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Effect of Mid- to Late- Season Water Stress on Sugarbeet Growth and Yield[1]

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ABSTRACT

Costs of irrigation (labor, water, and energy) and sometimes limited-late-season water are factors associated with the choice of crop and economic returns. Sugarbeets (*Beta vulgaris* L.) have shown certain tolerance to water stress, therefore the objective of this study was to evaluate growth rates and characteristics, sucrose accumulation, and N uptake by sugarbeets grown under mid to late-season soil water deficit and plant water stress.

Sugarbeets were grown in a field experiment on a Portneuf silt loam soil (Durixerollic Calciorthids; coarse-silty, mixed, mesic) under normal irrigation until 15 July, after which further irrigation was terminated or reduced on two treatments during a 2-year period. Root yield, sucrose concentration, sucrose yield, plant N uptake, and petiole NO_3-N were determined from samples taken throughout each season. These experiments demonstrated that very little, if any, sucrose yield reduction can be expected in the Idaho area if irrigations are discontinued after filling the soil profile with water about 1 August and if the soil contains at least 200 mm of available water to a soil depth of 160 cm. During dry years, there may be an advantage to applying a light irrigation about 1 month after water cutoff and to have sufficient surface soil water present at harvest to prevent loss of roots by breaking. Use of deficit water management during August, September, and October curtailed leaf growth, reduced leaf area when no longer needed, reduced N uptake from the soil, increased sucrose concentration in the beet root, and decreased fresh root yield. These effects on yields were mainly caused by dehydration of the beet tops and roots so sucrose production was scarcely affected even though only 70% of the normal irrigation water was applied. Limited irrigations reduced evapotranspiration rates because of drier surface soil and partial stomatal closure, thereby decreasing the rate of water extraction from the soil reservoir by the plant. Use of mid to late-season deficit water management could substantially reduce sugarbeet production costs in irrigated areas and economically benefit the consumer, producer, and manufacturer.

Additional index words: **N uptake, Petiole NO_3-N, Leaf area index, Dry matter production, Sucrose production, Evapotranspiration.**

THE water requirements of sugarbeets (*Beta vulgaris* L.) have been studied extensively and have been reviewed by Jensen and Erie (9). The general consensus of opinion is that in irrigated areas early light irrigations are needed to assure seed germination to establish and maintain a good stand with vigorous early growth. Soil water during midseason should be maintained at a favorable level to allow sufficient top growth and maintain leaf turgidity so as not to restrict the photosynthetic process. However, Kohl and Cary (11) found that afternoon wilting of sugarbeet leaves did not affect yields. Adequate soil water for plant growth is considered more important during midseason than later in the season or 4 to 6 weeks before harvest. Ferry et al. in California (7) and Erie and French in Arizona (6) found that water stress several weeks before harvest of fall-planted beets reduced root yield but increased sucrose percentage. They concluded that since sucrose production is not reduced significantly by soil and plant water stress late in the season, irrigation can be discontinued 3 to 4 weeks before harvest for maximum water economy. However, sufficient soil water should be present at harvest to prevent loss of roots by breaking.

The objective of this study was to evaluate the seasonal growth rates and characteristics, sucrose accumulation, and N uptake of sugarbeets grown under mid to late-season soil water deficit and plant water stress.

MATERIALS AND METHODS

Field experiments were conducted in 1977 and 1978 on Portneuf silt loam soil (Durixerollic Calciorthids; coarse-silty, mixed, mesic) near Twin Falls, Id. This soil has a weakly cemented hardpan at the 50- to 60-cm depth that has little effect on water movement when saturated but may restrict root penetration. The areas used were cropped to barley (*Hordeum vulgare* L.) (straw burned) the previous year and were deficient in N (3) and P (20). The plots were fertilized for an expected maximum yield of 63 metric tons of beet roots per hectare.

A uniform application of 252 kg N/ha as ammonium nitrate and 56 kg P/ha as concentrated superphosphate was broadcast on plots 15.2 × 15.2 m (13 April planting, 77-M_1 irrigation) and 6.7 × 15.2 m (all other treatments) in 1977. In 1978, N fertilizer as ammonium nitrate was broadcast at rates of 168 and 336 kg/ha on plots 21.3 × 12.2 m as well as a uniform application of 56 kg P/ha. The fertilizer was incorporated with the upper 10 cm of soil and the seedbed prepared.

Sugarbeets (Cultivar, 'Amalgamated AH-10') were planted on one-half the experimental plots on 13 April and the other half on 29 Apr. 1977 and on 13 Apr. 1978. All beets were planted in 56-cm rows and were thinned to a 23 to 30-cm spacing in early June. 1978 experiment had an over-the-row application of aldicarb at a rate of 2.24 kg of active ingredient per hectare after thinning and before cultivation.

Three replications of two dates of planting and three irrigation treatments (M_1 and M_5, M_3 and M_6, M_4) were used in 1977. Four replications of two N fertilizer treatments and three furrow irrigation treatments (M_1, M_2, and M_3) were used in 1978. The irrigation times and amounts are summarized in Fig. 1 for the following treatments:

- M_1, M_5 — Adequately irrigated based on previous irrigation experiments. Irrigation dates were based on estimated soil moisture depletion (8) with 1 or 2-day adjustments so as not to interfere with plant sampling. Irrigation durations depended on the amount to be applied (M_1 planted on 13 April, M_5 planted on 29 April)
- M_2 — A light irrigation (50 mm) was applied on 1 September after the soil profile was filled with water on 1 August. Irrigations were the same as M_1 before 1 August (planted on 13 April).
- M_3, M_6 — No irrigation was applied after the soil profile was filled with water on 1 August. Irrigations were the same as M_1 or M_5 before 1 August. (M_3 planted on 13 April, M_6 planted on 29 April).
- M_4 — No irrigations after the soil profile was filled with water on 15 July. Irrigations were the same as M_1 before 15 July. (Planted on 13 April).

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No irrigation was applied before the final harvest in 1977. In 1978, a light irrigation was applied to all treatments 1 week before harvest. In 1977, alternate furrow irrigation (every other furrow and alternating furrows at each irrigation) was used on all treatments except on the 77-M_1 irrigation treatment after 16 June irrigation, which was sprinkle irrigated the rest of the season. Previous experiments (2) have indicated that the method of irrigation (sprinkler or furrow) had little effect on root and sucrose yields. In 1978, alternate furrow irrigation was used throughout the season except for the full irrigation on 1 August, when each furrow was used.

