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Nitrogen Source, Timing, and Rate Alternatives for Furrow-irrigated Sugarbeet

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Abstract

Furrow irrigation poses particular challenges for optimizing sugarbeet (*Beta vulgaris*) nitrogen uptake. The purpose of this research was to evaluate six N sources available to sugarbeet producers, including three dry products (urea and two enhanced-efficiency urea products) and three fluid products [urea-ammonium-nitrate (UAN)-32 and two enhanced-efficiency fluid products]. Products were evaluated at two application timings (split preplant and side dress, and all preplant) and two rates (typical grower rate and soil-test-based rate). Results show subtle but possibly economically important differences in sugar yield, with knife-injected fluid UAN-based products performing best. These fluid N sources performed as well at soil-test-based N rates as at the higher N rates.

Introduction

Flood irrigation techniques are notoriously inefficient with respect to water application and pose special challenges for soil fertility management (9,24). Nitrogen management can be especially challenging because of the crucial nature of adequate N at the right time for optimal sugar production and the high potential of loss through leaching, volatilization, and denitrification (16). Enhanced-efficiency N sources that reduce these losses may be beneficial for producers of furrow-irrigated sugarbeet.

Plants produce sugar through canopy light interception, so in sugarbeet production, rapid early canopy development is crucial for optimal sugar content and depends upon an adequate supply of readily available N early in the season until full canopy cover (> 85% cover) is reached (17). Sugarbeet plants can continue to take up N after that, potentially consuming an additional 100 lbs N/acre and increasing above-ground dry matter three fold, but the additional biomass does not contribute to increased sugar yield. Malnou et al. (17) established that N additions in sugarbeet production are necessary only for rapid early canopy growth and not for canopy maintenance later in the season. Excess N is often transported deep into the soil profile and can cause a reduction of extractable sugar as fine roots penetrate two to three meters or deeper in late summer (22).

Enhanced-efficiency solid and fluid N fertilizers developed in response to both environmental and economic concerns have proven to be profitable and beneficial to the environment for use on many crops (4,19). While much is known about sugarbeet N fertilizer rates [e.g. (1,14,23)], timing (8,13,17), and placement (24,25), information is needed about interactions among relatively new enhanced-efficiency fertilizer N sources and other factors, such as timing and rate. While results from studies on use of new enhanced-efficiency fertilizers on sugarbeet are scarce, research on more traditional slow-release materials like manure (12), biomass (15), and cover crops (5) show promising results for these N sources.

Objectives of this research were to evaluate six N sources available to sugarbeet producers applied under two timing approaches (all preplant vs. split preplant & sidedress) at three N rates. We measured soil N dynamics and the yield of roots and sugar to address four research questions: (i) Do enhanced-efficiency N fertilizers provide advantages for sugar-beet production? (ii) Do fluid fertilizers provide advantages? (iii) How does sugar production resulting from soil-test based fertilizer N rates compare to sugar production resulting from a higher rate typically used by north-central Wyoming sugarbeet producers (18)? And (iv) how does split application of N compare to all-preplant application?

Study Site

Field studies were conducted at the University of Wyoming Research and Extension Center at Powell, in the Bighorn Basin of northwestern Wyoming (44°45'45"N, 108°45'17"W; 4350-ft elevation). Thirty-year mean annual precipitation at the Powell field station is 6.90 inches, over 50% (3.7 inches) of which comes during May, June, and July, and nearly 80% of which (5.4 inches) comes during April through September (26). The mean annual temperature is 44.2°F, with very warm summer months. Average maximum and minimum daily temperatures are over 85°F and 50°F, respectively, during July and August (26). Soil at the station is classified as Garland series (fine-loamy over sandy or sandy-skeletal, mixed, superactive, mesic Typic Haplargids) and consists of 20 to 50 inches of clay loam and loam underlain by basalt sand, gravel, and cobbles.

Farming Practices

Each sugarbeet crop evaluated was preceded by barley (*Hordeum vulgare* L.) from which the crop residue was left on the field. Primary tillage was done by moldboard plow in the fall and secondary tillage by two passes with a roller harrow and two passes with a leveling blade in the spring prior to planting. Sugarbeet seed (variety HM Treasure in 2007, HM 9025RR in 2008, and HM 9036RR in 2009) was planted on 6 May 2007, 21 April 2008, and 23 April 2009, at one-inch depth with row spacing of 22 inches and seed spacing of approximately five inches. As is common practice with dry spring conditions in the Bighorn Basin, plots were irrigated immediately after planting to initiate germination and fill the soil profile with water. Irrigation water was applied for this and subsequent irrigations using a constant-flow furrow system that directs water down every other row.

