Late Season Irrigation Management for Optimum Sugarbeet Production[1]

C. Dean Yonts, Karen L. Palm and David L. Reichert

University of Nebraska
Panhandle Research and Extension Center
4502 Avenue I, Scottsbluff, NE 69361

ABSTRACT

In the irrigated sugarbeet growing regions of the U.S., water supplies can be limited or restricted due to drought or the over-development of ground water resources. When water supplies are limited, this means sugarbeet must be water stressed at some time during the growing season to reduce the total water use by the crop. By reducing irrigation late in the growing season, water stress can occur at a time when sugarbeet has developed a full root system and may be able to better withstand a period of water stress. The objective of this study was to compare different levels of water stress on sugarbeet late in the growing season using both furrow and sprinkler irrigation methods. Three late season, mid-August through harvest, water stress treatments were compared during a four year period. When irrigation was stopped in mid-August, sugar yield declined seven percent when compared to the low stress full season irrigation treatment. Sugarbeet were grown on a very fine sandy loam soil.

Additional Keywords: *Beta vulgaris* L., sugar beet, water stress, limited irrigation

Critical water issues face irrigated agriculture, including increased cost of pumping, decreased ground water supplies, decreased snow pack, and increased competition for water resources. Irrigated agricultural production, therefore, will need to become more efficient in

[1]A contribution of the University of Nebraska Agricultural Research Division, Lincoln, NE 68583. Research Bulletin No. 13834. The research was partly funded by the Western Sugar Grower Joint Research Committee Inc.

the use of available water resources. In the central High Plains of Nebraska, Wyoming and Colorado, sugarbeet production is dependent on irrigation. When water shortages occur, growers face the dilemma of whether to irrigate early in the season to establish the sugarbeet plant and encourage early growth or save limited water supplies for irrigating later in the growing season.

A number of studies to determine the impact of irrigation on sugarbeet yield have been conducted. Studies by Fonken et al. (1974), Cassel and Bauer (1976), Miller and Aarstad (1976), Ehlig and LeMert (1979) and Parashar et al. (1976), focused on season-long irrigation management to define sprinkler system capacity requirements, season-long irrigation requirements, the effect of deficit high frequency irrigation, influence of systematic under-irrigation and net economic return based on number of irrigations, respectively. In a study on season-long irrigation, Reichman et al., (1977) found that with a shallow water table of approximately 100 cm, irrigation treatments of 0.0, 0.5, 1.0 and 1.5 times evapotranspiration (ET) had no affect on yield. However, as the water table depth increased to 170 cm and 205 cm, root yield increased on a near linear relationship from irrigation levels of 0.0 to 1.5 times ET. In North Dakota, Stegman and Bauer (1977) found that fresh root yield was linearly related to seasonal ET accumulation, with an average production response of 1.5 t/ha-cm.

Trials have also been conducted to study the effect of limited irrigation on sugarbeet production during a specific time of the growing season. Carter, Jensen and Traveller (1980) indicated that mid- to late-season water stress had several advantages, including: 1) reduced irrigation water needs, 2) reduced water demand late in the season during water supply shortages, 3) lower labor costs, 4) reduced pumping costs, 5) increased root quality with a subsequent reduction in processing costs, and 6) reduced transportation costs due to less water content in the sugarbeet.

Two related studies, Hang and Miller (1986a) and Hang and Miller (1986b) used an irrigation line-source system (Hanks et al., 1976) to establish water stress treatments beginning at the time of canopy closure on two different soils. On a loam soil that holds 0.16 to 0.20 cm/cm of available water, Hang and Miller found that sugarbeet could be stressed by reducing irrigation by 40 to 50% of estimated ET without affecting yield. On a sandy soil that holds approximately 0.08 to 0.1 cm/cm available water, irrigation rates below 85% of estimated ET decreased sugarbeet yield. At canopy closure, soils were near field capacity for both studies.

