until 41 days (4 leaf stage) after planting. Prior to treatment initiation, the soil had been kept well watered. Three irrigation frequencies of 1 week, 2 weeks, and 3 weeks were used with each irrigation amount computed to refill the 2.5 m soil profile to field capacity. Irrigation was withheld 3, 5, and 7 weeks prior to the harvest date of October 6 for the 1 and 2 week irrigation frequencies. The 3 week irrigation frequency had the irrigations cutoff 3, 4, and 7 weeks prior to harvest. The 9 treatments (3 irrigation frequencies $\times$ 3 cutoff times) were arranged in a randomized block design, with each plot consisting of eight 0.76 m wide rows each 24 m long in a north-south direction. One row from both sides of each plot was maintained as a border row (2 border rows between adjacent plots) and was treated like the plot. Each treatment was replicated 4 times for a total of 36 plots. These treatments were selected since they encompassed the current practices utilized by many growers in the western San Joaquin Valley.

Gated pipe was used to apply the irrigation water to the "dead" level plots. Application rates were measured volumetrically. Furrows were bordered at the beginning and end of each plot to prevent runoff.

A neutron access tube was installed in the center of the bed in the fourth row of each plot on April 28, three days after emergence. The soil moisture was measured with a Troxler 2600 series depth-moisture probe, using 15 s counts and 0.3 m increments to a depth of 2.5 m. Soil moisture measurements were obtained the day before an irrigation to determine the amount of water needed to replenish the 2.5 m profile. Field capacity was determined by the measurement made 3 days following the pre-treatment irrigation and irrigation amounts were computed to bring the soil profile back to this level with each irrigation.

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* Mention of trade names implies no endorsement by either USDA-ARS, University of California, or Spreckles Sugar Co.

A microprocessor weather station (Howell et al. 1984) located in a grass plot at the UC-WSFS (about 0.4 km west of the experimental field) measured solar and net radiation, wind speed, vapor pressure, temperature, and precipitation. Evapotranspiration was calculated from the weather data (Doorenbos and Pruitt 1977) to verify water use amounts obtained from the neutron probe method once full canopy was established.

Plant sampling to determine growth characteristics began June 1 and continued every two weeks until July 11, after which samples were taken every 3 weeks until harvest. The center four plot rows were reserved for soil water measurements and final yield samples, and the adjacent row on each side of the center yield rows was used for plant sampling. The biweekly sample area was 0.5 m^2 for both roots and vegetative matter. After July 11, the sampling area was 0.76 m^2 for vegetative matter and 1.52 m^2 for roots. Fresh and dry weights for roots, leaves, and stems were determined. Leaf area was measured with a Li-Cor model 3100 optical integrating leaf area meter. The leaf area index (LAI) was computed based on a subsample (>0.5 m^2 leaf area) of specific leaf area (leaf area per unit dry leaf mass) from each plot times the total leaf dry matter for the plot. LAI measurements were not taken after August 22 due to deteriorating leaf quality. After July 11, Spreckles Sugar Company at Mendota, California, analyzed root samples for net clean mass, total percent sucrose, and root NO_3-N.

Final yield was determined by machine harvesting 4 rows in the center of each plot on October 6. Subsamples from each harvest row (4 subsamples/plot) were analyzed for total sucrose content, net clean mass (i.e. net mass = gross mass − crown − tare), and root NO_3-N. Gross harvest mass was measured by a basket scale on the harvester. The sugar yield was determined by the product of the net clean mass and the sucrose percentage.

Results and Discussion

Weather

The climatic conditions of the 1983 growing season were typical for the San Joaquin Valley, with near normal maximum temperature throughout the growing season. However, the minimum temperatures during July were about 3 °C below normal and, consequently, so was the daily average temperature. Sky conditions were typically "clear" for the San Joaquin Valley from mid-May to mid-August. The only rainfall which occurred after neutron tube installation was 10 mm from April 28 to May 4, and 46 mm on September 29 and 30. The rain in late September came just a week before harvest and most likely had no significant effects except to lower the sucrose percentage slightly and to improve the harvest operation in the drier treatments. Daily potential evapotranspiration (Doorenbos and Pruitt 1977) computed by the Penman combination equation illustrated a typical growing season pattern (Fig. 1), with maximum daily evapotranspiration seldom exceeding 11 mm.