The amount of water delivered to the plots in 1978 from 1 August until harvest was measured using a single propeller totalizing flow-meter. Model HS flumes were used to measure runoff from each treatment and replication. The net amount of water applied during both years was estimated using intake rates determined in 1978 and previous intake measurements on this soil. Flow measurements were not made in 1977. The following equations were used to estimate the amount applied by furrow irrigation:

$$I = 5.54t^{1/2} + 4.98\ t \qquad [1]$$

$$I = 7.21t^{1/2} + 6.93\ t \qquad [2]$$

where I is the depth of water in millimeters and t is the irrigation duration in hours. Equation [1] represents alternate furrow irrigations (112-cm intervals) and Eq. [2] represents irrigations using every furrow (56-cm intervals). The amount of water applied with sprinklers was estimated from sprinkler head spacing, nozzle pressure, and nozzle size (16).

The soil water content in the 0 to 30-cm depth was determined gravimetrically from 4 August to 16 October. Two access tubes located within the row in each plot and a calibrated neutron probe were used to measure soil moisture in the 30 to 160-cm depth.

Root and top samples were manually harvested from three uniform 3-m row sections at 1 or 2-week intervals throughout the season. Six 3-m row sections were used for the final harvest on 17 to 21 Oct. 1977 and 23 to 25 Oct. 1978. Root samples were washed, root and crown tissues were separated at the lowest leaf scar, and all fresh tissue weighed before and after drying. A subsample of leaf blades was separated from the petioles and weighed for leaf area measurement. Duplicate root samples (triplicate for final harvest) of 12 to 14 roots were taken for sucrose and purity analyses.

Subsamples of roots harvested before mid-July were mixed with equal amounts of distilled water by weight, homogenized, frozen, and the samples stored until analyzed for sucrose. Root samples harvested from mid-July until late September were rasped (Keil-Dolle rasp), and the samples frozen and stored until analyzed for sucrose. The rest of the samples were rasped (modified Spreckles multiple circular gang saw) and analyzed for sucrose using the Sachs-le Docte cold digestion procedure as outlined by McGinnis (13).

The leaf area index (LAI) was determined by measuring the area of a weighed subsample of green blades from a 3-m row with a Lambda LI-3100 area meter.[3] Discolored blades were considered photosynthetically inactive and were not included in the LAI.

Petiole samples consisting of 25 of the youngest fully-mature petioles were selected at random from each plot at weekly intervals. The petioles were cut into 0.5-cm sections, dried at 65 C, ground to pass through a 40-mesh sieve, subsampled, and analyzed for NO_3-N, using a nitrate specific ion electrode (14).

The beet tops, roots, and crowns were dried at 65 C and dry weights determined. The dried samples were ground to pass a 40-mesh sieve and the total N was determined by the semimicro-Kjeldahl procedure modified to include nitrate (1). Nitrogen uptake was calculated by assuming that the N concentration was the same in both the fibrous and storage roots, and that the weight of the unharvested fibrous roots was equal to 25% of the total harvested storage root weight (10).

RESULTS AND DISCUSSION

In 1978, the excess N level (336 kg/ha) relative to the optimum (168 kg/ha) significantly increased LAI, top dry matter yield, and N uptake by tops and roots; significantly reduced root dry matter yield, wet sucrose concentration and sucrose yield; but had no effect on fresh root yield and sucrose concentration expressed on a dry matter basis (Table 1). These effects of N on sugarbeet growth are similar to those previously

[3] Mention of trade names or companies is for the benefit of the reader and does not imply endorsement by the USDA.

Treatment	IRRIGATIONS AND RAINFALL					
	to 13 July	July	Aug.	Sept.	Oct.	Total
	mm					
1977, Rain		18	9	16 4		47¶
77-M_1†	473	65 63	63 89 68	57	57	935
77-M_3	438	82 73	100§			693
77-M_4	438	106§				544
77-M_5‡	388	82 73	73 108 73	70	56	923
77-M_6‡	388	82 73	100§			643
1978, Rain			6	53 8		67#
78-M_1	400	73	79 79 79	79	56	845
78-M_2	400	73	108§	50	67	698
78-M_3	400	73	102§		67	642

† Sprinkler irrigated
§ Irrigated using every furrow to fill profile
‡ 29 April planting
¶ After 15 July
# After 1 August

Fig. 1. Irrigation water applied and rainfall in 1977 and 1978. Sugarbeets were planted 13 April and irrigated using alternate furrows except as noted. Arrows above the quantity of water refers to the application date.

reported (3, 5). The reduced irrigation level of the 78-M_3 treatment significantly increased sucrose concentration on a wet basis and decreased LAI. Effects of all other factors were insignificant. Because of the lack of significance of N-irrigation interaction, only the plant growth and yield components for the 168 kg N/ha treatments were used to evaluate the effects of irrigation level on sugarbeet growth in 1978.

Leaf area index during the two seasons on the adequate irrigation treatments (M_1, M_5) increased until the latter part of August and then decreased as top growth rate decreased as the older leaves died (Fig. 2). Leaf area index started to decrease 2 to 3 weeks after water cutoff as the plants began to show water stress. Rate and extent of this decrease in LAI depended upon the intensity and duration of plant water stress. In 1978, irrigation and rainfall received in September caused a regrowth of the beet tops on all treatments. Top regrowth was most noticeable on the 78-M_2 irrigation treatment.

Fresh root yields on the adequately watered irrigation treatments (M_1, M_5) increased rapidly during the June through September period with the greatest rate of increase occurring from mid-July until late August (Fig. 3). Terminating irrigations on 15 July (M_4) or 1 August (M_3, M_6) decreased the rate of root mass accumulation beginning from 2 to 4 weeks after water cutoff when the plants started to show water stress. In 1978, irrigation water was applied before a reduction in rate of root increase occurred (78-M_2) and there was no decrease in root yield at harvest. September rainfall received after the rate suppression in

Table 1. The effect of N and soil water levels on final sampling (24 October) parameters in 1978*,.**

Treatment	Root yield	Sucrose		Sucrose yield	Dry matter		N uptake		Leaf area‡ index
		Wet	Dry		Tops	Roots†	Tops	Roots†	
	kg/ha	%	%	kg/ha	kg/ha	kg/ha	kg/ha	kg/ha	
				Mean N effects					
168 kg N/ha	69,400x	19.1x	76.9x	13,200x	6,800x	18,800x	119x	185x	3.1x
336 kg N/ha	67,900x	17.7y	76.0x	12,000y	8,400y	17,800y	183y	234y	3.9y
				Mean water effects					
78-M_1	70,100a	18.1a	76.4a	12,700a	7,800a	18,400a	162a	218a	3.7a
78-M_2	70,600a	18.4ab	75.8a	13,000a	7,610a	19,000a	153a	209a	3.7a
78-M_3	65,300a	18.7b	77.0a	12,200a	7,400a	17,600a	139a	202a	3.1b

*,** Means within main effects not followed by the same letter a, b or x, y are significantly different at the $P < 0.05$ or $P < 0.01$, respectively, by Duncan's Multiple Range Test. † Includes crown tissue. ‡ 26 September sampling date.