Erie and French (1968), found that water stress 3 to 4 weeks before harvest of fall planted sugarbeet in Arizona resulted in reduced root yield and increased sucrose. This combination meant that the overall sugar production level remained similar to sugarbeet that was fully irrigated. Based on this work, Carter, Traveller and Rosenau (1980) and Carter, Jensen and Traveller (1980) found that if soil was filled with water to field capacity about August 1, with no subsequent irrigations, mid- to late-season stress on spring-planted sugarbeet in Idaho resulted in little reduction in sucrose production. Their conclusions were based on using a Portneuf silt loam soil and they considered the findings valid for a soil having a plant useable soil water content of at least 200 mm.

As water supplies become more limiting and society pressures agriculture to be a more efficient water user, an understanding of the impact of limiting irrigation will be critical to improving the water use efficiency of current sugarbeet varieties. Furrow and sprinkler irrigation systems are known to be distinctly different in terms of the amount of water applied with each irrigation. This study addresses both furrow and sprinkler irrigation systems with the specific objective of determining the effect of late season water stress on the yield of sugarbeet grown in a sandy loam soil.

Previous research has been concentrated on soils having moderately high water holding capacities. Information is needed in areas where sugarbeets are grown on coarser textured soils having less water holding capacity. In these conditions, water stress may occur much quicker when irrigation water is withheld late in the growing season.

MATERIALS AND METHODS

The study was conducted at the University of Nebraska, Panhandle Research and Extension Center in Scottsbluff, Nebraska from 1995 through 1998. Average precipitation for Scottsbluff from August 10 through October 15 is 6.0 cm. Rainfall, for each year during the study period, is given in Table 1, and range from 5.0 cm in 1995 to 9.5

Table 1. Tare, percent sugar, root yield, sugar yield, irrigation, rainfall, soil water, total water and water use for study period between mid-August and harvest of 1995 through 1998.

Year	Irrigation method	Water stress	Tare	Sugar	Root yield	Sugar yield	Irrigation water	Rainfall	Soil water	Total water	Water use
			%	%	t/ha	t/ha	cm	cm	cm	cm	Cm
1995	Furrow	Low	7.8	13.8	40.1	5548	27.6	5.0	-	32.6	25.9
		Medium	8.6	14.2	42.4	6030	20.7	5.0	-	25.7	25.9
		High	8.5	14.5	34.9	5072	6.9	5.0	-	11.9	25.9
		LSD @ 5%	NS	NS	NS	NS					
1996	Furrow	Low	7.1	16.4	55.6	9088	27.6	9.5	-	37.1	23.9
		Medium	7.2	16.5	57.1	9411	13.8	9.5	-	23.3	23.9
		High	6.9	16.8	56.4	9470	13.8	9.5	-	23.3	23.9
		LSD @ 5%	NS	NS	NS	NS					
1996	Sprinkler	Low	5.5	16.5	70.6	11585	12.0	9.5	-	21.5	24.9
		Medium	6.0	16.2	68.8	11148	7.5	9.5	-	17.0	24.9
		High	4.8	16.9	68.4	11554	4.5	9.5	-	14.0	24.9
		LSD @ 5%	NS	NS	NS	NS					
1997	Furrow	Low	6.6	12.1	47.5	5745	27.6	6.1	3.3	37.0	25.4
		Medium	6.6	11.8	45.8	5411	13.8	6.1	4.8	24.7	25.4
		High	5.3	11.1	44.4	4892	6.9	6.1	9.6	22.6	25.4
		LSD @ 5%	NS	NS	NS	NS					

Table 1 (continued). Tare, percent sugar, root yield, sugar yield, irrigation, rainfall, soil water, total water and water use for study period between mid-August and harvest of 1995 through 1998.