Study Design and Treatments

All treatments were replicated four times in a randomized complete-block design except the 2007 fluid injected treatments, which were replicated three times. Dry product treatments were broadcast on 11- by 35-ft plots arranged in four blocks (reps). Equipment used to inject fluid products required more space, so fluid product treatments were applied to whole-field strips one planter-width wide (11 ft) located adjacent to the dry product plots. All sampling and harvesting for analyses occurred within a 35-ft-long plot in each treatment strip.

Phosphorus was applied as granular dry monoammonium phosphate (MAP; $NH_4H_2PO_4$) each year at the rate of 106 lbs P_2O_5/acre (contributing 23 lbs N/acre), which is the typical rate applied annually for sugarbeet production at the Powell station, and incorporated with the bedding operation. Nitrogen contributed by the application of MAP was included in all N fertilizer rate calculations for the treatments evaluated.

Nitrogen source treatments included three dry N forms and three fluid N forms. Dry forms included granular dry urea [$(NH_2)_2CO$] (46% N) and two types of controlled-release urea: Agrium ESN SmartNitrogen (ESN) (44% N) (Agrium Advanced Technologies Inc., Loveland, CO) and urea impregnated with Simplot NutriSphere-N (NSN) (46% N) (J. R. Simplot Co., Boise, ID). Agrium ESN is described as urea with an insoluble polymer time-release coating (3). Agrium ESN was mixed with urea at 60% ESN to 40% urea as per Agrium recommendations. NutriSphere-N is described as liquid concentrate with minimum 40% maleic-itaconic co-polymer that is mixed with dry urea at a rate 4.4 pints NSN/ton urea to reduce volatilization, nitrification, and denitrification of N fertilizer when applied to the soil (21). Dry products were broadcast before planting and disk-incorporated immediately afterward. Fluid forms included

UAN (32% N), Agro-Culture High NRG-N (NRG) (Agro-Culture Liquid Fertilizers, St. Johns, MI), and Georgia-Pacific Nitamin Nfusion (Nfusion) (Georgia-Pacific LLC, Atlanta, GA). Agro-Culture NRG (27% N) is described as liquid N fertilizer derived from ammonium nitrate (NH_4NO_3), ammonium sulfate [(NH_4)2NO_3] and urea with "managed N availability that matches crop demand curves" (2). Agro-Culture NRG was applied at an N rate of 56% of the N application goal as per manufacturer's recommendations. Nfusion is described as a slow-release liquid N fertilizer that contains 22% N, 94% of which is slowly available (11). Nfusion was blended at 80% UAN to 20% N fusion also according to manufacturer's recommendations. The Nfusion + UAN blend was added to the trial for the 2008 and 2009 field seasons. Liquid products were injected with a backswept-knife applicator 3 inches below and 6 inches to the side on the dry side of the seed row.

To evaluate soil-test-based N rate recommendations against typical N rates used at the station, each N source was applied at the soil-test-based recommended rate for each season and at the rate of 220 lbs N/acre typically applied to sugarbeet at the UW Powell Research and Extension Center. Bulk soil samples from 28, 0- to 12-inch depth cores were collected from across the study area in March of each season and analyzed at the University of Wyoming Soil Testing Laboratory, Laramie, Wyoming, which provided the soil-test N rates based on a yield goal of 26 tons roots/acre (6). The algorithm used by the University of Wyoming Soil Testing Laboratory uses assumes each ton of sugarbeet produced requires nine lbs of N, and credits N mineralization of soil organic matter (SOM) at 20 lbs N per one% SOM (6). The soil-test-based recommended N rates (soil test rates) were 150, 118, and 120 lbs N/acre in 2007, 2008, and 2009, respectively. The soil tests showed high residual N concentrations of approximately 65, 96, and 94 lbs N/acre in 2007, 2008, and 2009, respectively.

The effect of application timing was evaluated by comparing all-preplant and split applications of each combination of N source and N rate. Split application consisted of one-half the N goal applied preplant as the N source being evaluated and one-half side-dressed in late June as UAN-32 knife-injected as described above for application of liquid products, which is the typical side-dress application procedure for the Powell station and many Bighorn Basin producers. For fluid products, the two timing options were evaluated only during the 2008 and 2009 seasons.