Soil Moisture and Evapotranspiration

Seasonal ET for sugarbeets may vary from 450 mm for crops grown in the Northern Plains to over 1,000 mm for sugarbeets grown under semi-arid conditions in Arizona (Jensen and Erie 1971) according to climatic conditions and the length of the growing season. Water use and application amounts for the different irrigation treatments used in this experiment are given in Table 1. Treatments differed by a maximum of 327 mm and 195 mm for water applied and water used, respectively. The resulting mean soil water content for the total soil profile (2.5 m depth) during the season in response to the applied treatments is shown in Fig. 2 along with

Table 1. Applied water and water use for sugarbeets in response to irrigation frequency and cutoff

Irrigation frequency	Irrigation cutoff	Total water applied[1]	Total water used[2]	Soil moisture extraction[3]
weeks		mm		
1	3	1206	1138 a[4]	−68 a
	5	1079	1064 ab	−15 ab
	7	975	1014 bc	39 b
	Mean	1087	1072 B	−15 A
2	3	1116	1080 a	−36 a
	5	989	1012 bc	23 b
	7	888	943 c	55 bc
	Mean	998	1012 A	14 A
3	3	1006	1045 b	39 b
	4	981	1021 b	40 b
	7	879	978 bc	99 c
	Mean	955	1055 A	59 B
Mean	3	1109	1088 c	−27 a
	5*	1016	1032 b	26 a
	7	914	978 a	64 b
	Mean	1013	1033	23

[1] Includes 200 mm of irrigation prior to initiation of irrigation treatments on May 27 and 56 mm of seasonal rain
[2] Total of soil moisture extraction and applied water
[3] Differences in 2.5 m soil profile water content from April 28 to October 5
[4] Different letters within the same column indicate treatment differences at the 5% level (Duncan's Multiple Range Test)
* Nominal 5-week cutoff average

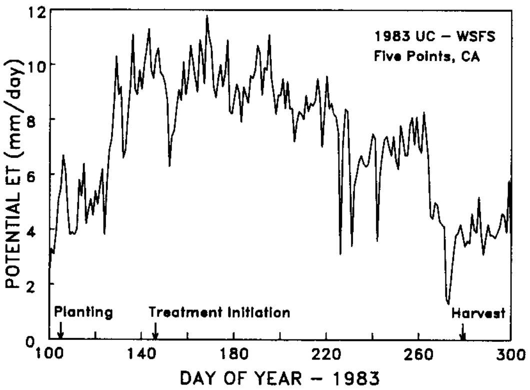

Fig. 1. Daily potential evapotranspiration rates as estimated by the Penman combination equation (Doorenbos and Pruitt 1977) for the sugarbeet growing season at the University of California, West Side Field Station, located near Five Points, CA