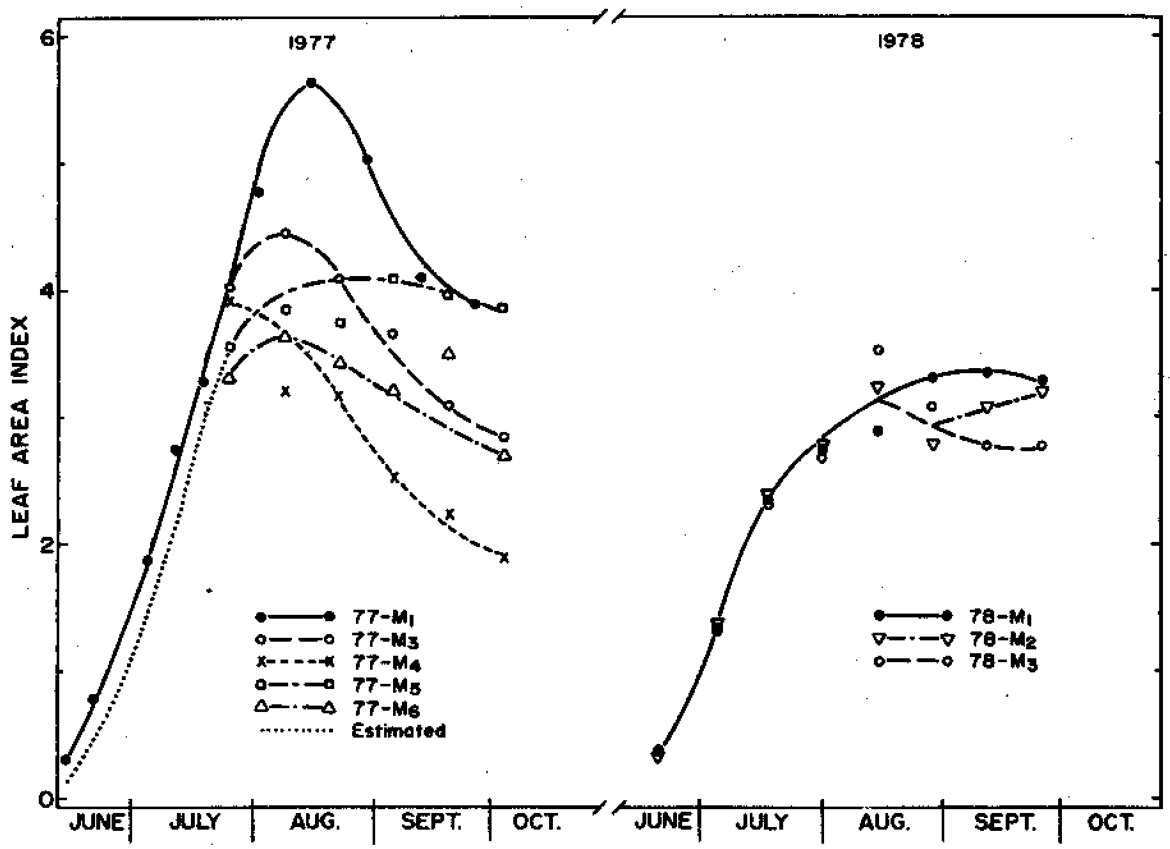

Fig. 2. Leaf area index as affected by time of sampling and irrigation water treatments in 1977 and 1978.

1977 and 1978 also caused a higher root growth rate to resume. The late September increase in root yield was at least in part due to both a rehydration of the beet roots with increased soil water and increased growth of the roots. However, potential root yield lost during the extended dry period was not completely replaced by harvest. The yield plateau shown in the 1978 data (Fig. 3) during September was caused by cold weather and snow. In 1977, 13 April planting, the 15 July cutoff of irrigation water (77-M_4) decreased root yields at harvest by 18% and the 1 August water cutoff (77-M_3) by 7% as compared with the 77-M_1 treatment. In the sugarbeets planted on 29 April, the 1 August cutoff of irrigation water (77-M_6) decreased root yields by only 2% as compared with the 77-M_5 treatment. In 1978, the 78-M_2 treatment did not decrease root yields at harvest, but the 78-M_3 treatment decreased them by 8% as compared with the 78-M_1 irrigation level.

Sucrose concentration increased most rapidly during June and July on the adequate irrigation (M_1, M_5) treatments (Fig. 4). Where water was adequate from late July until harvest, the rate of increase remained rather constant. On the water stress treatments, the sucrose concentration calculated on a wet weight basis started to increase significantly more than the control about 2 weeks after the last irrigation when the surface soil became dry and the sugarbeet leaves showed signs of water stress. The rate of increase in sucrose concentration was generally higher during this initial period of plant stress. Following the initial large increase in sucrose concentration due to water stress, the rate of increase was similar to that in the control. The increase in sucrose concentration above that in the control was not evident when the sucrose concentration was calculated on a dry weight basis. This indicates that the increase in sucrose concentration as determined on a wet weight basis was largely due to dehydration of the roots. This was further demonstrated in 1978 on all treatments by the decrease in sucrose concentration after the water application by irrigation or rainfall to stressed plants. The increase in sucrose concentration that occurred during mid-August on the 78-M_1 moisture treatment was due to reduced water content of these beets caused by a delay in irrigation. The large increase in sucrose concentration that occurred on the 77-M_6 treatment between 4 October and final sampling on all replications appears to be an anomaly (Fig. 4). Sucrose concentration at final harvest was lowest on the M_1 and M_5 irrigation treatments and highest on the water stressed plots, depending upon the level of dehydration of the beet roots.

