Nitrogen Fertigation Interval for Sugarbeet Grown on Soils With a High Leaching Potential

Wm. Bart Stevens, William M. Iversen, and Jay D. Jabro

USDA-ARS Northern Plains Agricultural Research Laboratory, 1500 North Central Ave., Sidney, MT 59270

Corresponding author: Wm. Bart Stevens
bart.stevens@ars.usda.gov

ABSTRACT

Nitrogen (N) management for sugarbeet is challenging due to the variable effects of weather on soil N transformations and N losses, and may be particularly difficult on soils subject to N leaching. A field study was conducted to determine if extending the in-season N application termination date beyond the conventional cutoff date of 10 weeks after planting would improve sucrose yield. Three in-season N application timing treatments were evaluated, each consisting of three fertigation events totaling 84 kg N ha^{-1} in addition to a preplant application of 67 kg N ha^{-1}. Treatments were 28 kg N ha^{-1} applied: (1) every 7-8 days from June 15 to June 30 (10 weeks after planting); (2) every 14-16 days from June 15 to July 15; and (3) every 28 to 32 days from June 15 to August 15. Treatments did not affect yield components, except in 2009 when terminating N application on August 15 reduced root sucrose concentration by 6.0 g kg^{-1}. Compared to the conventional June 30 cutoff, gross economic return was negligible for the July 15 cutoff and was consistently negative (–\$146 ha^{-1}) for the August 15 cutoff showing no advantage to extending the N application period beyond June 30.

Additional key words: *Beta vulgaris,* recoverable sucrose, fertilizer application timing, fertigation

Abbreviations: ET, evapotranspiration; SLM, sugar loss to molasses

Maximizing sucrose yield in sugarbeet (*Beta vulgaris* L.) production requires balancing the offsetting effects of N availability on root yield and root sucrose concentration. Moreover, excessive N application is known to increase root impurities that interfere with sucrose extraction during processing (Halvorson and Hartman, 1980). Root sucrose concentration and extractability are typically greatest when sugarbeet plants become N-deficient from 4 to 6 weeks prior to harvest (Hill, 1984). Nitrogen fertilizer applied too late in the growing season has been shown to negatively affect root sucrose concentration and impurities (Carter and Traveller, 1981). Consequently, N applications after early July are not allowed under the terms of most grower contracts in northern U.S. growing areas. Hill (1984) emphasized that optimum sucrose production usually is achieved when the entire N fertilizer requirement is applied prior to planting to encourage rapid canopy development and to maximize the interception of sunlight. Nitrogen fertilizer applied late in the growing season has been reported to provide little improvement in root yield while significantly reducing quality (Halvorson and Hartman, 1980; Carter and Traveller, 1981). In contrast, it has also been reported that mid-season N applications can prove beneficial when sugarbeet plants are N-deficient and soil moisture is not limiting (Lamb and Morgan, 1993). Wiesler et al. (2002) concluded that split N applications can maximize sucrose yield even when the final application occurs relatively late in the growing season (16 weeks after planting), but cautioned that the success of this practice will vary according to late season weather conditions. Most of this research was conducted more than 20 years ago with some (e.g., Carter and Traveller, 1981; Hill, 1984) carried out more than 35 years ago and production practices have changed considerably since then. Sugarbeet yields have increased by approximately 45% (Panella et al., 2014) due, at least in part, to improved genetics and more efficient agronomic practices. Nitrogen response was not shown to vary among conventional sugarbeet varieties (Stevens et al., 2009) but the introduction of glyphosate-tolerant traits has had a significant positive effect on plant health, growth characteristics and yield (Morishita, 2016) and these improvements might affect N uptake patterns compared to older varieties. Over the past four decades a significant portion of surface irrigated crop production has been replaced by overhead sprinkler irrigation (Stubbs, 2016) which increases water application efficiency from 45 – 65% with surface practices to 75 – 85% with overhead sprinklers (Irmak et al., 2011). Improved water application efficiency leads to greater N use efficiency (Eckhoff et al., 2005). Because of these factors, combined with variable effects of weather on soil N mineralization/immobilization reactions and N loss through denitrification, ammonia volatilization and nitrate leaching, it continues to be challenging to predict N requirements and provide the optimum amount of available N to the growing sugarbeet plant, especially late in the growing season.