To evaluate effects of the N source, N rate, and N application timing treatments on seedling emergence and survival, plants were counted in two 3-m sections of rows in each plot twice between May 15 and June 15 of each season.

Data Collection and Analysis

Sugarbeets were harvested in early October each year of the study using a one-row research digger to harvest 30 ft of row in each plot. Samples were weighed and trucked to the Western Sugar Cooperative tare laboratory, where they were analyzed for sugar content corrected for sugar-loss-to-molasses.

To analyze mineral-N dynamics across treatments and growing seasons, soil samples were collected four times per season (at planting, before side dressing, 85% canopy, and at harvest) by bulking eight 0- to 12-inch depth cores from each plot. To evaluate movement of mineral N in soil profiles, samples were collected from six depth intervals (0-12, 12-24, 24-36, 36-48, 48-60, 60-72 inches) in each control and typical-N rate, split application and typical-N rate all-preplant urea plot in early August and early October, 2007. Soil samples were bagged and placed on ice immediately after sampling for transport to the laboratory.

Immediately upon returning to the laboratory, a 0.35-oz subsample from each field-moist soil sample was extracted in 1.70 fl oz of 0.5*M* K_2SO_4. Concentrations of nitrate (NO_3-N) (7) and ammonium (NH_4-N) (10) were determined using a microplate spectrophotometer (Powerwave HT, BioTek Instruments, Winooski, VT) and adjusted for soil moisture and gravel content. To estimate the amount of plant-available N in soil profiles, N concentrations were converted to pounds per acre for each 12-inch depth interval assuming an average bulk density of 1.45 g/cm³, or 4,000,000 lbs/acre-ft of soil.

Statistical analyses were conducted using the MIXED, MEANS, and UNIVARIATE procedures of the Statistical Analysis System (ver 9.2, SAS Institute Inc., Cary NC). Mean separation for those variables for which a significant effect was indicated by the ANOVA ($P < 0.05$) was conducted using the LSD post-hoc procedure of PASW 18.0 (IBM Inc., Somers, NY) with $\alpha = 0.05$. Evaluation of the dry products and fluid products were analyzed as separate experiments because of the spatial separation of those treatments in each of the three years. Results for the fluid N product Nfusion + UAN were analyzed by conducting the same analyses over the two years that product was applied (2008 and 2009).

Sugarbeet Root Yield, Sugar Content, and Sugar Yield

Statistical analysis indicated equal variances and normally distributed residuals for all datasets, and that there were no interactions among the variables analyzed. There were no significant differences in seedling emergence and establishment among any of the treatments.

Overall sugar yield across all treatments and years was 4.66 tons/acre for dry products and 4.84 tons/acre for fluid products. For dry products, root and sugar yields were similar in 2007 and 2009, while sugar content differed significantly for each study year (Table 1). Sugar content was especially low in 2009, probably due to an early hard freeze that interrupted harvest. Upon subsequent thawing, sugar in frozen sugarbeets may be subject to rapid microbial immobilization of sugar into organic forms, which reduces sugar content. For fluid products, sugar content, root yield, and sugar yield were significantly different each year of the study (Table 1), with 2008 producing the highest sugar content and yields and 2009 the lowest. N-fusion + UAN results are excluded from Tables 1 to 4 (except as noted) because this product was not included in the 2007 trial; however, analysis of yield by fluid N source for 2008 and 2009 indicate no significant differences ($P > 0.05$) among the fluid products for those two years.

Table 1. Overall beet quality and yield by study year. Dry and fluid products were analyzed as separate experiments. Means followed by different letters within a column and product type indicate significant differences at the >95% confidence level.