Year	Irrigation method	Water stress	Tare	Sugar	Root yield	Sugar yield	Irrigation water	Rainfall	Soil water	Total water	Water use
			%	%	t/ha	t/ha	cm	cm	cm	cm	Cm
1997	Sprinkler	Low	12.8	14.4	60.6	8563	25.4	6.1	0.5	32.0	25.7
		Medium	11.1	13.5	61.4	8262	13.9	6.1	4.3	24.3	25.7
		High	10.8	13.1	60.1	7893	4.3	6.1	7.4	17.8	25.7
		LSD @ 5%	NS	NS	NS	NS					
1998	Furrow	Low	8.8	17.1	68.3	11722	34.5	7.5	-2.3	39.7	30.5
		Medium	8.6	17.1	37.2	11455	20.7	7.5	2.5	30.7	30.5
		High	8.3	16.8	58.6	9880	6.9	7.5	7.9	22.3	30.5
		LSD @ 5%	NS	NS	NS	NS					
1998	Sprinkler	Low	17.8	15.1	63.0	9564	20.1	7.5	2.0	29.6	30.5
		Medium	16.3	15.1	61.3	9246	11.3	7.5	-3.5	15.3	30.5
		High	17.8	16.0	55.5	8853	2.5	7.5	-1.0	9.0	30.5
		LSD @ 5%	NS	NS	NS	NS					
1995-1998	Furrow/ Sprinkler	Low	9.5	15.4	57.8	8823	24.8	7.2	0.5	32.8	26.7
		Medium	9.2	14.9	57.6	8701	14.5	7.2	1.1	24.1	26.7
		High	8.9	15.0	54.0	8223	6.5	7.2	3.4	17.3	26.7
		LSD @ 5%	NS	NS	2.9	490					

cm in 1996. Two experiments were conducted each year, furrow and sprinkler. The furrow irrigated experiment resulted in refilling the soil profile with water during each irrigation. For the sprinkler irrigated experiment, water was applied using a center pivot at higher frequency and a reduced application rate compared to the furrow experiment. Sprinkler irrigated and furrow irrigated experiments were located less than 0.5 km apart during each year of this study.

Both experiments were irrigated after planting to aid in germination and emergence. Cultural practices were the same for all plots among the sprinkler and furrow sites other than the late season irrigation treatments. Soil type was a Tripp very fine sandy loam (Typic Haplustoll) with pH 8, 1% organic matter and a plant available water holding capacity of 0.15 to 0.17 mm/mm.

The late season irrigation treatments included the following:

1) Low water stress from mid-August to harvest - Low stress
2) Medium water stress from mid-August to harvest - Medium stress
3) High water stress from mid-August to harvest - High stress

The medium stress treatment schedule was determined by eliminating approximately every other irrigation scheduled for the low stress treatment. The goal for the high stress treatment was to eliminate most if not all irrigations after mid-August. Each irrigation treatment was replicated six times in a randomized complete block design. Plots under the center pivot were a minimum of 30 m long and twelve rows wide (56 cm row spacing). For the furrow irrigated experiment, the plots were 60 m long and eight rows wide (56 cm row spacing).

Planting date, variety, beginning stress date and harvest date are given in Table 2. In 1995, sugarbeet production for the sprinkler irrigated experiment was lost due to rhizoctonia disease and not harvested. The furrow irrigated experiment was located in a separate field and rhizoctonia did not have a significant impact on sugarbeet yield potential. The start date for each irrigation treatment coincided with a scheduled irrigation event each year for the furrow and sprinkler experiments. Irrigation prior to beginning the restriction of irrigation was intended to

Table 2. Planting date, variety, beginning stress date, and harvest date for sprinkler and furrow irrigation treatments conducted during 1995 - 1998.

Sprinkler irrigated

	1995	1996	1997	1998
Planting date	5/5	4/23	4/28	5/7
Variety	Monohikari	Seedex Halt	Seedex Halt	Beta 4546
Beginning stress date	8/8	8/12	8/7	8/12
Harvest date	-	10/16	11/5	11/11

Furrow irrigated

	1995	1996	1997	1998
Planting date	4/27	4/18	4/24	4/21
Variety	Monohikari	ACH 184	Laser	Beta 4546
Beginning stress date	8/10	8/6	8/8	8/13
Harvest date	10/24	10/9	10/30	11/12

fill the soil profile to near field capacity. With the exception of 1996, the majority of rainfall during the treatment period occurred approximately one month prior to harvest. This resulted in rainfall providing favorable conditions for harvesting sugarbeet each year in all irrigation treatments.

Two 15 m long rows were mechanically harvested from within each plot and weighed. Two, 7.0 kg, sub-samples were collected and sent to the Western Sugar Tare Lab in Scottsbluff, Nebraska, for analysis of tare and sucrose content.