Difficulties managing late-season N availability are often exacerbated on fields with sandy soils due to high rates of water infiltration and internal drainage and lower water holding capacities. Though irrigation prevents low moisture stress on these soil types, excessive rainfall during the early or middle parts of the growing season can result in N leaching and early onset of N deficiency symptoms. In-season applications combined with pre-plant applications may be recommended as a means to increase N-use efficiency and yield on coarse textured soils (Wolkowski et al., 1995; Moore et al., 2009). Given the reduced nutrient holding capacity of sandy soils compared to fine-textured soils, it may be beneficial to extend the period of N application later into the growing season so as to prevent premature N deficiency. Overhead sprinkler irrigation allows for convenient application of N regardless of crop growth stage. Fertilizer N can easily be split into multiple applications with part applied preplant and the remainder applied through one or more fertigation applications. It has been shown that for potato and corn such an approach consistently improves fertilizer N use efficiency and may improve yield when weather conditions favor N loss (Wolkowski et al., 1995). It is unclear if the production of recoverable sucrose can be enhanced by extending the N application period for sugarbeet grown on sandy soils beyond the typical contract cutoff date used for fine-textured soils. Our objective was to compare the conventional practice of terminating N application by June 30 (10 weeks after planting) to that of extending the termination date to either July 15 or August 15 (12 or 16 weeks after planting, respectively). It was hypothesized that extending N application to July 15 may be beneficial due to the well-drained soil type, but that applying N on August 15 would likely decrease sucrose yield by causing a decrease in root sucrose concentration.

MATERIALS AND METHODS

A field study was conducted from 2007 to 2009 at the North Dakota State University Williston Research Extension Center Irrigation Research and Development Project at Nesson Valley (approximately 37 km east of Williston, ND; 48.1640 N, 103.0986 W). Soil at the research facility is mapped as Lihen sandy loam (sandy, mixed, frigid Entic Haplustoll) consisting of very deep, somewhat excessively or well drained, nearly level soil that formed in sandy alluvium, glacio-fluvial, and eolian deposits in places over till or sedimentary bedrock. Detailed soil characteristics for the study site were reported earlier based on laboratory analysis of soil samples collected at the study site (Jabro et al., 2016; Sainju et al., 2010). In brief, respective sand, silt, and clay contents were 725, 184, and 91 g kg^{-1} for the 0- to 40-cm soil layer. Soil pH was 7.7 and soil organic C concentration was 10.9 g kg^{-1} (0 to 20 cm).

Experimental units were 15.2 x 18.3 m plots, which were arranged in a randomized complete block design with five replications. Treatments consisted of three different in-season fertilizer application timing schedules. The experiment location was changed each year between adjacent fields where a 2-yr rotation of sugarbeet and barley (*Hordeum vulgare* L.) had been established since 2005. Plots were tilled each year in the spring using one pass with a disk followed by two passes with a mulching seedbed conditioner equipped with S-tine spring teeth and two rollers (Brillion Inc., Brillion, WI). Dry fertilizers (urea, monoammonium phosphate and potassium chloride) were broadcast immediately prior to tillage. Based on current North Dakota State University soil fertility guidelines (Franzen, 2018), soil test P (7 mg kg^{-1}) was low and soil test K (83 mg kg^{-1}) was well below the 120 mg kg^{-1} critical value in some areas of the study site. To ensure these nutrients did not limit yield and to build up soil test nutrient levels, P fertilizer was applied at 168 kg P_2O_5 ha^{-1} and K fertilizer was applied at 187 kg K_2O ha^{-1} in each of the study years representing 2.7 and 1.9 times the recommended application amounts, respectively (Franzen, 2018). The preplant level of available soil N was estimated to be about 34 kg ha^{-1} based on 1.2 m soil samples collected each fall following malt barley harvest. Urea was applied preplant to all plots at a rate of 67 kg N ha^{-1}. Sugarbeet seed (glyphosate-tolerant variety BTS 47RR31, Betaseed Inc., Shakopee, MN) was planted 2.5 cm deep in early spring each year (Table 1) at 135,000 seeds ha^{-1} in rows spaced 61 cm apart.