Year	Sugar	Root yield	Sugar yield
	(%)	(tons/acre)	
– **Dry products** –			
2007	18.1 a	23.6 b	4.23 b
2008	18.5 b	31.1 a	5.77 a
2009	16.5 c	25.2 b	4.17 b
– **Fluid products** –			
2007	18.4 b	26.2 b	4.76 b
2008	18.9 a	30.2 a	5.70 a
2009	16.8 c	24.4 c	4.09 c

Average yields by N fertilizer product across N rates and application timings (Table 2) show that all the products yielded significantly more root mass than the control plots, but were not significantly different from one another among either the dry or fluid N-source products. Though not compared statistically to dry products, the fluid product UAN produced the highest sugar yield overall at 4.98 tons/acre over the three-year study, compared to the highest yielding dry product, ESN, at 4.74 tons of sugar per acre. Considering the somewhat higher yielding two-year period of 2008 and 2009 when Nfusion + UAN was included in the fluid product experiment, that product produced the highest yields at

5.17 tons of sugar per acre, which is not significantly higher than the yield from UAN at 5.04 tons of sugar per acre or NRG at 4.87 tons of sugar per acre ($P > 0.05$) during 2008 and 2009. These results suggest that, other factors such as ease of application or convenience being equal, price per unit N should be a major factor in choosing N fertilizer products.

Table 2. Overall beet quality and yield by N fertilizer product averaged across the three study years. Dry and fluid products were analyzed as separate experiments. Means followed by different letters within a column and product type indicate significant differences at the >95% confidence level.

Product[x]	**Sugar**	**Root yield**	**Sugar yield**
	(%)	(tons/acre)	
– **Dry products** –			
Control	17.9 a	24.3 b	4.39 a
Urea	17.7 a	27.1 a	4.71 a
ESN	17.6 a	27.2 a	4.74 a
NSN	17.7 a	26.8 ab	4.68 a
– **Fluid products** –			
Control	17.7 a	23.5 b	4.17 b
UAN	17.9 a	27.6 a	4.98 a
NRG	18.1 a	26.3 a	4.78 a
Nfusion+UAN[y]	17.7 a	29.1 a	5.17 a

[x] ESN = Agrium ESN SmartNitrogen; NSN = Simplot Nutrisphere-Nitrogen; UAN = urea ammonium nitrate; NRG = Agro-Culture High NRG; Nfusion = Georgia-Pacific Nitamin Nfusion. See text for more information.

[y] Applied only in 2007 and 2008 and evaluated against other means for those years.

Timing of application, either all-preplant or split between preplant and early-summer side dress, produced statistically similar yields of both root mass and sugar (Table 3). The dry products yielded more root mass than the control plots under both timing methods, but sugar yield was variable among the plots and neither timing treatment yielded more than the control plots (Table 3). All-preplant and split application of fluid products were compared only in 2008 and 2009, which likely explains the slightly higher yields than recorded for the dry products (Table 3). Both timing methods for application of fluid products yielded more root mass and sugar than the control plots. These results concur with earlier research (8,13) and suggest that applying all fertilizer preplant is as effective as split application.

Table 3. Overall beet quality and yield by application timing averaged across the three study years for dry products and two study years for fluid products. Dry and fluid products were analyzed as separate experiments. Means followed by different letters within a column and product type indicate significant differences at the >95% confidence level.

Timing	Sugar (%)	Root yield (tons/acre)	Sugar yield
– Dry products –			
Control	17.9 a	24.3 b	4.35 a
All preplant	17.6 a	27.1 a	4.71 a
Split	17.7 a	26.9 a	4.71 a
– Fluid products –			
Control	17.4 a	23.9 b	4.22 b
All preplant	17.9 a	27.5 a	4.94 a
Split	17.7 a	28.8 a	5.11 a

[x] Evaluated only in 2008 and 2009.

Results averaged by N rate applied (Table 4) suggest that N application according to soil-test-based recommendations yields as much sugar as the typical N rate used at the Powell research farm, which, in this case, is nearly 100 lbs more N per acre. For dry products (Table 4), the full N rate treatment yielded significantly more root mass than the soil-test N rate (P = 0.034) and control plots (P = 0.004), but not significantly more sugar than the soil-test N rate (P = 0.108) or control plots (P = 0.055). For fluid products (Table 4), the full N rate treatment resulted in significantly lower sugar content than both the soil-test N rate (P = 0.014) and the control plots (P = 0.016), but statistically equivalent root mass to the soil-test N rate (P = 0.155) and control plots (P = 0.105). This resulted in statistically equivalent sugar yields among the three N rates applied with fluid products (P = 0.753 and 0.685 for full N rate vs. soil-test N rate and full N rate vs. control plots, respectively).

Table 4. Overall beet quality and yield by N application rate averaged across the three study years. Dry and fluid products were analyzed as separate experiments. Means followed by different letters within a column and product type indicate significant differences at the > 95% confidence level.