Irrigation was scheduled for each treatment rather than for each individual plot. For the furrow experiment, water was applied at a quantity so as to refill the soil profile to a minimum depth of 90 cm. This resulted in water being deep percolated below the 90 cm depth to insure the active rootzone was filled for all treatments. Irrigation application was measured for the sprinkler experiment by determining total water applied to a given area. The irrigation application amount was based on using approximately 50% of the plant available water from the soil profile in the low stress treatment. For the sprinkler trial, irrigation application was determined based on the ability of the soil to infiltrate water into the soil profile without producing runoff. Water application was generally less than 2.5 cm for each irrigation event. The low stress treatment was used to determine the irrigation schedule.

To calculate the amount of water used from the soil profile, measurements were taken at the beginning of the treatment period and again at harvest time. Soil water was measured in each plot to a depth of 1.2 m using a neutron probe. Wire connections supporting the neutron probe failed at the end of the growing season in both 1995 and 1996. As a result, the amount of water used from the soil was only determined for 1997 and 1998.

RESULTS

Irrigation Schedule

Tables 3a-3d provide irrigation schedule, irrigation amount, rainfall and total irrigation during the treatment period for both the sprinkler and furrow experiments of each year studied. The treatment period was considered to be from the last irrigation in mid-August that occurred among all treatments until harvest. The sprinkler irrigation experiment was abandoned in 1995 due to rhizoctonia disease. In 1996, the high stress treatment in both the sprinkler and furrow experiments were inadvertently irrigated within four days of initiating the treatments and therefore delayed the start of crop water stress.

Table 3a. 1995 furrow late season irrigation schedule, irrigation amount, rainfall, and total irrigation during treatment period for the low, medium and high water stress treatments.

Irrigation date	Rainfall	Furrow treatment water stress		
		Low	Medium	High
	cm	cm water applied		
Aug 10		6.9	6.9	6.9
Aug 18		6.9	6.9	0.0
Sept 1		6.9	0.0	0.0
Sept 13		6.9	6.9	0.0
Sept 14	0.4			
Sept 19	0.5			
Sept 20	1.0			
Sept 21	0.9			
Sept 29	0.9			
Oct 4	1.3			
Total	5.0	27.6	20.7	6.9

Table 3b. 1996 sprinkler and furrow late season irrigation schedule, irrigation amount, rainfall, and total irrigation during treatment period for the low, medium and high water stress treatments.

Irrigation		Sprinkler treatment water stress			Furrow treatment water stress		
date	Rainfall	Low	Medium	High	Low	Medium	High
	cm	cm water applied			cm water applied		
Aug 6					6.9	6.9	6.9
Aug 12		1.5	1.5	1.5			
Aug 15		1.5	0.0	1.5			
Aug 16					6.9	0.0	6.9
Aug 20		1.5	0.0	1.5			
Aug 23	0.9						
Aug 27	1.5	1.5	0.0	6.9	6.9	0.0	
Aug 28	1.2						
Aug 29	1.5	1.5	1.5	0.0			
Sept 5	0.6	1.5	1.5	0.0			
Sept 6	0.4						
Sept 10					6.9	0.0	0.0
Sept 11		1.5	0.0	0.0			
Sept 17	2.6						
Sept 19	1.4						
Sept 26	0.9						
Oct 9		1.5	1.5	0.0			
Total	9.5	12.0	7.5	4.5	27.6	13.8	13.8

Table 3c. 1997 sprinkler and furrow late season irrigation schedule, irrigation amount, rainfall, and total irrigation during treatment period for the low, medium and high water stress treatments.

