NITROGEN MANAGEMENT IN SUGAR BEET GROWN IN FINER TEXTURED SOILS OF THE RRV

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Nitrogen (N) is an essential nutrient for all plant life and is the most managed nutrient in crop production. Careful management of N in sugar beet production is especially critical. A typical sugar beet crop will accumulate from 180 to 220 lbs. N A^{-1} under non-N limiting conditions (Armstrong and Milford, 1985; Pocock et al., 1990; Duval, 2001). Nitrogen accumulation above this range can severely reduce sugar beet root quality (Armstrong and Milford, 1985; Pocock et al., 1990). However, N accumulation within this range is required for optimum sugar beet production. Root yield is determined by the biomass produced in actively functioning leaves and transported to and accumulated in the root. Nitrogen does not increase the conversion efficiency of intercepted light to biomass, but it does increase the size of the leaf canopy that intercepts more light (Armstrong et al., 1983). Light interception and dry matter production increases as the leaf canopy increases up to a leaf area index of 3-4.

The sugar beet crop obtains its N from three major sources in the soil; residual inorganic N, N mineralized from the organic material, and applied fertilizer N. Researchers have used labeled non-radioactive N^{15} as a fertilizer source to trace the fate of the fertilizer N. Sugar beet can acquire N down to a soil depth of at least 4 ft (Broeshart, 1983), but applied fertilizer N may contribute only 40% of the total N accumulated in the beet plant (Lindemann et al., 1983). Frequently the fertilizer uptake efficiency is 50% or slightly higher (Haunold, 1983; Lindemann et al., 1983). The inability of the sugar beet plant to acquire more than 50% of the applied fertilizer is consistent with what has been reported for other crops and reflects the complex dynamics of N in the soil environment. These findings also emphasize the contribution needed from the residual soil N and mineralized N to the sugar beet crop for optimum production. Residual soil N is estimated using soil testing to measure the amount of nitrate-N to either the 2-ft or 4-ft soil depth. The amount of residual soil N is a product of the overall N management strategy used in the entire cropping season as well as environmental factors affecting crop production. Mineralized N reflects several soil characteristics that include temperature, moisture, organic matter content and type, aeration, and microbial population, to name a few (Jansson and Persson, 1982; Myrold and Bottomley, 2008). This might suggest soil classification could be used to estimate fertilizer N requirements for sugar beet production, but after several investigations, the overwhelming conclusion was that soil classification based on soil texture and soil survey series was ineffective as a predictor of fertilizer N needs (Webster et al., 1977). Rather, estimates of residual soil N and the amount of N mineralized during the growing season were better predictors of fertilizer N needs. Soil N mineralization is almost impossible to predict ahead of time because of all the variables influencing mineralization.

Recently, the American Crystal grower data base from two production years were subjected to geostatistical analysis based on total N used (residual soil N plus fertilizer N) in sugar beet production (Sims, 2009). There was a clear geospatial relationship with total N used by the sugar beet producers. There were several areas where total N use was higher than current N recommendations (Lamb et al, 2001), but the largest single area started in northwest Polk County and ran along western Marshall and Kittson Counties in Minnesota. Though not subjected to geospatial analysis, this same area tends to have soils with heavier or finer textures than areas showing lower total N use.

This same area also tends to have some of the lower sugar beet root yields, but higher sugar beet root quality than other American Crystal growing areas (Personal communications with Tyler Grove, American Crystal Fieldman). Why does this area seem to require greater total N use without the typical corresponding increase in root yield and reduction in root quality? Sims (2010) found that sugar beet root yields tended to increase only slightly, but continuously, over a range of 0 to 240 lbs. applied N A^{-1}. At the same time, sugar beet root quality increased up to about 90 lbs. applied N A^{-1} then leveled off at higher N rates (did not decline). Nitrate in the most recently mature leaf petiole collected in mid-July was low regardless of the fertilizer N rate (Sims, 2010) suggesting either the N was not available or the sugar beet plant was not able to gain access to it. The lack of N in the plant would also explain why root yields did not increase dramatically and quality did not decline. Visual observations suggests the dark soil layer, signifying organic matter, in these soils is not very deep. Combined with higher amounts of fine textured clay in these soils, is it possible that N mineralization is less in these soils? If that is the case, then higher rates of total N or fertilizer N would be required to meet sugar beet N demands. While this may explain why growers in the area use more N, it does not explain why the higher rates of applied N are either unavailable to the sugar beet plant or the sugar beet plant unable to gain access to it. In 2010, a follow up trial examined the possibility of increasing N available to the plant by sidedressing in a band near the plant row (Sims, unpublished data). Petiole samples taken about one week after the sidedress application revealed that plants sidedressed with 60 lbs. N A^{-1} (90 lbs. N applied preplant for a total of 150 lbs. N A^{-1}) had nitrate levels as high or higher than that of 210 lbs. of fall applied N. This suggested the sidedress band of N near the seed row was accessed relatively quickly by the sugar beet plant. Ultimately, this sidedress treatment resulted in root yields similar to those of the high rate of fall applied N with no detrimental effects on root quality. These results suggest that a more intense N management strategy may improve fertilizer N utilization efficiency in sugar beets grown in these areas where higher N use is typical.