Rate	Sugar (%)	Root yield (tons/acre)	Sugar yield
– Dry products –			
Control (23 lbs N/acre[x])	17.9 a	24.3 b	4.35 a
Soil test (134 lbs N/acre[y])	17.7 a	26.2 b	4.57 a
Full rate (220 lbs N/acre)	17.7 a	27.9 a	4.85 a
– Fluid products –			
Control (23 lbs N/acre[x])	18.5 a	25.4 a	4.66 a
Soil test (134 lbs N/acre[y])	18.3 a	26.5 a	4.72 a
Full rate (220 lbs N/acre)	17.8 b	27.5 a	4.77 a

[x] Contributed with application of monoammonium phosphate.

[y] Average soil-test-based N rate across the three years.

The roll of N fertilization in tradeoffs between root and sugar yield is well documented [e.g. (1)], and soil fertility testing is an excellent tool for determination of proper N rates, including techniques that account for deep soil

N (27). However, many producers are suspicious of soil-test-based N recommendations, possibly because they often indicate N rates unrealistically low relative to producers' knowledge. Many farmers forgo soil testing and apply N to sugarbeet at rates their experience has proven to be profitable. One reason that soil N tests often result in lower recommended N rates than farmers are comfortable with may be the high residual soil N concentrations that carry over from excessive N application. In plots at the Powell Research and Extension Center where an N scavenger crop was grown prior to a sugarbeet N rate experiment, soil N tests resulted in much higher recommended N rates (190 lbs N/acre) due to lower residual soil N than was observed in the study reported here (J. B. Norton, *unpublished data*). This suggests that conversion to soil-test-based N application would result in low recommended N rates at first that would increase in subsequent seasons as soil N became balanced with crop demands. The high value of sugar may encourage over application of N, which can incur substantial costs in terms of both fertilizer and lower sugar content. Adams et al. (1) found that fertilizing for optimal sugar yield required an average of 83 lbs/acre less N than fertilizing for optimal root yield.

Soil N Dynamics

Soil available N contents are variable but show distinct seasonal patterns with some significant differences among products, N rates, and application timings (Fig. 1). Available soil N content in crop fields reflects a combination of applied fertilizer and plant uptake. High N contents in late June likely resulted from high temperatures that increased mineralization of N from SOM, which may be enhanced by priming effects of N from fertilizers (e.g., 20). Inadequate early-season N may cause plant growth to lag, reducing N uptake and increasing soil mineral N content. Therefore low fertility early in the season can cause higher N concentrations later because roots have not grown rapidly enough to access N mineralized from SOM. Rapid decline in concentrations during the June and July rapid growth phase is probably due to combined uptake by plant roots and soil microbes, as well as possible leaching with deep and frequent furrow irrigations.