Irrigation date	Rainfall	Sprinkler treatment water stress Low	Sprinkler treatment water stress Medium	Sprinkler treatment water stress High	Furrow treatment water stress Low	Furrow treatment water stress Medium	Furrow treatment water stress High
	cm		cm water applied			cm water applied	
Aug 7		4.3	4.3	4.3			
Aug 8					6.9	6.9	6.9
Aug 10	1.9						
Aug 11	0.3						
Aug 22		4.3	0.0	0.0	6.9	0.0	0.0
Aug 29		2.4	2.4	0.0			
Sept 5		2.4	0.0	0.0			
Sept 9					6.9	6.9	0.0
Sept 12		2.4	2.4	0.0			
Sept 16		2.4	0.0	0.0			
Sept 18		2.4	0.0	0.0			
Sept 19	1.3						
Sept 20					6.9	0.0	0.0
Sept 29		2.4	2.4	0.0			
Oct 8	0.3						
Oct 12	0.3						
Oct 16		2.4	2.4	0.0			
Oct 23	1.1						
Oct 27	0.9						
Total	6.1	25.4	13.9	4.3	27.6	13.8	6.9

Table 3d. 1998 sprinkler and furrow late season irrigation schedule, irrigation amount, rainfall, and total irrigation during treatment period for the low, medium and high water stress treatments.

Irrigation		Sprinkler treatment water stress			Furrow treatment water stress		
date	Rainfall	Low	Medium	High	Low	Medium	High
	cm		cm water applied			cm water applied	
Aug 12		2.5	2.5	2.5			
Aug 13					6.9	6.9	6.9
Aug 14	0.4						
Aug 21							
Aug 21	0.7	1.9	0.0	0.0			
Aug 25					6.9	0.0	0.0
Aug 26		1.9	1.9	0.0			
Aug 31		2.3	0.0	0.0			
Sept 1					6.9	6.9	0.0
Sept 3		2.3	2.3	0.0			
Sept 8		2.3	0.0	0.0			
Sept 10		2.3	2.3	0.0			
Sept 11					6.9	0.0	0.0
Sept 18		2.3	0.0	0.0			
Sept 21	0.3						
Sept 24		2.3	2.3	0.0			

Table 3d (continued). 1998 sprinkler and furrow late season irrigation schedule, irrigation amount, rainfall, and total irrigation during treatment period for the low, medium and high water stress treatments.

Irrigation		Sprinkler treatment water stress			Furrow treatment water stress		
date	Rainfall	Low	Medium	High	Low	Medium	High
	cm		cm water applied			cm water applied	
Oct 1					6.9	6.9	0.0
Oct 4	2.7						
Oct 5	0.8						
Oct 16	0.4						
Oct 27	0.9						
Oct 28	0.4						
Nov 2	0.6						
Nov 3	0.3						
Total	7.5	20.1	11.3	2.5	34.5	20.7	6.9

Irrigation

Results for the seven site years studied are given in Table 1. Irrigation water applied was generally greater for the furrow trials as compared with the sprinkler trials. This is primarily due to the fact that irrigation with furrow systems for the soils in this study generally result in refilling the soil profile to capacity. On average, the low stress treatment had 24.8 cm of water applied through irrigation during the irrigation treatment period of mid-August to harvest. The medium stress treatment had 60% of the water applied compared to the low stress treatment, or 14.5 cm. Only 25% of the water applied to the low stress treatment, or 6.5 cm of water, was applied to the high stress treatment. Irrigation efficiency was not considered in the total quantities given.

Rainfall

Because of close proximity of the furrow and sprinkler trials, precipitation was collected to represent both trials in a given year. Rainfall of less than 0.2 cm for a given event was not considered effective and therefore not included in the total amounts reported. Rainfall greater than 0.2 cm was considered to be 100% effective.

Soil Water

Water available from the soil profile was only determined during 1997 and 1998. Negative values of soil water (Table 1) indicate that more water was being stored in the soil profile at the end of the study period than stored in the soil profile at the beginning of the test period. As stated earlier, rain occurred late in the growing season providing adequate soil water for harvesting the sugarbeet roots, even in the high stress treatment. Adequate soil water late in the growing season could have contributed to masking sugarbeet yield reductions by stimulating growth during the last month of the growing season.

Water Use

Sugarbeet water use was estimated based on daily evapotranspiration (ET) data from the University of Nebraska High Plains Regional Climate Center. Water use for sugarbeet is given in Table 1 for each year and treatment.