Table 1. Dates when selected field operations were performed in each of three study years at the North Dakota State University Williston Research Extension Center Irrigation Research and Development Project near Williston, North Dakota.

Operation	2007	2008	2009
Pre-plant fertilizer	April 19	April 30	May 4
Tillage	April 23	April 30	May 5
Planting	April 24	May 1	May 6
First fertigation	June 15	June 20	June 23
Last fertigation	August 17	August 15	August 26
Harvest	September 24	September 23	September 23

Three in-season N application timing treatments were compared, each consisting of three 28-kg-N-ha^{-1} fertigation events. Season total fertilizer N application rate was 151 kg N ha^{-1} for all timing treatments providing 185 kg N ha^{-1} total available N (residual soil nitrate + fertilizer N). Application timing treatments were: (1) N applied every 8 days beginning June 15 (approximately the 8-leaf growth stage) and ending

June 30 (conventional cutoff date of 10 weeks after planting); (2) N applied every 16 days beginning June 15 and ending July 15 (12 weeks after planting); and (3) N applied every 32 days beginning June 15 and ending August 15 (16 weeks after planting). Actual beginning and ending application dates (Table 1) varied from target dates somewhat based on weather conditions and other scheduling interferences. In-season N was applied as urea-ammonium nitrate (28% N) solution through a self-propelled linear-move overhead sprinkler system (Valmont Irrigation, Valley, NE) modified to allow differential irrigation to each plot. Detailed information about the irrigation system was provided by Evans et al. (2010). A water application depth of 1.27 cm was used for each fertigation event. The same amount of N was applied for all application timing treatments. Irrigation applications other than fertigation events were scheduled based on calculated crop water use data obtained from the North Dakota Agricultural Weather Network (NDAWN) website (http://ndawn.ndsu.nodak.edu/crop-water-use-table-form.html). Daily reference evapotranspiration (ET) values were automatically calculated by NDAWN using a modified Jensen-Haise equation (Burman et al., 1983). Reference ET values were multiplied by a crop water-use coefficient (K_c) for sugarbeet (Stegman et al., 1977) to estimate crop water use. The depth of irrigation water applied to each plot was based on the estimated ET adjusted for rainfall, soil moisture, and an assumed application efficiency of 85% that was selected based on average values from various field studies reviewed by Schneider (2000).

Harvestable (> 5 cm diameter) sugarbeet roots were collected in late September (Table 1) from two randomly selected 1.85-m^2 areas within each plot. Roots were hand-harvested using a shovel, separated from the tops with a knife, and placed in a bag for delivery to the Sidney Sugars, Inc. (Sidney, MT) tare laboratory where they were cleaned, weighed and analyzed for sucrose concentration. A brei extract was collected at the tare laboratory and sent to AgTerra Technologies, Inc. (Sheridan, WY) for impurity analysis. Recoverable sucrose yield was calculated by multiplying the fresh-weight root yield (Mg ha^{-1}) by the fresh-weight root sucrose concentration (g kg^{-1}) adjusted for sugar loss to molasses (SLM; g kg^{-1}).

Economic impact of delayed N timing treatments was estimated by subtracting the gross return resulting from the alternative timing (16 or 32 days) from that of the conventional timing (8 days). Gross return was calculated based on a payment of \$54 Mg^{-1} of fresh root yield at 175.0 g kg^{-1} sucrose adjusted by \$4.41 Mg^{-1} for each 10 g kg^{-1} change in root sucrose concentration. Sugar loss to molasses was not included as a factor in the Sidney Sugars, Inc. payment calculation at the time of publication (D. Peters, personal communication, 2018).

Analysis of variance was performed using the MIXED procedure of SAS (SAS Version 9.2; SAS Institute; Cary, NC) treating N application timing and year as fixed effects. Block and block interactions were considered random effects. Year was considered fixed rather than random due to notable weather differences among study years. Response variables that exhibited interactions with year were analyzed within years. Least squares means, with probability differences, were estimated to determine significant differences among treatment means. Effects were considered significant if p was ≤0.05.