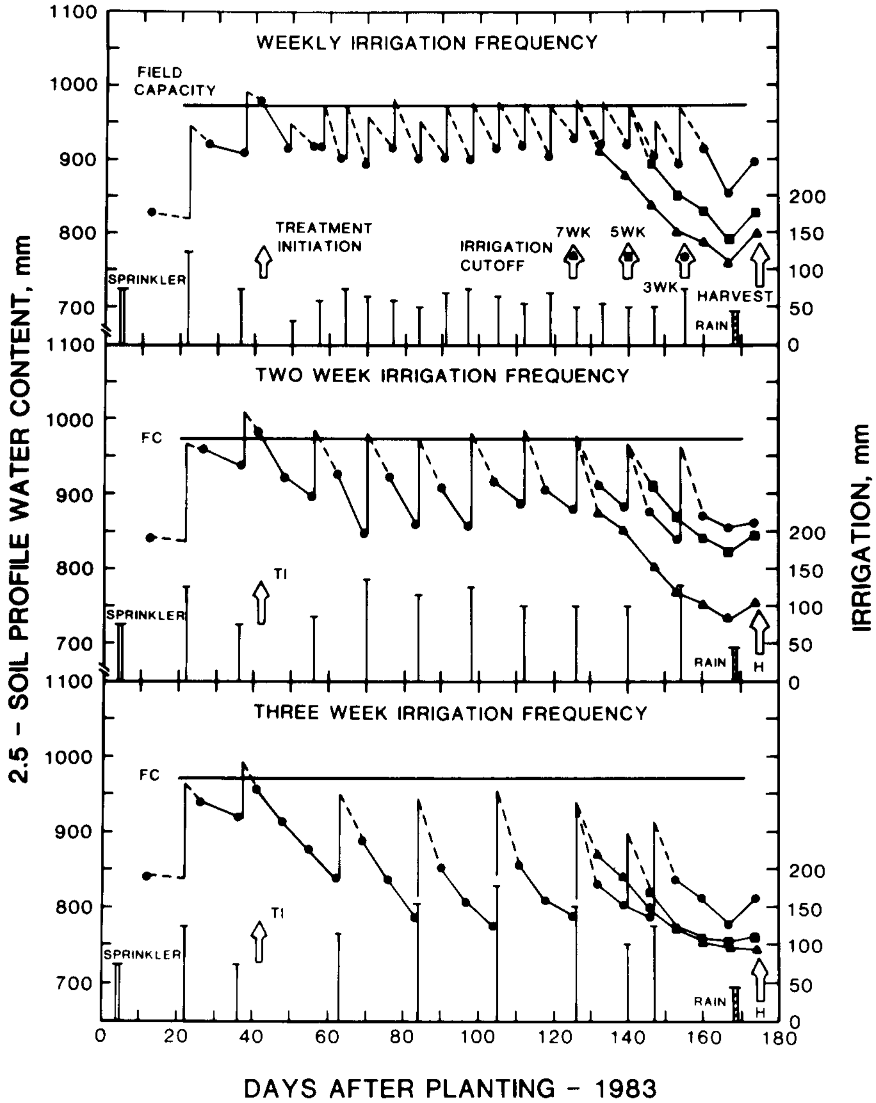

Fig. 2. Profile soil water content to a depth of 2.5 m in response to 3 irrigation treatments and 3 irrigation cutoff dates. Irrigation dates and amounts are also shown

irrigation dates and amounts. The irrigation frequency treatments allowed depletions of approximately 25, 45, and 60 percent of the total extractable soil water (275 mm for the 2.5 m profile) for the 1-, 2-, and 3-week irrigation frequencies, respectively (Fig. 2).

Soil moisture extraction increased as the irrigation duration increased to 2 or 3 weeks and also with earlier cutoff. Previous work by Jensen and Erie (1971), Bauer et al. (1975), and Martin (1983) has shown that sugarbeet rooting depth was between 1.5 and 2.0 m for a normal growing season. The depth at which soil water