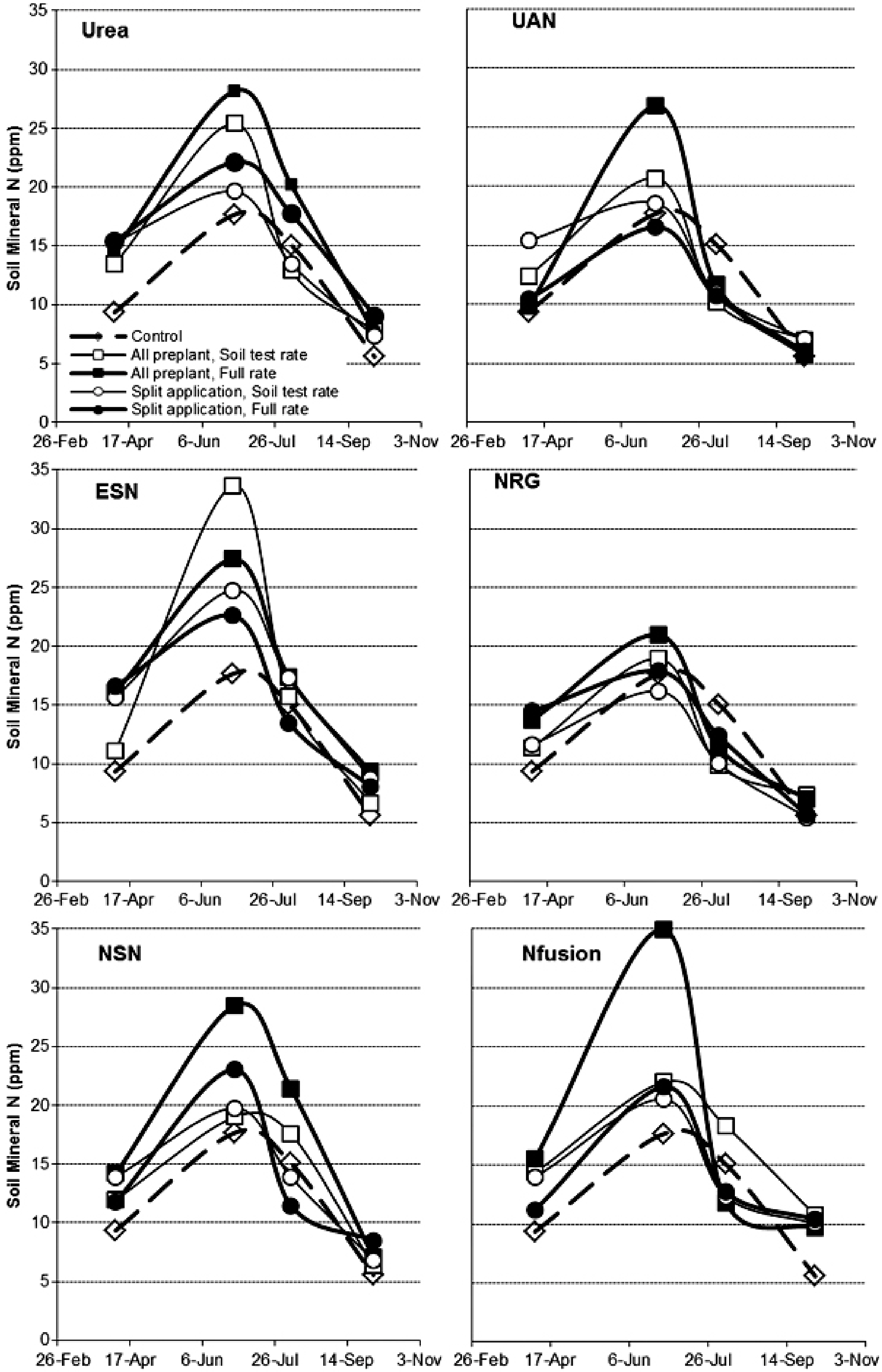

Fig. 1. Mean available N concentrations in 0- to 12-inch soil depth for median sampling date over the three years, except Nfusion, which is averaged over 2008 and 2009. Standard error ranges from 0.65 to 3.28 mg/kg for 7 April; 1.94 to 7.57 mg/kg for 28 June; 1.97 to 5.97 mg/kg for 6 August; and 1.24 to 3.65 mg/kg for 2 October. Actual sampling dates in 2007 were 22 March, 28 June, 13 August, and 2 October; in 2008 were 9 April, 30 June, 6 August, and 2 October; and in 2009 were 29 April, 22 June, 3 August, and 7 October.

All the treatments started and ended the season with statistically similar soil available N to the control (Fig. 1). Soils under NRG had statistically similar concentrations to the control through the season, while other products showed a significant ($P < 0.05$) spike in late June and depression in early August relative to the control. This suggests that low concentrations in the control at the beginning of the season caused plant growth to lag behind the other treatments and prevented utilization of available N in early August. In all treatments except ESN, the full-N rate, all-preplant applications had the highest late-June spike in available soil N. This is probably because application of all the fertilizer N at once stimulated early growth, but not enough to utilize a significant portion of available N by late June. Available N under all the treatments dropped to below initial concentrations by early August and dropped further by harvest in early October. The pattern for ESN at the soil-test N rate suggests that the low amount of starter urea combined with the time-release function of ESN may have inhibited early plant growth, causing a spike as N was released but not accessed by roots.

The side-dress application of the split treatments was applied soon after the late-June soil samples were collected, so N concentration probably spiked soon afterward, but the equivalent performance of the all-preplant treatments to the split application treatments suggests the side-dress applications of UAN did not provide any advantage.