RESULTS

Temperature and precipitation were near or below long-term averages for all three years (Table 2), but growing conditions were generally favorable with no highly unusual weather events such as freezing temperatures or hail. Average temperature for the May to September growing season was near normal in 2007 but substantially cooler in 2008 and 2009. Estimated crop water use was predictably related to mean air temperature such that lower seasonal crop water use values occurred in cooler years (compare Tables 2 and 3). Cumulative precipitation for the growing season was below normal in 2007 but 2008 was particularly dry (31.0 and 65.8 mm below average, respectively). Precipitation for the 2009 growing season was near long-term averages falling only 12.2 mm below average. Dry conditions did not adversely affect growth because soil moisture was maintained with supplemental irrigation. The sum of precipitation and effective irrigation was between 37 and 71 mm greater than estimated crop water use in each of the three study years (Table 3). This suggests that water inputs should have been sufficient to meet the crop ET demand but may have also been enough to leach nitrate-N, especially in in 2007 and 2009.

Table 2. Difference between actual temperature and precipitation for the study period compared to long-term averages. Data are for the months of May through September in each of the three study years (2007-2009) as recorded by a weather station at the research site (Hofflund) east of Williston, ND (source: https://ndawn.ndsu.nodak.edu/).

Year	Departure from average		Months with excess§ precipitation	Departure from average monthly precipitation (mm)
	Temperature† (C)	Precipitation‡ (mm)		
2007	0.22	–31.0	May	+48.8 (46.2)¶
2008	–0.89	–65.8	None	--
2009	–1.33	–12.2	July	+47.2 (72.9)

†Based on average temperatures for the period of May 1 through September 30.
‡Based on cumulative precipitation amounts for the period of May 1 through September 30.
§Precipitation amount was defined as excess when actual precipitation was at least 50% greater than average.
¶Departure from average for the month indicated in the preceding column. Numbers in parentheses show amount of precipitation falling in the largest event during the given month.

Table 3. Precipitation and irrigation compared to estimated crop water use for the three study years (2007-2009). Weather data are for the months of May through September in each of the three study years as recorded by a weather station at the research site (Hofflund) east of Williston, ND (source: https://ndawn.ndsu.nodak.edu/).

Year	Crop Water Use†	Precipitation	Effective Irrigation‡	Precipitation + Irrigation
		mm		
2007	609	224	456	680
2008	565	211	391	602
2009	465	266	259	525

†Crop water use was estimated using daily weather data entered into the Jensen-Haise equation (Burman et al., 1983).
‡Effective irrigation amount was calculated as 85% of the amount of irrigation water applied to account for estimated application inefficiencies.

The interval between fertigation applications had little impact on sugarbeet yield components. When averaged across the three study years, root yield, root sucrose concentration and recoverable sucrose yield varied by only 1.9 Mg ha^{-1}, 2.8 g kg^{-1}, and 388 kg ha^{-1}, respectively, for the different N application timing treatments and none of these differences was statistically significant (Table 4). When results from each year were evaluated separately, it is clear that extending the N application period into July or August did not increase root yield. The application interval effect was not significant for any of the three individual years and the 32-day interval resulted in the lowest value observed for root yield in each year (Table 4). Root sucrose concentration was significantly affected by N application interval only in 2009 when the latest fertigation treatment (target ending date, August 15) caused a 6.0-g-kg^{-1} decrease compared to the conventional treatment (target ending date, June 30). No pattern is apparent in the 2007 root sucrose concentration results while in 2008 root sucrose concentration values were lower with both the 16- and 32-day intervals than with the conventional practice, though these differences were not significant. Sugar loss to molasses was noticeably lower in 2007 under more typical weather conditions than in the other two years when the average growing season temperature was lower than the long-term average. Differences in SLM among N application interval treatments were not significant in any year and there is no clear trend. Given that recoverable sucrose yield is calculated from root yield, root sucrose concentration and SLM, it is not surprising that the effect of N application interval on overall sucrose yield was not statistically significant, though the lowest value in each year occurred when the final N application was delayed the most.