Sucrose accumulation on the M_1 and M_5 moisture treatments followed a rather consistent pattern during the 2 years of this study (Fig. 5). The highest rate of increase in sucrose accumulation occurred from late July until early September. Water stress during midseason slightly increased or decreased the sucrose produced. In 1977, when the water stress became severe about 1 September on the treatments having 15 July (77-M_4) and 1 August (77-M_3) cutoff dates (planted on

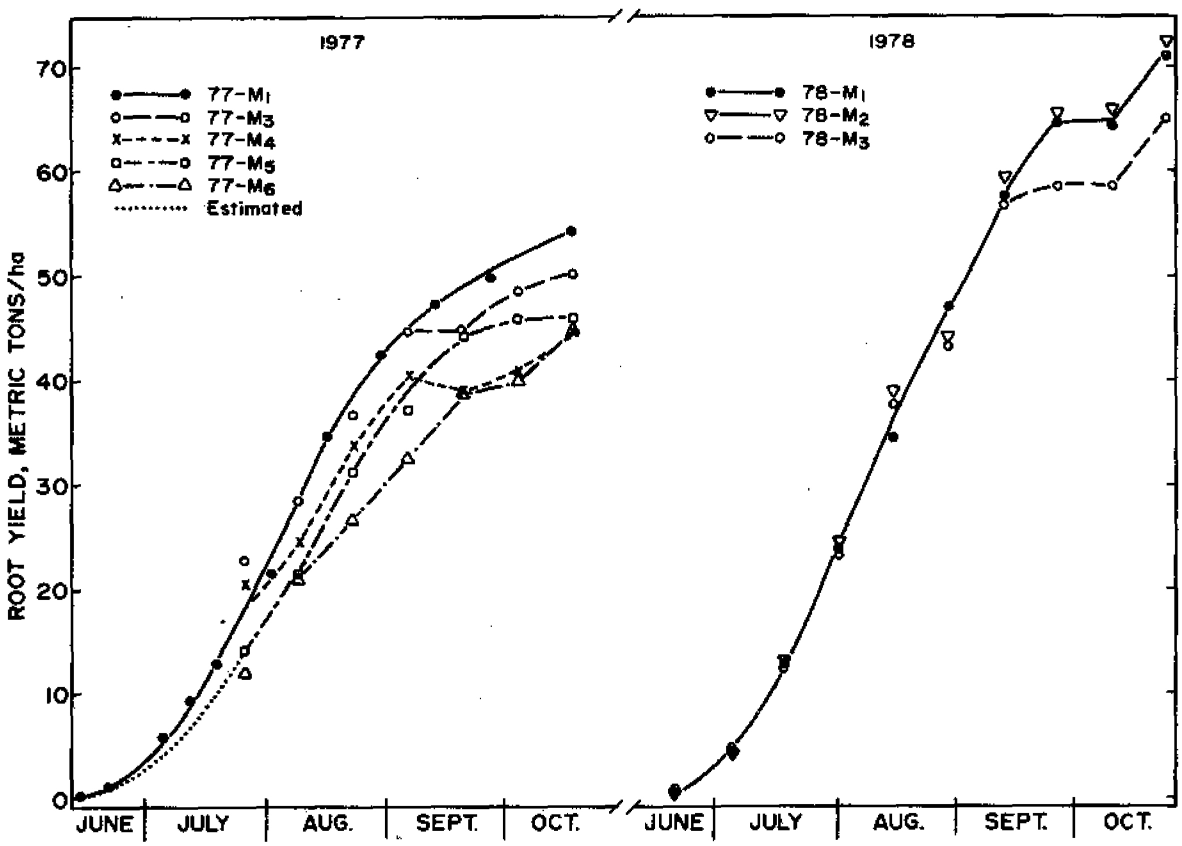

Fig. 3. Root yield as affected by time of sampling and irrigation water treatments in 1977 and 1978.

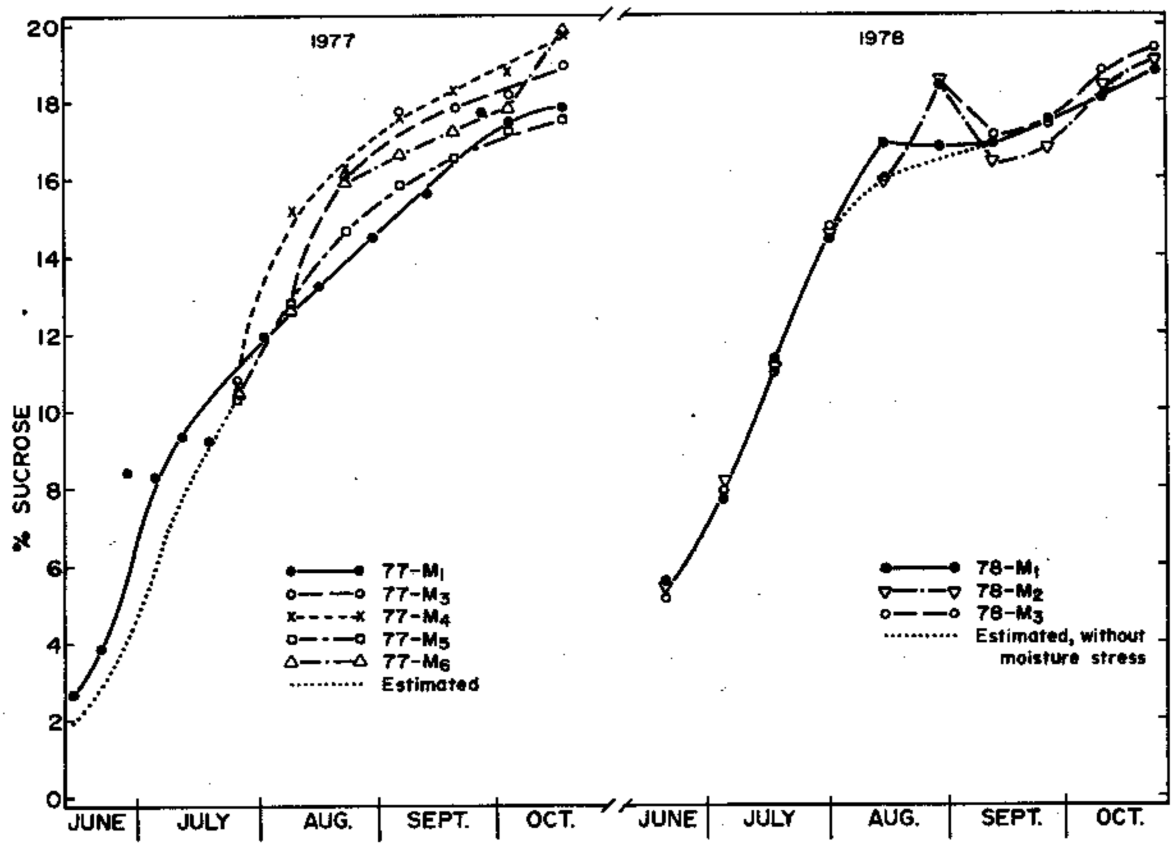

Fig. 4. Sucrose concentration (wet weight basis) as affected by time of sampling and irrigation water treatments in 1977 and 1978.