Soil profiles below the full-rate urea split and all-preplant treatments (Fig. 2) had a distinct increase in the amount of plant available N below 40 inches compared to soil profiles beneath the control plots in August, but low and consistent amounts of plant-available N across all depths and treatments in the same plots in October. This suggests that N from both the all-preplant and split application treatments moved downward with early irrigations and then was either taken up by roots later in the season, or continued to move to below the 72-inch depth. Total soil profile plant-available N in August was estimated at 84.9, 149, and 177 lbs/acre beneath control, full-rate split-application urea, and full-rate all-preplant urea, respectively. In October, the soil profile plant-available N totaled 69.2, 71.1, and 73.6 lbs/acre beneath control, full-rate split-application urea, and full-rate all-preplant urea, respectively. This means that the difference of 15.7, 78.3, and 103 lbs N/acre beneath control, full-rate split-application urea, and full-rate all-preplant urea, respectively, was taken up or lost through deep leaching from August to October.

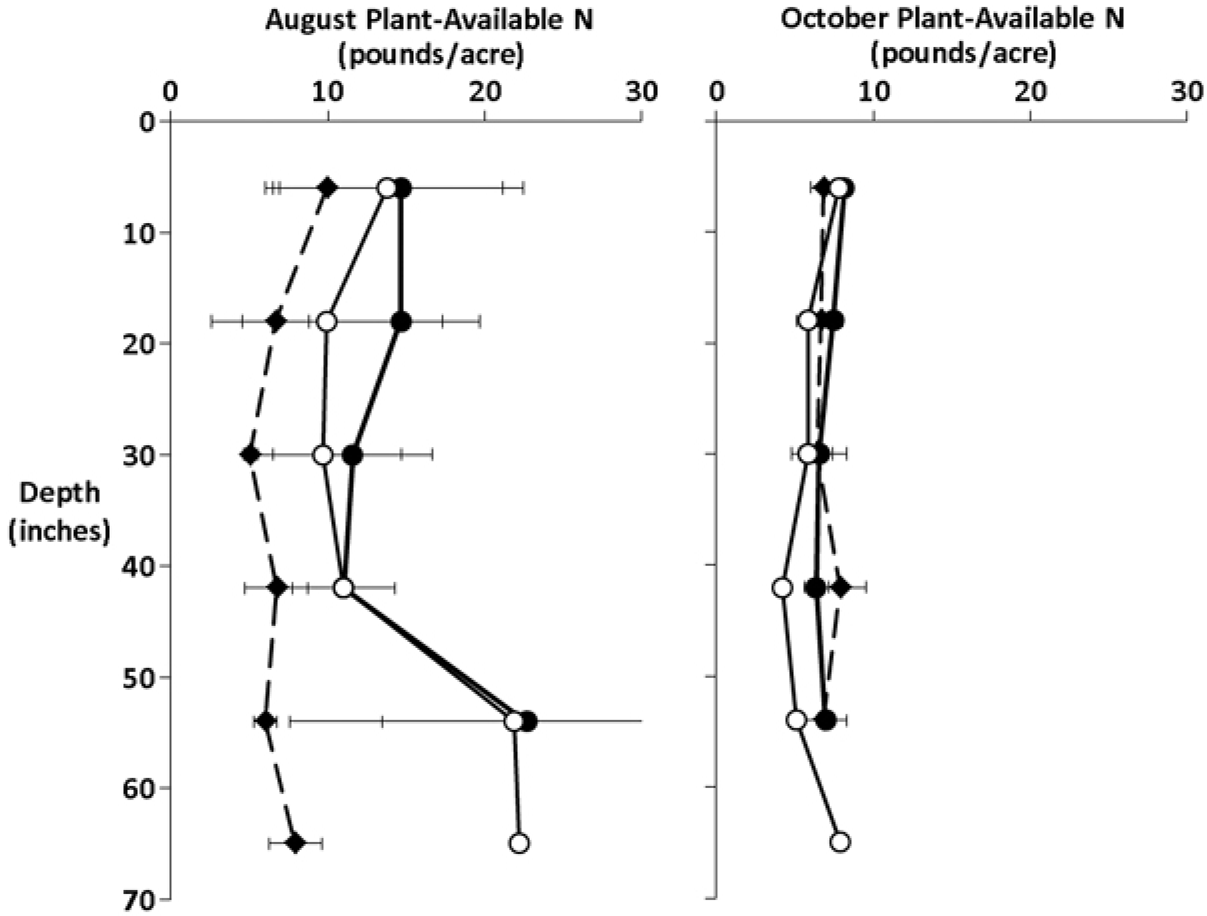

Fig. 2. 2007 soil mineral N concentration at six depth intervals beneath typical rate treatments of urea applied all preplant (black circles), applied ½ preplant as urea and ½ in late June side dressed as UAN (open circles), and the control (dashed line). Markers represent the midpoint of each 12-inch depth interval. Error bars represent standard error (n = 4).

