Sprinkler and Flood Irrigation Effects on Sugarbeet Yield and Quality

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ABSTRACT

The number of irrigated hectares in eastern Montana and western North Dakota continues to increase and sugar beet (*Beta vulgaris*) producers are converting from flood to sprinkler irrigation. This study provides needed information on the relative yield and quality of sugarbeet under furrow-flood irrigation and low-pressure sprinkler irrigation. Sugarbeet was planted in a field with flood and sprinkler irrigation capability. Half of the planted area was irrigated using furrow flood irrigation and half was irrigated using a low-pressure overhead linear sprinkler system. Ground water was sampled during the growing season under both irrigation systems and analyzed for nitrate-N concentration. Nitrate-N concentration of irrigation water and run-off water was also measured. The type of irrigation did not affect stand, sucrose concentration, or root yield. Sodium (Na), potassium (K) and amino-N concentrations were significantly greater under sprinkler irrigation than under flood irrigation. Because of higher impurities, sugarbeet produced under sprinkler irrigation had greater sucrose loss to molasses (SLM) and lower extraction than sugarbeet produced under flood irrigation. Greater nitrate-N concentration was detected in ground water under flood irrigation than under sprinkler irrigation, and nitrate-N was detected in run-off water from flood irrigation. These data indicate that more leaching and run-off of available N occurs in a flood irrigation system than in a sprinkler irrigation system and that sprinkler irrigated sugarbeet probably needs less applied N than flood-irrigated sugarbeet because of reduced N losses to leaching and run-off.

Additional key words: *Beta vulgaris* L., irrigation, nitrate-N, ground

water.

Gravity furrow flood irrigation is the predominant irrigation system used to irrigate sugarbeet in the lower Yellowstone River Valley. Irrigation in this area is expanding with overhead sprinkler irrigation systems being used, because overhead sprinkler irrigation has greater application efficiency and is more labor efficient. Additional hectares now under flood irrigation are being converted to sprinkler irrigation systems.

Sugarbeet water use and irrigation has been studied extensively and much has been published concerning irrigation management of sugarbeet. Cassel and Bauer (1976) reported that sugarbeet needed 56-62 cm of water for optimum sugarbeet production. Draycott and Messem (1977) reviewed irrigation research conducted in eastern England and reported differences in the amount of irrigation water applied did not necessarily cause the differences detected in yield. They reported that timing of irrigation was more important than irrigation amount, with the main factor affecting yield being the length of the water deficit. Average precipitation during the growing season (April-September) in those studies was 30.7 cm. A number of studies which evaluated reduced irrigation reported that reduction of water late in the season reduced root yield, but increased sucrose concentration so that sucrose yield was not reduced (Hang and Miller, 1986; Yonts et al., 2003). Carter et al. (1980) reported that sucrose yield was not reduced much, if any, when irrigation was stopped late in the season, if the soil contained at least 200 mm available water to a depth of 160 cm. Tognetti, et al. (2003) compared sugarbeet response under drip and low-pressure sprinkler irrigation in Italy and reported that yield of drip-irrigated sugarbeet with 75% estimated evapotranspiration (ET) matched, in most cases, yield of sugarbeet irrigated with 100% estimated ET under low-pressure sprinkler. They did not test sprinkler irrigation with 75% ET.

Data comparing response of sugarbeet under furrow-flood irrigation with response of sugarbeet under low-pressure sprinkler irrigation is not available. The objectives of this study were to compare yield and quality of sugarbeet produced under these two irrigation systems, and to evaluate ground water quality differences under the two irrigation systems.

MATERIALS AND METHODS

This study was conducted at the Montana State University Eastern Agricultural Research Center in Sidney, Montana, from 1997-2002. Soil is Savage silty clay (fine montmorillonitic Typic Argiboroll) with 2.5% organic matter. Average growing season (April through September) precipitation is 27.5 cm.