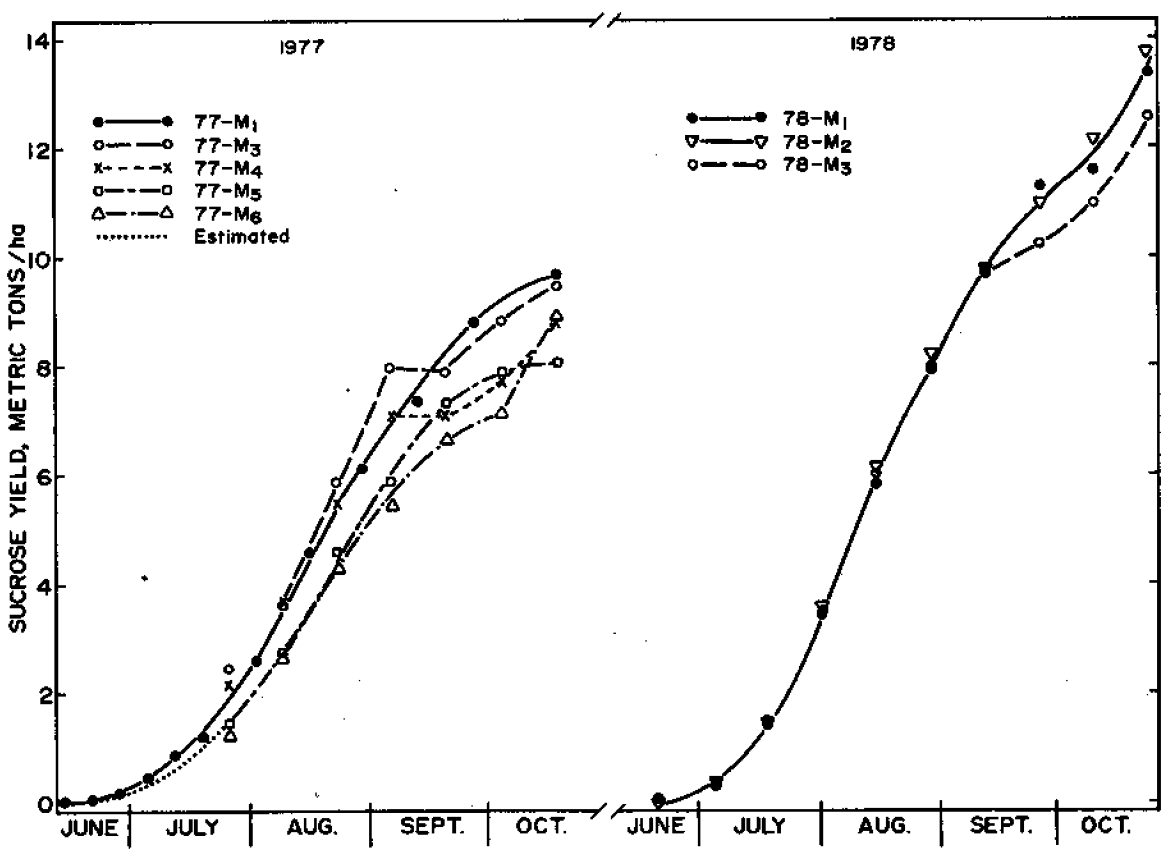

Fig. 5. Sucrose yield as affected by time of sampling and irrigation water treatments in 1977 and 1978.

13 April), a plateau was reached in sucrose production. This was followed by an increase, probably caused by rainfall. However, this did not occur on treatments having the later planting date (77-M_6). Thus, an irrigation during early September probably would be necessary to keep near maximum growth of roots and sucrose accumulation. In 1978, when significant amounts of rainfall occurred in early September, sucrose accumulation increased only slightly when an irrigation was applied 1 month after water cutoff on 1 September (78-M_2). As with root yield and sucrose concentration, the one anomaly was the large increase in sucrose accumulation from 4 October to harvest on the 77-M_6 treatment (Fig. 5). In 1977, on the 13 April planting, the 15 July (77-M_4) cutoff of irrigation water decreased sucrose yield at harvest by 9.3%; and the 1 August (77-M_3) cutoff decreased it only 1.8% as compared with the 77-M_1 irrigation level. In the case of the 29 April planting, the 1 August (77-M_6) cutoff of irrigation water increased sucrose yield by 11% as compared with the 77-M_5 irrigation level. This increase cannot be explained and probably could not be repeated. Therefore, the results must be considered the same as the control. In 1978, the 78-M_2 treatment increased sucrose yields at harvest by 3% and the 78-M_3 treatment decreased them by 5.8% as compared with the control.

Dry matter production of the tops increased from the first sampling date in early June until harvest on the adequate irrigation (M_1, M_5) treatments. The rate of increase was highest from early July until early August (Fig. 6). Dry matter production of the roots also increased from June until harvest; the rate of increase was highest from late July until early September. Water deficit had very little effect on dry matter production in 1978. The only difference was a slight decrease in dry matter on the 78-M_3 treatment. However, in 1977 when the water stress was much more severe, generally less dry matter was produced in both the tops and roots on the water deficit treatments. Most of the decrease in dry matter occurred in the tops that was caused by both cessation in growth and the drying and falling off of the older leaves. Although attempts were made to collect all the leaves when harvesting, some of the tops undoubtedly were lost.

Total N uptake followed a rather typical pattern on the M_1 and M_5 irrigation treatments during the 2 years of this study (Fig. 7). Water stress reduced the N uptake in both the tops and roots both years. The majority of this reduction occurred in the tops; the extent depended upon the degree of stress imposed and its duration. The reduction was greater for M_4 as compared with the M_3 and M_1 irrigation treatments. This reduction was probably caused by a reduced N need by the plant with a reduction in top growth caused by water stress and lower amounts of N being available to the plant in the drier soil. This would be mainly due to the lack of movement of NO_3-N to the roots and the reduced N available from mineralizable sources in the drier soil (18, 19).