DISCUSSION

Few significant differences were observed among treatment means, but some observations and discussion may be beneficial as results are considered within the context of weather conditions each of the three years. The 2007 growing season (May through October), was characterized by an average air temperature that was near normal and total precipitation that was 31.0 mm below average but it is noteworthy that May precipitation was 48.8 mm above the long-term average (Table 2). Moreover, there was a single rain event in late May totaling 46.2 mm. Crop water use from May 8 (emergence date) to May 31 averaged only about 1.0 mm d^{-1} and totaled 24.6 mm. Given this low rate of water use, the excess precipitation may have been sufficient to cause some nitrate-N to leach beyond the root zone in the well-drained sandy loam soil, potentially explaining the lower root yield and higher root sucrose concentration observed in 2007 (Table 4). Because this rain event occurred before fertigation applications began on June 15, it affected all treatments equally resulting in little if any difference in yield across N application timing treatments. Rapid development of the leaf canopy is crucial to maximizing photosynthetic production of sucrose but leaf expansion is dependent primarily on favorable spring temperatures and adequate N availability (Milford et al., 1985a, b). Stevens et al. (2007) showed that increasing early season N availability by placing preplant N close to the sugarbeet row improved sucrose yield by 603 kg ha^{-1} compared to broadcast application. However, in well-drained soil, excessive early-season precipitation may reduce availability by leaching N beyond the root zone. An advantage of in-season N application is that the portion of N applied is not subject to leaching loss during early-season rain events that occur before the period of rapid N uptake begins. However, in our study a 2 to 3 week period of N deficiency stress may have occurred before supplemental N was applied. This period of deficiency could have potentially reduced yield by up to 3 Mg ha^{-1} (Milford et al., 1985b). Splitting the total N fertilizer application using fertigation apparently did not overcome any early season N deficiency that may have been caused by excessive May precipitation. Other researchers have reported similarly that mid- to late-season N applications failed to rescue sugarbeet from stress caused by low soil N during earlier growth stages (Carter and Traveller, 1981; Lamb and Moragahn, 1993).

In contrast to 2007, there were no unusually heavy rain events in 2008 to cause nitrate-N leaching (Table 2). Precipitation was well below the long-term average in both May and July. Root yield with the conventional practice of terminating N application on June 30 was good (72.8 Mg ha^{-1}) and root sucrose concentration was a little below average for the region (172.2 g kg^{-1}) suggesting that N availability was sufficient throughout the growing season. Extending the last N application into July or August did not improve root yield and may have decreased sucrose concentration slightly, though differences were not significant. This non-significant trend is in agreement with results reported by Carter and Traveller (1981) showing that applying N in mid-July or mid-August decreased extractable sucrose.

The 2009 growing season began with temperatures much cooler than average. Soil temperature remained at or below 4 C throughout April, delaying planting until May 6 (Table 1). The season-average air temperature was much cooler than the long-term average but precipitation was near normal (Table 2). As in 2007, there was a significant leaching event but it occurred later in the season on July 7 and 8 when 72.9 mm of rain fell. The conditions were exacerbated three days prior (July 3 and 4) when a separate rain event, combined with a light irrigation, resulted in 36.3 mm of water for a 6-day total of 109.2 mm. These events, combined with the late planting date and overall cooler conditions, seem to have reduced yield of all treatments equally. Delaying N application until after the July 7-8 rain event did not increase root yield. However, there was a significant decrease in root sucrose concentration when the last N application extended until August 26 (the latest application date in the 3-year study), causing the largest decrease in gross return (–\$192 ha^{-1}) observed in the 3-year study (Table 5). These results agree with those of Carter and Traveller (1981) who showed that N added in mid-August increases top growth at the expense of root growth and sucrose accumulation in roots. They estimated that N applied in late July or late August caused a high percentage of photosynthate to be partitioned to dry matter production in plant tops at the expense of dry matter and sucrose accumulation in roots. Consequently, these authors concluded that sucrose yield will be reduced when N is added from late July through early September. Stevens et al. (2009) also reported an inverse relationship between top growth and sucrose yield when late season N availability was increased due to excessive amounts of N being applied to eight sugarbeet varieties.