Total Water

In Table 1, total water available for crop use is calculated for 1995 and 1996 by summing the amount of irrigation and rainfall for each treatment. For 1997 and 1998, total water is the sum of applied irrigation, rainfall and water available from the soil. Average total water for the seven site years combined for the low stress treatment was 32.8 cm. The medium stress treatment averaged 24.1 cm while the high stress treatment averaged 17.3 cm. This represents total water available of 73% and 53% for the medium and high stress treatments, respectively, compared to the low stress treatment.

Total water available for the furrow low stress treatment averaged 36.6 cm. Total water available in the medium and high stress furrow treatments were 81% and 55%, respectively, compared to the low stress treatment. For the low stress sprinkler experiment, total water available averaged 27.7 cm. Total water available for the medium and high stress sprinkler treatments were 68% and 50%, respectively.

Total water for the low stress treatment was nearly equal to or greater than the estimated crop water use value for each experiment, with the exception of the 1996 sprinkler experiment where total water was nearly 3.5 cm less than estimated crop water use. In both 1995 and 1996, soil water was not included in the total water values. Total water available for the medium stress treatments were, on average, 2.5 cm or 10% below estimated crop water use values. The greatest difference between total water and estimated crop water use for the medium stress treatment occurred in the 1998 sprinkler experiment, 15.2 cm. For the high stress treatment, the difference in total water and estimated water use ranged from a 70% difference in the 1998 sprinkler experiment to a 2% difference in the 1996 furrow experiment. Average total water available subtracted from average estimated water use was approximately 9.5 cm, a 35% reduction in available water for the high stress treatment.

Sugarbeet Yield

Percent tare, sugar content, root yield and sugar yield for sugarbeet is given in Table 1. Differences in yield parameters were not significant within each of the seven site years tested. When the furrow and sprinkler experiments were combined, tare and percent sugar were similar from the three water stress treatments. Root yield was similar for the low and medium stress treatments and both treatments were approximately 3.8 t/ha greater than the high stress treatment. Sugar production was not significantly different for the low and medium stress treatments, 8,823 and 8,701 kg/ha, respectively. High stress produced 600 kg/ha less sugar than the low stress irrigation treatment.

DISCUSSION

Elimination of irrigation and relying on rainfall late in the growing season (after mid-August) for spring planted sugarbeet, decreased sugar yield by nearly 7% when compared to using sprinkler or furrow irrigation to meet full crop water requirements. Based on these results, sugarbeet yield was influenced to a small degree by the amount and timing of irrigation late in the growing season. If water for irrigation is a limiting factor, and available water supplies are expected to be evenly distributed late in the growing season, having some water stress late in the sugarbeet growing season will have little effect on yield for sugarbeet grown using either sprinkler or furrow irrigation systems. This assumes that adequate water was available early in the growing season to encourage a deep root system and the soil profile is filled to near field capacity in early August.

These results are based on sugarbeet grown in a medium textured soil with a plant water holding capacity of approximately 0.15 to 0.17 mm/mm. Based on a 90 cm rooting depth and allowing a 50% water extraction by sugarbeet, this soil could store approximately 72 mm of available water. The results of this study follow closely the results of the previous studies cited. For example, a fine textured soil with a greater water holding capacity(200 mm of useable water), such as described by Carter, Traveller and Rosenau (1980), would allow irrigation cutoff to occur sooner in the growing season without impacting yield. On the other hand, sugarbeet grown in a coarse textured soil, such as that described by Hang and Miller (1986a), would be expected to experience more severe water stress and would require irrigation to be continued much later in the growing season.

From mid-August to mid-September, crop water requirement for sugarbeet in the central plains region of Nebraska, Colorado and Wyoming averages approximately 40 mm each week (Yonts, 2002). Having a full soil profile means that, without rainfall, crop water use can be met for nearly a two week period using stored soil water in a sandy loam soil having 72 mm of available water. With the combination of cooler temperatures and a fully developed root system in the fall, sugarbeet could use water beyond the recommended 50% depletion level and obtain water from depths greater than 100 cm. Increasing allowable depletion to 60% and depth of water extraction to 120 cm could provide over 40 mm of additional water late in the growing season. Add to this the increased potential for rain in September, and reducing irrigation late in the growing season may actually result in a more efficient use of stored water and late season rainfall. Without the ability to store water, crop water stress will occur and yield will be reduced. In effect, the results would tend to follow the straight line relationship between fresh root weight and ET developed by Stegman and Bauer (1977).