The experimental sites were located in a field with sprinkler and flood irrigation capabilities. The test sites were located in different areas within the field from year to year. A four-year rotation of sugarbeet-small grain-potato-small grain was used. The entire field is approximately 10 ha, so in each year, sugarbeets under both irrigation treatments were within an area of about 2.5 ha. Each treatment was about 185 m long and 55 m wide. The two treatments were separated by a strip 55 m wide that was planted to potatoes. Sugarbeet was irrigated with either a low-pressure overhead linear sprinkler irrigation system or gravity furrow-flood irrigation system with gated pipe. The treatments were not randomized in the field each year because movement of linear wheels over furrows would destroy the furrows and make proper flood irrigation impossible. Because of this, sugarbeet yield and quality data were analyzed using years as reps.

In the fall prior to each planting season, eight soil samples of three cores each were collected to 120 cm in 30 cm increments from each irrigation system. Fertilizer rate was determined by soil tests and a recommended nitrogen (N) budget system (Halvorson and Hartman, 1975a; Halvorson and Hartman, 1975b). This budget is as following: total estimated N requirements for anticipated yield at 5 kg N/Mg of expected yield less kg soil nitrate-N to a depth of 120 cm less estimated N derived from soil organic matter (13.5 kg for each percent OM). The site was irrigated, fertilized, plowed, mulched twice, and leveled.

Sugarbeet was planted to stand at a rate of one seed every 14.2 cm with a row spacing of 61 cm (Eckhoff et al., 1991). Approximately 1-1.2 ha of sugarbeets were planted under each irrigation system. Table 1 shows planting and harvest dates and varieties used, and Table 2 shows irrigation dates. In 1997-2000, irrigation dates were determined using a Paul Brown probe and the “soil feel” method, in which soil moisture is estimated by observing how crumbly the soil is after squeezing some in the hand. In 2001 and 2002, tensiometers were used to schedule irrigation dates. Approximately 2.0-2.5 cm was applied with each sprinkler irrigation event and about 7.5 cm was applied with each flood irrigation event.

Two ground water monitoring wells were installed in each of the upper and lower ends of the field under each irrigation system, for a total of eight wells (four each under sprinkler irrigation and flood irrigation). Distance between wells in the upper and lower ends of the field was about 120 m. Ground water was sampled throughout the growing season to determine nitrate-N concentration. Water samples were

Table 1. Varieties, planting and harvest dates, residual soil nitrate-N and applied N for sugarbeet grown under low-pressure overhead sprinkler irrigation and furrow flood irrigation, Sidney, Montana, 1997-2002.

Year	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**
Variety	Beta 2398	Beta 1252	HH 112	Beta 2185	Beta 2185	Beta 2185
Planting date	May 6	Apr 22	Apr 28	Apr 21	May 1/ May 23†	May 4
Harvest date	Sep 25	Sep 18	Sep 21	Sep 18	Oct 1	Sep 26
Residual soil nitrate-N kg/ha, 120 cm	94	153	104	121	98	131
Applied N, kg/ha	91	33	58	42	65	34
Precipitation, Apr-Sep, cm	31.3	23.8	31.9	24.5	35.4	23.7
Precipitation, Jun-Aug, cm	24.1	17.2	20.5	15.6	26.9	16.1

† Planted May 1, sprinkler site wind damaged and replanted May 23

Table 2. Irrigation dates of sugarbeet grown under low-pressure overhead sprinkler irrigation and furrow flood irrigation, Sidney, Montana, 1997-2002.

1997		**1998**		**1999**	
Sprinkler	Flood	Sprinkler	Flood	Sprinkler	Flood
May 21	May 22	May 5	May 5	Jun 28	Jul 1
Jun 12	Jun 17	May 29	Jul 1	Jul 12	Jul 22
Jun 27	Jun 30	Jun 29	Jul 13	Jul 21	Aug 5
Jul 17	Jul 18	Jul 15	Jul 28	4 Aug	Aug 19
Jul 29	Jul 28	Jul 21	Aug 10	18 Aug	Sep 1
Aug 5	Aug 11	Jul 28	Aug 24	26 Aug	
Aug 18	Aug 25	Aug 3		2 Sep	
		Aug 12			
		Aug 25			
2000		**2001**		**2002**	
Sprinkler	Flood	Sprinkler	Flood	Sprinkler	Flood
Apr 25	May 3	May 10	May 10	May 22	May 22
Jun 14	Jun 26	May 17	Jul 6	Jun 20	Jul 4
Jun 28	Jul 14	Jun 22	Aug 3	Jul 12	Jul 15
Jul 18	Jul 26	Jul 6	Aug 14	Jul 23	Jul 29
Jul 28	Aug 7	Jul 10		Jul 31	Aug 13
Aug 18	Aug 18	Jul 20		Aug 7	
Sep 7	Aug 28	Aug 2		Aug 14	
Sep 14		Aug 14		Aug 27	
		Aug 22			
		Sep 4			