When treatment means were averaged over the 3-yr study period, there were no significant differences among N application timing treatments (Table 4) for any of the yield components. Even when N application was delayed well past the typical June 30 cutoff date, sucrose yield was somewhat surprisingly not affected, yet it is noteworthy that the latest N termination treatment produced the lowest numerical sucrose yield values in each of the three years (Table 4). Given the lack of treatment effects on agronomic parameters, it follows that few conclusions regarding economic return can be drawn within typical confidence limits. The change in gross economic return resulting from the alternative fertigation intervals was negligible (3-year average of –\$12.19 ha^{-1}) when the last application occurred in mid-July and was consistently negative (3-year average of –\$146 ha^{-1}) when the last application occurred in mid- to late August (Table 5). These results confirm that there is no economic advantage to delaying the final N application beyond June 30 and suggest that delaying N application until August 15 or later will reduce economic return.

Table 4. Sugarbeet yield and quality as affected by N fertigation interval and last application date. Actual application dates varied somewhat from target dates due to weather and other scheduling interferences. First and last fertigation dates are given in Table 1.

Target Application interval days	Target date of last N application	Root yield	Root sucrose concentration	SLM	Recoverable sucrose yield†
		Mg ha^{-1}	g kg^{-1}	g kg^{-1}	kg ha^{-1}
			2007		
8	June 30	63.8	185.1	6.76	11337
16	July 15	65.6	183.8	7.31	11571
32	Aug 15	62.4	185.4	7.03	11092
		ns	***ns***	***ns***	***ns***
			2008		
8	June 30	72.8	172.2	9.01	11873
16	July 15	72.5	168.0	9.80	11426
32	Aug 15	71.6	168.5	8.87	11416
		ns	***ns***	***ns***	***ns***
			2009		
8	June 30	63.3	182.8 a	10.61	10880
16	July 15	64.4	182.0 a	10.56	11017
32	Aug 15	62.9	176.8 b	10.44	10416
		ns	*	***ns***	***ns***
			3-yr Average		
8	June 30	66.6	178.7	8.79	11363
16	July 15	67.5	175.9	9.22	11338
32	Aug 15	65.6	177.0	8.78	10975
		ns	***ns***	***ns***	***ns***

*Treatment means within the year indicated are significantly different ($P \leq 0.05$); ***ns*** indicates that treatment means within the year indicated are not significantly different.

†Adjusted for SLM (sugar loss to molasses).

Table 5. Change in gross return of sugarbeet as affected by delayed N application. Values represent the increase (+) or decrease (–) in gross revenue produced by each delayed N application date (July 15 or August 15) compared to the conventional practice of applying N no later than June 30.

Application interval days	Date of last N application	2007	2008	2009	Average
Gross return†, \$ ha^{-1}					
16	July 15	+\$67	–\$146	+\$42	–\$12
32	Aug 15	–\$70	–\$176	–\$192	–\$146

†Gross return was calculated based on a payment of \$54 Mg^{-1} at 175.0 g kg^{-1} sucrose adjusted by \$4.41 Mg^{-1} for each 10.0 g kg^{-1} change in root sucrose concentration. Sugar loss to molasses was not included in the calculation.

SUMMARY AND CONCLUSIONS

Sugarbeet producers have reported that sugarbeet yield is sometimes unsatisfactory on sandy soils, raising questions about whether N applied later in the growing season might compensate for N leaching losses and improve late-season plant vigor and sucrose yield. Results showed no benefit to extending the N application period beyond the conventional June 30 cutoff date (10 weeks after planting). In one of three years, applying N through July and terminating on August 15 (16 weeks after planting) caused lower root sucrose concentration. It was concluded that:

1) Extending the June 30 N application termination date to either mid-July or mid- to late August did not improve sucrose yield.
2) In one of three years, late N application reduced root sucrose concentration by 6.0 g kg^{-1}.
3) Gross return was reduced by an average of –\$146 ha^{-1} due to reduced root sucrose concentration when the last fertigation occurred on August 15 or later.

The practice of applying additional N (i.e., above the recommended N rate) after June 30 was not evaluated in this study. This may have been beneficial in 2007 when early season leaching may have decreased N availability for the remainder of the growing season. Conversely, the late August application of N in 2009 was detrimental even after a substantial leaching event in early July 2009. Thus, overall results suggest that applying additional N late in the growing season is not beneficial even on sandy textured soils where N is easily leached.

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