A significant negative linear relationship between sugar content and August soil mineral N concentration below 24 inches (Fig. 3) suggests that substantial deep soil N was taken up by sugarbeet late in the summer, increasing impurities and reducing sugar yield. Stevanato et al. (22) also found a strong negative relationship between deep soil N and sugar content of roots at harvest. This initial evaluation of deep movement and uptake of soil N in furrow-irrigated sugarbeet of the Big Horn Basin may have important environmental, agronomic, and economic implications and warrants further study.

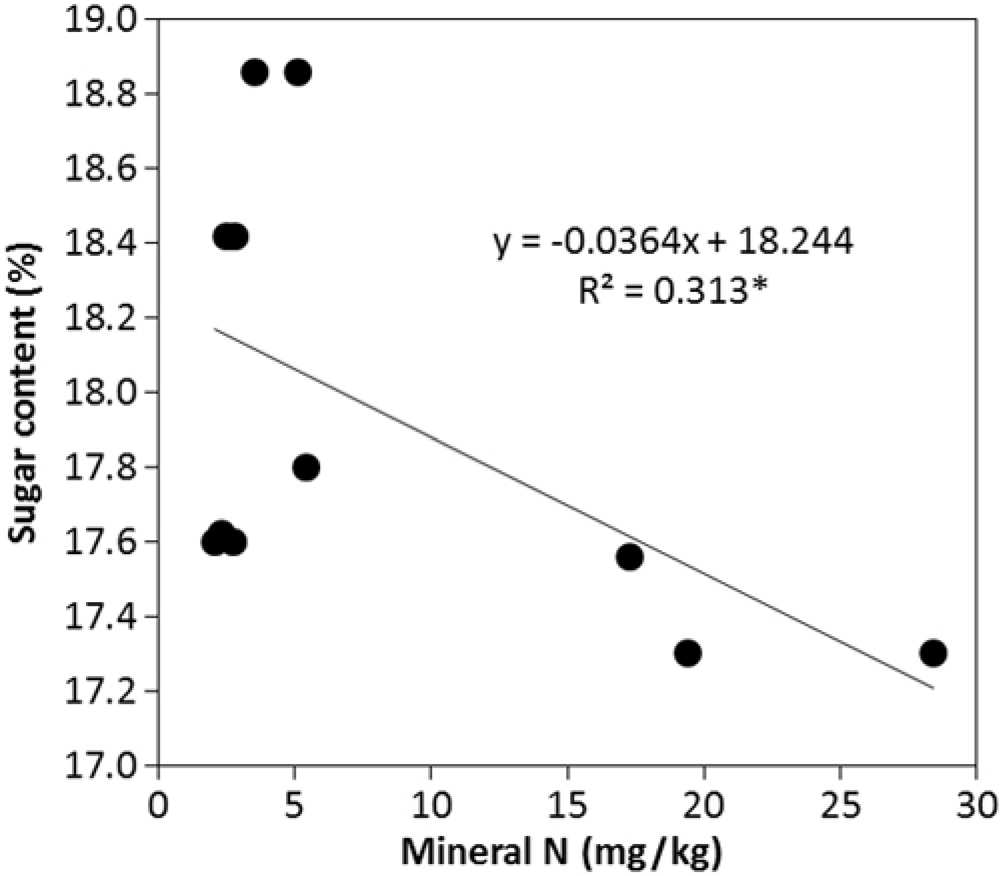

Fig. 3. Relationship between sugar content and soil mineral N between 36 and 60-inches depth measured in August 2007. N = 12. Includes control and typical N rate urea split plot and all-preplant. * Linear relationship is significant at the P < 0.05 level.

Management Implications

Subtle differences in sugar yield among treatments suggest that the least expensive N source and lower N rates based on soil tests may be wise choices for sugarbeet producers. Beets grown with injected fluid products apparently benefited from precise placement and produced the most sugar. The all pre-plant applications performed as well as split applications, and the split-application, soil-test N rate performed as well as the higher N rate treatments. Farmers should especially take notice of the small yield differences resulting from large N application rate differences.

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