collected by pumping each well dry, then collecting recharge water. Samples of irrigation and run-off water were also collected for evaluation of nitrate-N concentration. Water samples were immediately filtered and frozen until nitrate-N analysis could be completed. Nitrate-N was measured using a Lachat Quik-Chem 8000 flow injector analyzer. Each year, sugarbeet samples were harvested from eight locations within each irrigation system. Four harvest sites within an irrigation system were located near each ground water sampling well, and four sites were evenly spaced between ground water sampling wells, from the top to the bottom of the field. Area of each harvested test site was 5.4 m^2. Root yields were determined in the field using a mobile scale attached to a sugarbeet plot harvester. Twelve to 15 sugarbeets were randomly selected from each harvested sample and used for tare and sucrose concentration determinations, which were measured in the tare lab at the Holly Sugar factory in Sidney, MT. Impurities and sucrose loss to molasses were measured at the Holly Sugar Laboratory in Sheridan, WY. Sugarbeet yield and quality data were averaged for each irrigation system for each year, and the averages were analyzed using a single factor ANOVA with years as replications. The sprinkler site was to the north of the flood site in 2001 and severe north winds with blowing soil after planting and emergence damaged seedlings under the sprinkler system. That portion of the field was replanted on May 23. Because of the difference in planting dates, sugarbeet yield and quality data from 2001 were not included in the analyses.

Three soil cores, each 120 cm in 30 cm increments, were obtained from eight sites in each irrigation system immediately following harvest to test for residual soil nitrate-N, potassium and phosphate. Data were averaged for each irrigation system for each year, and the averages were analyzed using a single factor ANOVA with years as replications.

RESULTS

Plant populations under the two irrigation systems were similar (Table 3). Stands were lower in general in 1998, 2000, and 2002, compared to 1997 and 1999, because of dry conditions at planting, and plots were irrigated early in those years to improve germination and emergence (Table 2). Sucrose concentration, root yield, and sucrose yield were not significantly different between sugarbeet grown under sprinkler irrigation and sugarbeet grown under flood irrigation (Table 3).

Sugarbeet grown under sprinkler irrigation had greater concentrations of the impurities sodium (Na), potassium (K), and amino-N than sugarbeet produced under flood irrigation (Table 3). The

Table 3. Yield and quality of sugarbeet grown under low-pressure overhead sprinkler and furrow flood irrigation, Sidney, Montana, 1997-2002.

irrigation	plants ha^{-1}	sucrose gm kg^{-1}	root yield, Mg ha^{-1}	sucrose yield, kg ha^{-1}	Na, ppm	K, ppm	amino-N, ppm	SLM	percent extraction
sprinkler	88,920	169.8	57.7	9861	512	1770	277	1.33	92.0
flood	83,360	175.4	61.1	10748	347	1627	180	1.05	93.9
probability	0.648	0.260	0.357	0.226	0.020	0.021	0.002	0.004	0.009
CV (S/mean)	15.1	3.7	7.6	9.2	17.6	3.8	10.7	6.8	0.7
CV (SE/mean)	6.7	1.6	3.4	4.1	7.9	1.7	4.8	3.0	0.3
LSD0.05	ns	ns	ns	ns	132	114	43	0.14	1.2

Table 4. Soil residual nutrients following sprinkler and flood irrigated sugarbeet, Sidney, Montana, 1997-2002.

	N, kg/ha 0-30 cm	N, kg/ha 30-120 cm	N, kg/ha 0-120 cm	P, ppm 0-15 cm	K, ppm 0-15 cm
Sprinkler	15	22	37	21	522
Flood	12	19	31	24	467
probability	0.192	0.0985	0.075	0.283	0.081
CV (S/mean)	22.7	14.6	14.6	17.1	9.2
CV (SE/mean)	9.3	6.0	5.9	7.0	3.8

increased impurities significantly increased SLM and lowered extraction rate under sprinkler irrigation compared to flood irrigation.