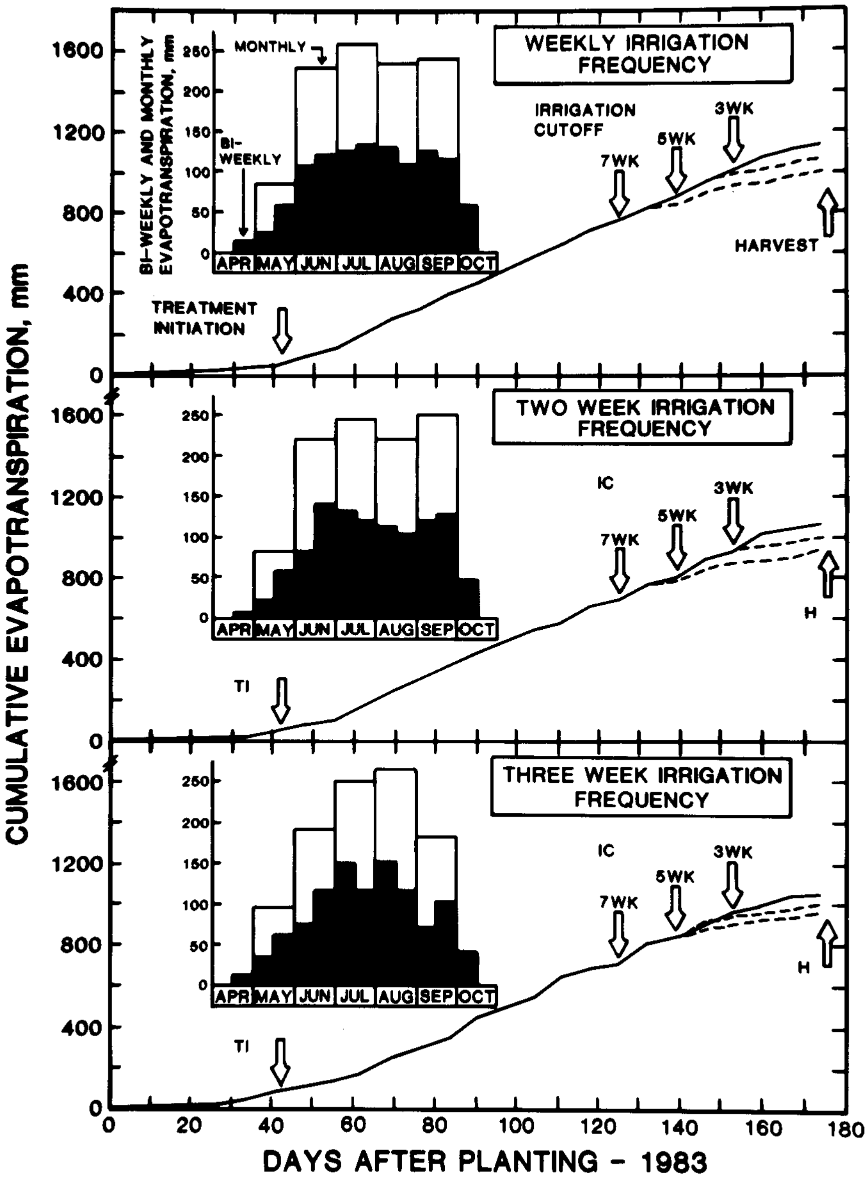

Fig. 3. Cumulative evapotranspiration of 3 irrigation frequencies as a response of irrigation frequency and irrigation cutoff for sugarbeets

was extracted in this soil was 2.25 m, regardless of the irrigation treatment. However, earlier cutoff or less frequent irrigation increased the quantity of water extracted from the profile (Table 1). Although water extraction did reach 2.25 m, the majority of the water used (95%) came from above 2.0 m.

The irrigation interval only slightly affected ET prior to irrigation cutoff. The time interval between a 2- or 3-week irrigation caused a small reduction in ET for

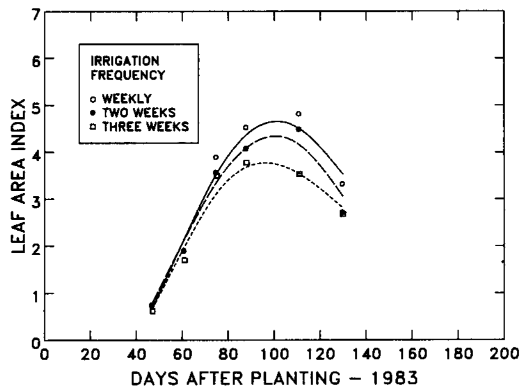

Fig. 4. Average leaf area index during the season for sugarbeets irrigated at frequencies of 1, 2, and 3 weeks

those weeks in which irrigation did not occur due to a slight water stress (Fig. 3). Irrigation cutoff 7 weeks prior to harvest reduced evapotranspiration for the weekly and 2-week irrigation intervals before it affected the evapotranspiration of the 3-week irrigation frequency. Less frequent irrigation may provide for acclimation effects which prevent early onset of water stress.

The measured evapotranspiration of the sugarbeets approached the calculated "potential" evapotranspiration (Doorenbos and Pruitt 1977) at 80 days after planting and remained slightly above (by 10 to 15%) the potential rates until 130 days after planting. The measured water use rate dropped below the calculated potential rate approximately 40 days before harvest.

Plant Growth

A leaf area index (LAI) between 3 and 4 (Fig. 4) was achieved approximately 70 days after planting for the different irrigation frequencies. Full ground cover for all irrigation frequencies occurred at approximately the same date. Treatment differences in LAI began to appear approximately 80 days after planting (Fig. 4), but a significant difference (0.05 level) between a weekly interval and a 3-week irrigation frequency only occurred at 111 days after planting.