As mentioned before, precipitation occurred late in the growing season during these experiments and provided adequate soil water for efficient harvest. If available water has been depleted to average 60% to a depth of 120 cm, the top 30 cm may be at or near the wilting point. If this occurs, additional water would likely have been needed to facilitate the harvesting process and reduce root breakage. Breakage and root loss during harvest can be significant as shown by Smith, et al. (1999). Stopping irrigation after August 15 induced late season plant water stress in sugarbeet. When sugarbeet were grown in a sandy loam soil with a moderate soil water holding capacity yields were reduced by approximately 7 percent.

During 1997 and 1998, yield results were more consistent with the water stress treatment levels tested. The inconsistency of yields in 1995 and 1996 could have been due to the precipitation pattern during those years and the delay in starting water stress in 1996 for the high water stress treatment. Sugar yield for the 1997 and 1998 high water stress treatment was reduced by over eleven percent when compared to the low water stress treatment.

LITERATURE CITED

Carter, J.N., D.J. Traveller and R.C. Rosenau. 1980. Root and sucrose yields of sugarbeets as affected by mid- to late-season water stress. J. Am. Soc. Sugar Beet Technol. 20(6):583-596.

Carter, J.N., M.E. Jensen and D.J. Traveller. 1980. Effect of mid- to late-season water stress on sugarbeet growth and yield. Agron. J. 72:806-815.

Cassel, D.K. and A. Bauer. 1976. Irrigation schedules for sugarbeets on medium and coarse textured soils in the northern great plains. Agron. J. 68:45-48.

Ehlig, C.F. and R.D. LeMert. 1979. Water use and yields of sugarbeets over a range from excessive to limited irrigation. Soil Sci. Soc. Am. J.43:403-407.

Erie, L.J. and O.F. French. 1968. Water management of fall-planted sugar beets in salt river valley of arizona. Trans. of ASAE 11:792-795.

Fonken, D.W., J.C. Steele and P.E. Fischbach. 1974. Sprinkler irrigation design criteria for sugar beets. Trans. of ASAE 17(5):889-891.

Hang, A.N. and D.E. Miller. 1986a. Responses of sugarbeet to deficit, high-frequency sprinkler irrigation. I. Sugarbeet development and partitioning to root growth. Agron. J. 78:15-18.

Hang, A.N. and D.E. Miller. 1986b. Responses of sugarbeet to deficit, high-frequency sprinkler irrigation. II. Sucrose accumulation, and top and root dry matter production. Agron. J. 78:10-14.

Hanks, R.J., J. Keller, V.P. Rasmussen, and G.D. Wilson. 1976. Line source sprinkler for continuous variable irrigation crop production studies. Soil Sci. Soc. Am. J. 40:426-429.

Miller, D.E. and J.S. Aarstad. 1976. Yields and sugar content of sugarbeets as affected by deficit high-frequency irrigation. Agron. J. 68:231-234.

Parashar, K.S., R. K. Chowdhary and C. Singh. 1976. Studies on the response of sugarbeet to irrigation and its economics in relation to root and sugar yield. Indian J. Agron. 21(2):88-91.

Reichman, G.A., E.J. Doering, L.C. Benz and R.F. Follett. 1977. Effects of water-table depth and irrigation on sugarbeet yield and quality. J. Am. So. Sugar Beet Technol. 19(4):275-287.

Smith, J.A., C.D. Yonts and K.L. Palm. 1999. Field loss from sugarbeet harvest operations. Trans. of ASAE 15(6):627-631.

Stegman, E.C. and A. Bauer. 1977. Sugar beet response to water stress in sandy soils. Trans. of ASAE 20(3):469-473.

Yonts, C.D. 2002. Crop water use in western Nebraska. NebGuide G02-1465-A. University of Nebraska, Lincoln, NE.