The reduction in soil N available to the sugarbeet plant is further substantiated by the degree of reduction in petiole NO_3-N with water stress that was parti-

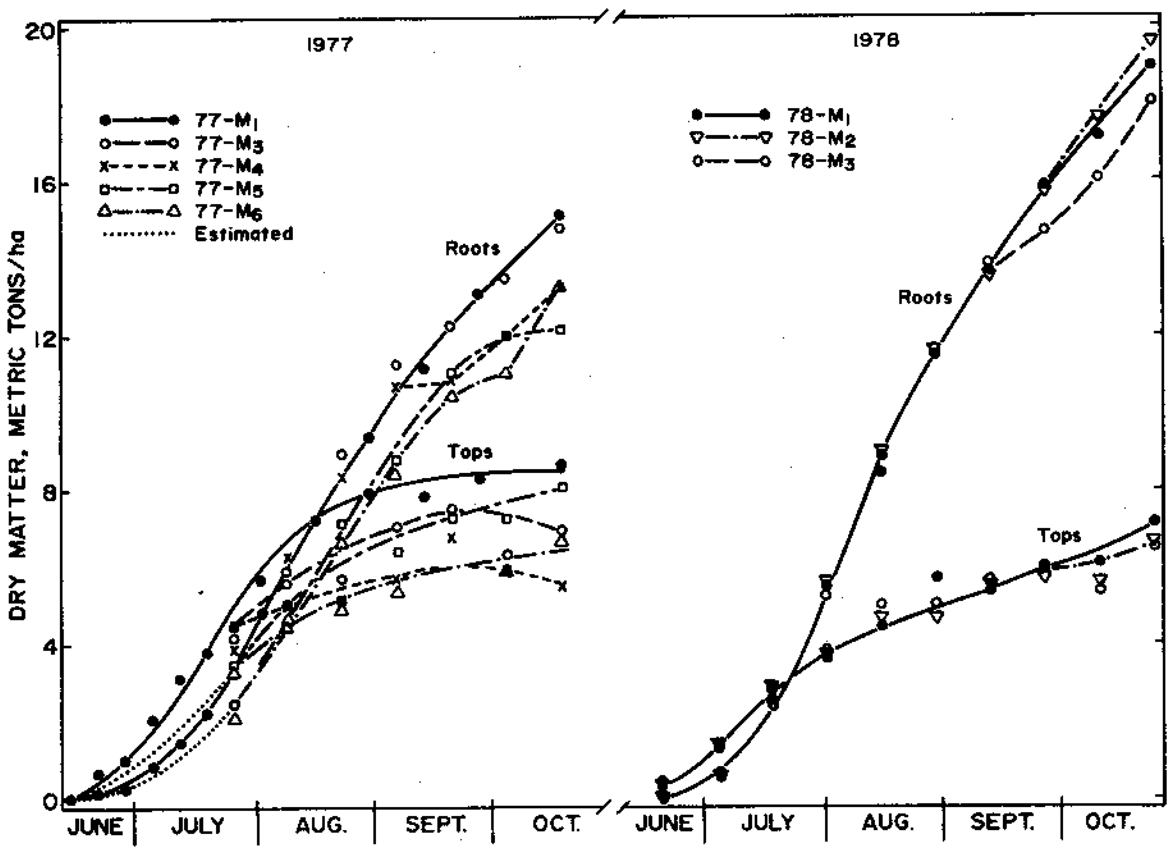

Fig. 6. Dry matter production as affected by time of sampling and irrigation water treatments in 1977 and 1978.

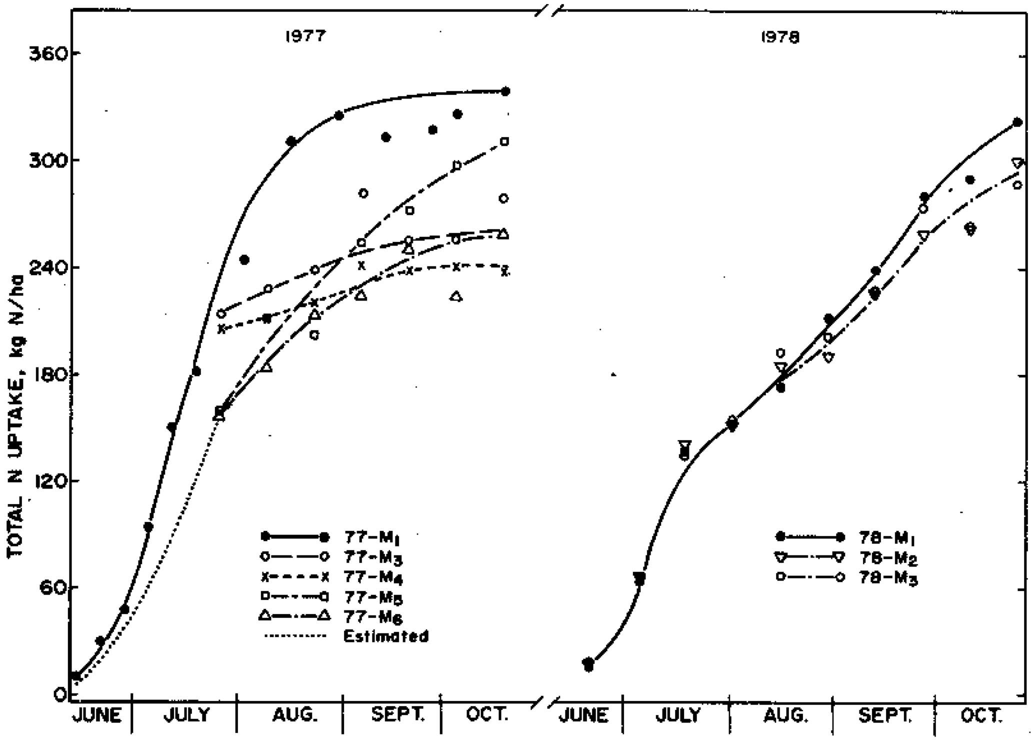

Fig. 7. Total N uptake as affected by time of sampling and irrigation water treatments in 1977 and 1978.