Although there was a slight difference in total fresh biomass for the irrigation frequencies during the season (Fig. 5), the only significant difference (0.05 level) occurred at 111 days after planting. The mass of fresh root produced remained approximately the same for the frequency treatments, but a significant difference (0.05 level) occurred at harvest (185 days after planting). This indicated that once full cover was reached, the amount of net photosynthate being translocated to the root was rather insensitive to irrigation frequency and the slight reduction in LAI (Fig. 4). Although total fresh biomass peaked at about 130 days after planting, net root yield continued to increase. This has been identified as the stage of growth where canopy growth rate approaches zero or even declines, while root growth rate is maximum (Martin 1983).

An increase in dry matter throughout the growing season was noted for all irrigation frequencies for both total biomass and root biomass (Fig. 6). No significant differences (0.05 level) were detected for any of the different irrigation

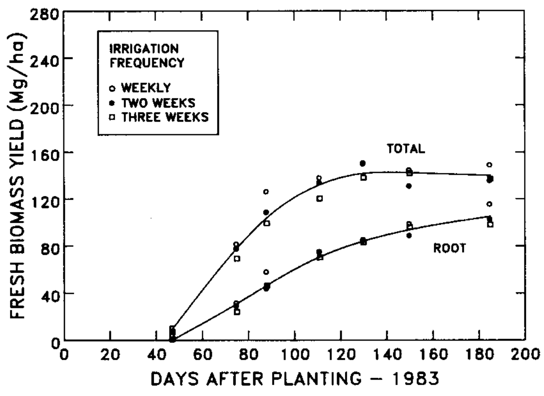

Fig. 5. Average fresh yield for both total and root biomass over the season for sugarbeets irrigated at 1-, 2-, and 3-week frequencies

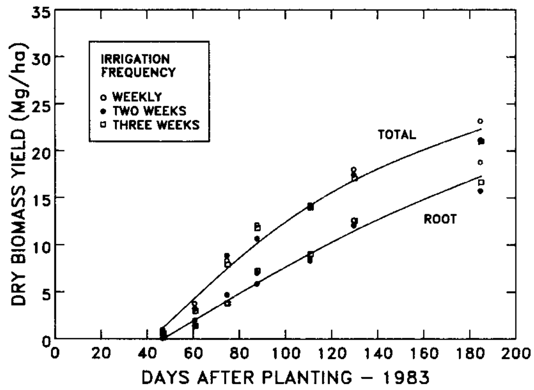

Fig. 6. Average dry yield for both total and root biomass over the season for sugarbeets irrigated at 1-, 2-, and 3-week frequencies

frequencies for either total or root biomass during the season. The proportion of total dry matter in the roots at the last sampling date was higher for a 7-week cutoff (16.1%) than a 5-week (15.7%) or 3-week (14.6%) cutoff date, irrespective of irrigation frequency.

Yield and Evapotranspiration

Net root, percent total sucrose, and sucrose yield for the different irrigation treatments and cutoff dates are presented in Table 2. Yields are similar to those reported by Pruitt et al. (1983) and Loomis and Haddock (1967) at Davis, CA, and Ferry et al. (1965) for Kern County in the southern San Joaquin Valley. The 3-week irrigation interval and 7-week irrigation cutoff date by themselves had no significant effect on sucrose yield (Table 2). A 3-week irrigation interval reduced net root yield a small amount, possibly due to water stress effects on assimilate transfer to the root. The 7-week cutoff had a significant effect on increasing sucrose percentage within the root (Table 2). This increased sucrose percentage was probably due to the reduced moisture content of the roots (Ferry et al. 1965; Carter et al. 1980).