Nitrate-N concentration was greater in ground water under flood irrigation than in ground water under sprinkler irrigation in five of the six years (Fig. 1). In most cases, ground water nitrate-N concentration increased sooner under flood irrigation than under sprinkler irrigation, and remained higher throughout the season. Nitrate-N content in ground water under sprinkler irrigation generally remained fairly constant through the growing season, while nitrate-N concentration under flood irrigation increased by a factor of two or more in four of the six years.

Irrigation water and run-off water from flood irrigation were analyzed for nitrate-N concentration. The sprinkler irrigation system produced no run-off. Nitrate-N content in run-off water was not measured in 2001. Nitrate-N concentration in irrigation water was usually less than 1 ppm, while run-off water always contained at least twice as much nitrate-N as the irrigation water applied to the field (Fig. 1).

Soil was sampled to a depth of 120 cm in 30 cm increments each year following harvest (Table 4). Residual soil nitrate-N to a depth of 120 cm was greater following sprinkler irrigated sugarbeet than flood irrigated sugarbeet. Residual soil K to a depth of 15 cm was also greater following sprinkler irrigated sugarbeet than flood irrigated sugarbeet. There were no differences between the two irrigation methods in residual soil nitrate-N to a depth of 30 cm or residual soil P to a depth of 15 cm.

DISCUSSION

Less water was applied with sprinkler irrigation than with flood irrigation, but no differences were detected in stand, root yield, or sucrose yield between the two irrigation methods. Sucrose concentration was lower in all years under the sprinkler irrigation than flood irrigation, with a difference of about 5 gm kg^{-1} when averaged across years, although this difference was not statistically significant (Table 3).

Concentrations of Na, K, and amino-N were greater in sugarbeet under sprinkler irrigation than in sugarbeet under flood irrigation in all years, and significantly so when analyzed across years (Table 3). These data suggest that more N was available to the sugarbeet under sprinkler irrigation than to the sugarbeet under flood irrigation, particularly at the end of the growing season, when excess available N contributes to a lower sucrose concentration and higher concentrations of impurities (Halvorson et al., 1978; Carter, 1986).

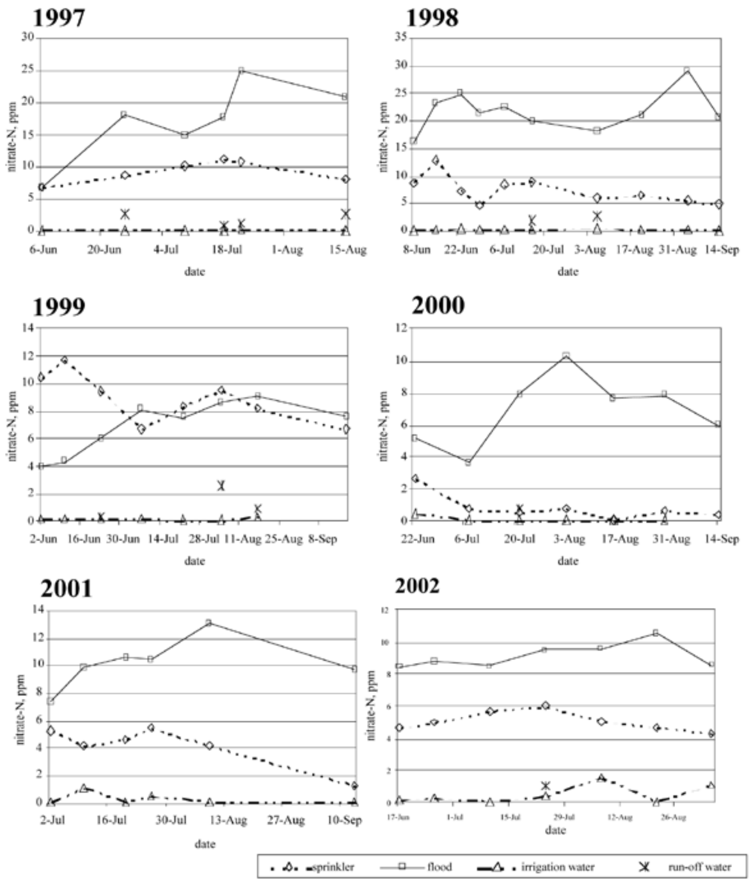

Fig. 1. Nitrate-N (ppm) in ground water under sprinkler and flood irrigated sugarbeet, in water used for irrigation, and in run-off water from flood irrigation. Ground water nitrate-N concentrations are each an average of four wells, Sidney, Montana, 1997-2002.