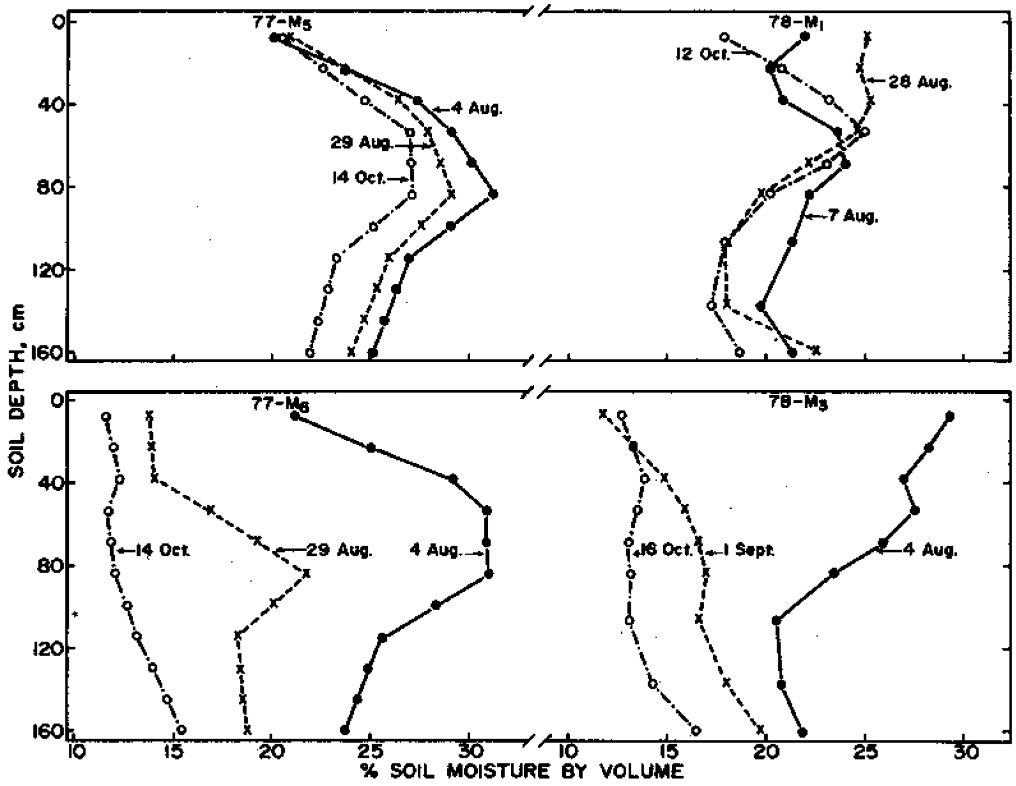

Fig. 8. Soil water on three dates illustrating the pattern of water use on irrigated (77-M_5 and 78-M_1) and nonirrigated or water stressed sugarbeets (77-M_6 and 78-M_3) during August, September, and October in 1977 and 1978.

cularly noticeable in the drier season of 1977. In most cases, the slope of the regression line of the stressed beets was greater (4) coupled with a decreased integrated average petiole NO_3-N during the stress period when compared to sugarbeets normally irrigated. However, the use of petiole analysis to evaluate the N status of the soil is complicated by the difficulties in selecting the latest mature leaves from dehydrated beets. This can be partially overcome by taking samples early in the day when most of the younger leaves are erect, which was done in this study.

When the surface soil to the 60-cm depth was wet after an irrigation or rainfall, most of the water for evapotranspiration (ET) came from this zone and amounted to as much as 60% of that used (Fig. 8). However, as the surface soil dried and approached the wilting range, as much as 80% of the water used for ET came from the hard layer and below the 60-cm depth. Generally, the root zone for sugarbeets on this soil has been considered to be above the hard layer. These experiments showed that some roots were able to extract water from the hard layer and below by penetrating the hard layer, perhaps in small cracks or in holes made by roots from a previous crop with a stronger rooting system such as alfalfa. The soil water within and below the hard layer supplied enough water to keep the plant growth processes active and yields either equal to or only slightly reduced when the top soil was near the wilting range.

The ET, estimated from water depletion of the profile using neutron probe measurements, followed a rather consistent pattern in 1977 and 1978 where adequate soil water was present as compared with the potential or reference ET (alfalfa, (*Medicago sativa* L.)) determined by methods of Wright and Jensen (21), (Fig. 9). The apparent high ET rate shortly after early August irrigations on the 77-M_3 and 77-M_6 treatments in 1977 probably included some deep percolation loss. Evapotranspiration generally decreased from early August until harvest on the water cutoff treatments as the soil water was depleted, although potential ET also decreased because of the lower solar radiation and air temperatures. After an irrigation or the rainfall that occurred in 1978, the ET rate increased for a few days, then steadily decreased. The ET values on the water cutoff plot ranged from 7 mm/day in early August to 0.6 mm/day in mid-October in 1977 and from 7.6 to 2.3 mm/day in 1978 during the same period. Again, as with sucrose concentration and yield, the one anomaly on the ET measurements was the apparent increase in ET that occurred early in September on the 77-M_6 treatment. Compared with