The relationships of several growth parameters to seasonal water use are given in Table 3. They are similar to those obtained by Pruitt et al. (1983). Differences in

Table 2. Yield components and water use efficiency for sugarbeet in response to irrigation frequency and cutoff

Irrigation frequency	Irrigation cutoff	Net root yield Mg/ha	Percent total sucrose %	Sucrose yield Mg/ha	Sucrose water use efficiency kg/m³
weeks					
1	3	74.6 a[1]	11.3 ab	8.41 ab	7.4 a
	5	72.8 a	11.5 abc	8.40 ab	7.9 ab
	7	72.6 a	12.0 bcd	8.71 b	8.4 ab
	Mean	73.3 A	11.6 A	8.51 A	7.9 A
2	3	75.0 a	11.0 a	8.22 ab	7.4 a
	5	72.0 a	11.6 bc	8.36 ab	8.3 ab
	7	72.6 a	11.3 ab	8.27 ab	8.8 b
	Mean	72.3 A	11.3 A	8.28 A	8.2 A
3	3	70.0 a	11.3 ab	7.89 a	7.6 ab
	4	70.0 a	11.1 ab	7.80 a	7.6 ab
	7	70.4 a	12.2 d	8.59 b	8.8 b
	Mean	70.1 B	11.5 A	8.09 A	8.0 A
Mean	3	73.2 A	11.2 A	8.17 A	7.5 A
	5*	71.6 A	11.4 A	8.19 A	7.9 A
	7	71.9 A	11.9 B	8.52 A	8.7 B
	Mean	72.2	11.5	8.29	8.0

1 Different letters within the same column indicate treatment differences at the 5% level (Duncan's Multiple Range Test)

* Nominal 5-week cutoff average

growth are nearly proportional to evapotranspiration differences of the various treatments on this type of soil (except total fresh biomass which was nonlinear). The relationship of fresh root yield to evapotranspiration was similar to data obtained at other sugarbeet growing sites in the Western United States (Hanks et al. 1983). Both dry root biomass and sucrose yield were highly correlated (0.01 level) to cumulative evapotranspiration.

The highest water use efficiency (8.8 kg/m³ sucrose yield/ET) was obtained with either a 2- or 3-week irrigation interval and a 7-week cutoff date prior to harvest (Table 2). Water use efficiency was influenced more by irrigation cutoff than irrigation frequency. The lowest water use efficiency was obtained with a 1- or 2-week irrigation interval and a late cutoff of 3 weeks.

Conclusions

A 3-week irrigation interval on a deep clay loam soil did not substantially reduce growth or yield of sugarbeets. However, 3-week irrigation intervals result in surface

Table 3. Relationships between yield components and cumulative evapotranspiration. Y in the relationships represents the respective dependent variable, and X represents the evapotranspiration in mm (independent variable)

Total Fresh Biomass (Mg/ha)

$Y = -30.087 + 0.405\ X - 2.3\ \text{E-4}\ x^2$
$r^2 = 0.96$
$Y = 28.119 + 0.127\ X$
$r^2 = 0.78$

Fresh Root Biomass (Mg/ha)

$Y = 12.380 + 0.143\ X - 4.0\ \text{E-5}\ X^2$
$r^2 = 0.97$
$Y = -1.578 + 0.093\ X$
$r^2 = 0.96$

Total Dry Biomass (Mg/ha)

$Y = -2.350 + 0.033\ X - 1.0\ \text{E-5}\ X^2$
$r^2 = 0.98$
$Y = 0.044 + 0.021\ X$
$r^2 = 0.96$

Dry Root Biomass (Mg/ha)

$Y = -1.698 + 0.0173\ X$
$r^2 = 0.99$

Sucrose Yield (Mg/ha)

$Y = -0.572 + 0.0108\ X$
$r^2 = 0.96$

irrigation applications that may be larger than practical due to the limited infiltration rate of a clay loam soil. Irrigation cutoff dates of 5 and 7 weeks prior to harvest produced higher sucrose percentages within the root and, in fact, may reduce processing costs due to higher root quality than irrigation cutoff just 3 weeks before harvest. The high water holding capacity of clay loam soils may allow for even longer cutoff dates than those used in this experiment; however, harvest problems could develop with digging in dry soils. A gross savings of 327 mm in applied irrigation water (and a net evapotranspiration savings of 160 mm), without a significant reduction in yield, was found between the weekly irrigation interval with an irrigation cutoff at 3 weeks before harvest and the 3-week irrigation interval with an irrigation cutoff at 7 weeks before harvest. Maintenance of economic yield under limited irrigation, in addition to a substantial water savings, may also provide for lower pumping and associated irrigation labor costs. In addition, irrigation cutoff for spring-sown sugarbeet of 4 to 6 weeks before harvest should result in more soil water depletion and, hence, greater storage capacity for winter precipitation.

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