Irrigation water running off the lower end of the furrow-flood irrigated fields contained more nitrate-N than the irrigation water applied to the field (Fig. 1). Sprinkler irrigation in this study had no run-off so no nitrate-N was lost to run-off under the sprinkler system. Fields in which run-off occurs during sprinkler irrigation events would probably lose some nitrate-N in run-off water. Nitrate-N content in run-off water was still greater than nitrate-N content in irrigation water in July and August, after several irrigation events. This indicates that N continued to be lost to flood irrigated sugarbeet late in the season due to runoff. Because there was no runoff under sprinkler irrigation, N would not be lost to runoff under sprinkler irrigation at any time during the growing season, and thus, would still be available to the sugarbeets under sprinkler irrigation.

Nitrate-N concentration was greater in ground water under flood irrigation than in ground water under sprinkler irrigation in all years except 1999 (Fig. 1). Nitrate-N concentration in ground water increased sooner under flood irrigation than under sprinkler irrigation, and remained greater throughout the season. Nitrate-N concentration in ground water under sprinkler irrigation usually remained fairly constant through the growing season, while nitrate-N concentration in ground water under flood irrigation increased by a factor of two or more in four of the six years.

Residual soil nitrate-N was greater following sprinkler irrigated sugarbeet than flood irrigated sugarbeet (Table 4), indicating less loss to leaching. Winter (1986) reported that in furrow flood irrigated fields, soil nitrate-N content was low in the upper portions of the field and high in the lower portions of the field, due to increased leaching at the upper end of the field where the water stood longer. He observed that nitrate-N below 120 cm had measurable effect on sugarbeet quality, and flood irrigated land had high rates of nitrate-N below 120 cm, probably from leaching.

The U.S. Environmental Protection Agency has established the maximum contaminant level of nitrate-N in drinking water for human consumption as 10 ppm (USEPA, 1973). Nitrate-N in ground water under sprinkler irrigated sugarbeet in this study exceeded that amount in two years, 10.7 ppm in 1997 and 10.1-12.7 ppm in 1999. Nitrate-N in ground water under flood irrigation exceeded 10 ppm in three of the years in this study, with concentrations as high as 24.8 ppm in 1997, 29 ppm in 1998, and 13 ppm in 2001. The years 1997 and 2001 had the greatest precipitation from June to August (Table 1). Precipitation was less during the 1999 growing season, but the ground water nitrate-N concentration started at a very high concentration. The site in the field with sugarbeet in 1999 was planted to durum in 1998. Irrigated durum yields in 1998 were lower than normal due to higher than average temperatures during the growing season. This reduced yield may have resulted in less N used by the durum crop, resulting in more N leaching into the groundwater.

SUMMARY

Quality of sugarbeet under the sprinkler was consistently lower than that of sugarbeet under flood irrigation, with Na, K, and amino-N concentrations being greater under sprinkler irrigation than under flood irrigation every year. Because of the higher impurity content, sugarbeet under sprinkler irrigation had greater sucrose loss to molasses and corresponding lower extraction rates than flood irrigated sugarbeet. More nitrate-N was detected in ground water under flood irrigation than under sprinkler irrigation, and nitrate-N concentration in run-off water from flood irrigation was greater than nitrate-N concentration in irrigation water going into the field. At the same time, soil nitrate-N was greater following sugarbeet under sprinkler irrigation than sugarbeet under flood irrigation. These data indicate that flood irrigation results in more leaching and run-off of available nitrate-N than sprinkler irrigation. Nitrogen budgets for the lower Yellowstone River Valley were developed under flood irrigation systems. Sprinkler irrigated sugarbeet may need less applied N than flood irrigated sugarbeet because of less loss to leaching and run-off, suggesting that sprinkler irrigated sugarbeet and flood irrigated sugarbeet may require different N budgets.

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