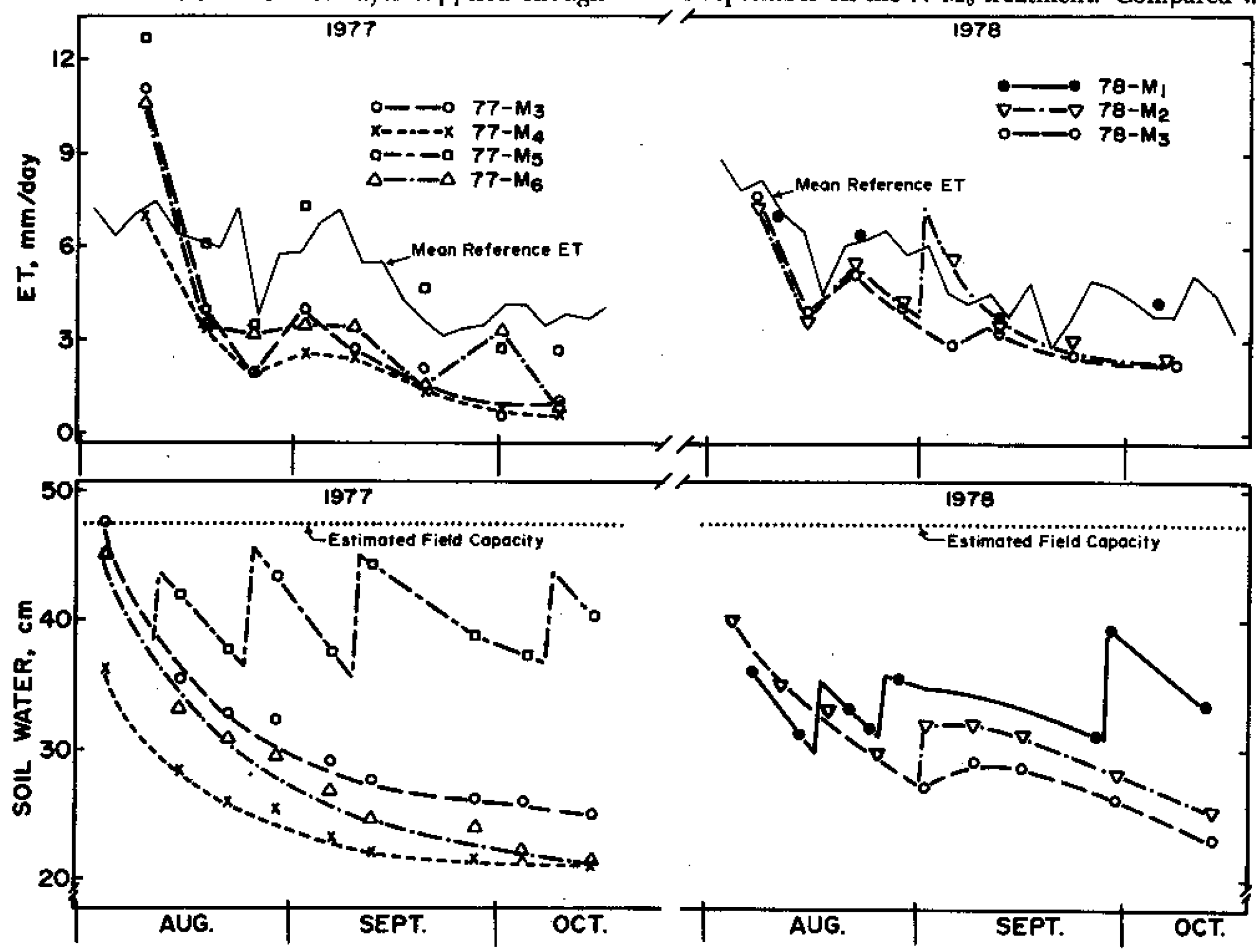

Fig. 9. Measured soil water content and evapotranspiration, mean reference ET, and estimated field capacity for 1977 and 1978. [Estimated field capacity determined at 0.33 bar (17). Mean (3-day) reference ET (alfalfa) determined by methods of Wright and Jensen (21)].

the adequate treatment, the water stress treatments reduced total ET in 1977 by 89, 197, and 90 mm (the 77-M_3, 77-M_4, and 77-M_6 treatments, respectively) and in 1978 by 67 and 99 mm (the 78-M_2 and 78-M_3 treatments, respectively).

The available water in the soil profile on the water cutoff treatments steadily decreased without either irrigation or the significant rainfall that occurred in 1978 (Fig. 9). The total available water in these silt loam soils between the estimated field capacity (0.33 bar) and the maximum extraction (about 10 bars) from the drier treatment (77-M_4) was 260 mm. However, since some water in 1977 was probably lost to deep percolation after the first water measurements, a more conservative estimate for useable water would be 200 mm. This value is further substantiated in that 200 mm of water was used from the soil reservoir on the drier treatment of 1977 (77-M_4) as compared with the adequately irrigated areas. This amount of water should be available from irrigation, rainfall, or soil water if similar results are to be obtained at other sites. With 200 mm of soil water available early in August, the total irrigation water normally applied can be reduced by about 30%. The amount of irrigation water is thus reduced when both water and hydroelectric power for pumping are in shortest supply. A depleted soil water reservoir at harvest also increases the retention of over-winter precipitation.

These studies and those of others (6, 7, 12, 15) have shown that sugarbeets are quite tolerant of mid to late-season water deficit and plant moisture stress. There are many explanations for this "drought tolerance," but the most evident in these studies is the change in top growth, N uptake, and partitioning of the photosynthate under dry conditions. New leaf development decreased and the older leaves dried up as the soil dried, starting about 2 to 4 weeks after water cutoff. This reduced new leaf development was due in part to the reduced N available from the dry soil and the reduced N uptake by the plant, which created a partial N deficiency in the sugarbeets. The green leaves that remained were the younger and more active in photosynthesis. These leaves were all fully exposed to sunlight with very little canopy shading and were erect during the morning. The total dry matter accumulation under these stressed conditions was reduced at final harvest by 21.6% on the 77-M_4 treatment; about three-fifths of this reduction occurred in the tops and about two-fifths in the roots. On the 77-M_3 treatment, there was an 8.6% reduction in total dry matter accumulation; about four-fifths of this reduction occurred in the tops and about one-fifth in the roots. The decrease in total dry matter production and accumulation in the tops and roots was probably due to reduced leaf area and CO_2 adsorption by the plant with moisture stress, which decreased the photosynthate produced. However, the roots became the dominate sink for the photosynthates that were produced, so root yield was reduced less than top yield. Sucrose production and accumulation were not reduced below those of the control until early September when the plants showed extreme moisture stress. This indicated that water from rainfall or a light irrigation would be necessary during this period to maintain sufficient photosynthesis for near maximum root and sucrose yields. However, during water-short years, when irrigation water is not available after 1 August, sucrose production can be maintained at a high enough level for profitable production even though the plants are subjected to severe mid to late-season water stress.

In conclusion, the results of this research clearly showed that sucrose yield is reduced very little in this area, if at all, if irrigations are discontinued after the soil profile is filled with water about 1 August on soils where the useable soil water reservoir is at least 200 mm. However, if no rainfall occurs, a light irrigation about 1 month after water cutoff may be advantageous. In addition, the soil should be wet enough at harvest to prevent loss of roots by breaking.

The use of deficit water management during August, September, and October curtailed leaf growth and a reduced leaf area, reduced N uptake from the soil, increased sucrose concentration in the beet root, and decreased fresh root yield. These effects on yields were mainly caused by dehydration of beet tops and roots so sucrose production was scarcely affected even though only 70% of the normal irrigation water was applied. The reduced irrigation water applied lowered ET rates because of the drier surface soil and dehydrated beet tops, and it increased the use of water from greater depth in the soil. If a full soil water reservoir is needed for the succeeding crop and winter rainfall does not replenish it, a preplant irrigation may be required.

The use of mid to late-season water stress management has the advantages of: 1) reducing the irrigation water needs of sugarbeet; 2) reducing the irrigation water demand during August and September in water-short years; 3) lowering irrigation labor costs; 4) lowering pumping costs, a particularly important advantage in high lift irrigation districts; 5) increasing root quality and reducing processing costs by increasing sucrose concentration; and 6) lowering the hauling costs by decreasing the water content which reduces both the weight and volume of the harvested roots.

Additional research is needed to determine if dehydrated beet roots can be stored successfully in piles and if there is any reduction in extractability of sucrose from these roots. The use of mid to late-season deficit water management could substantially reduce sugarbeet production costs in irrigated areas and economically benefit the consumer, producer, and manufacturer.

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