Objectives:

1. Determine if fertilizer N placement and timing can improve fertilizer N availability and utilization in sugar beet production on finer textured soils in the RRV.

Materials and Methods:

Two trials were established in the fall of 2013. One trial was established at the Northwest Research and Outreach Center (hereby referred to as the NWROC Site) on a Wheatville very fine sandy loam soil (coarse-silty over clayey, mixed over smectitic, superactive, frigid Aeric Calciaquoll). Attempts were made to find a suitable site at NWROC with similar soil properties as the North Site as was the case in 2013. Finding none suitable for an experiment the Wheatville soil site was selected for potential demonstration purposes. While all N placements, sources, and timings were the same at both experimental sites, the NWROC only had three N rates instead the usual four. The second trial was established ten miles north and three miles west of Alvarado, Minnesota on a Colvin-Fargo Complex soil (Colvin: fine-silty, mixed, superactive, frigid Typic Calciaquoll; Fargo: fine, smectitic, frigid Typic Epiaquert) hereby referred as the North Site. The North Site was typical of the general growing area where producers seem to need exceptionally relatively high N rates for adequate sugar beet production.

The experimental design in both trials was a split-plot randomized complete block with four replications. Whole plot treatments were N rates. Nitrogen rates were 90, 120, 150, and 180 lbs. N A^{-1} plus soil residual N. The NWROC Site used only the 90, 120, and 150 lbs. N A^{-1} rates. The North Site included two 0 N controls (NWROC Site included only one P N control) in each replication. Split-plot treatments consisted of fertilizer placement and timing:

1. Broadcast (Bdcst): Fall broadcast 100% of N fertilizer and incorporated.
2. Band: Fall band 100% of N fertilizer near where seed row will be placed in the spring.
3. Mixed: Combination Fall application with 50% N fertilizer broadcast and 50% N fertilizer banded.
4. Bdcst-Sidedress: Fall broadcast plus in-season sidedress of either 30 or 60 lbs. N Ac^{-1} depending on N rate.
5. Band-Sidedress: Fall Band plus in-season sidedress of either 30 or 60 lbs. N Ac^{-1} depending on N rate.

The broadcast fertilizer source was urea and the banded fertilizer source was liquid aqua ammonia. The sidedress nitrogen source was UAN (28% N). Sidedress N was applied in the center of the inter-row space when the sugar beets were in the 10 to 12 leaf growth stage.

All fall treatments were applied 29 October, 2013 at the NWROC Site and Nov 5, 2014 at the North Site. Prior to any nitrogen being applied 60 lbs. P_2O_5 Ac^{-1} of 0-46-0 was broadcast applied. After the broadcast N was hand applied to the appropriate plots the entire plot area was tilled with a field cultivator that incorporated broadcast fertilizer and worked the soil prior to the application of the banded N. The banded N treatments were applied right after the tillage operations using a Dawn fertilizer applicator calibrated to deliver the appropriate rates of aqua-ammonia in a band about 5 inches below the soil surface and approximately where the sugar beet row would be planted the following spring. No further tillage took place thereafter. Wheel tracks in the banded treatments were flagged at the time fertilizer was applied to identify the placement and direction of the tractor tires when the plots were planted the following spring. Sidedress N was applied on 1 July and 7 July, 2014 at NWROC and the North Sites, respectively. Sidedress N was either 30 or 60 lbs N Ac^{-1} as UAN (28-0-0) in a band about 5 inches deep near the center of the interrow space (about 11 inches from each seed row) using the calibrated Dawn fertilizer applicator. The two sidedress N rates were used to maintain the appropriate N rates for the Whole plot. That is, for the 90 lbs. N rate, 60 lbs. N were applied the previous fall with 30 lbs. N applied sidedress. Fall applied 60 lbs. N with 60 lbs. N sidedressed supplied a total 120 lbs. N Ac^{-1}. Fall applied 120 lbs. N with 30 or 60 lbs N sidedressed supplied a total of 150 and 180 lbs. N Ac^{-1}, respectively.

At planting we were able to use an auto-steer guidance system on the tractor, which we did not have available the previous fall when the banded N was applied. The six rows of banded N were placed as close to the center of the plot as possible by visually aligning the tractor with guidance flags. For planting, the six planted rows were placed as close as possible to the center of the plot use an established A-B alignment and letting the auto-steer control the actual placement. We estimate the fertilizer band was not further than an inch or two from the actual seed row. The NWROC Site was planted 17 May, 2014 and the North Site was planted 23 May, 2014. Crystal 885RR, coated with 45 gms of Tachagaren, was seeded at about 240 seed per 100 ft of row along with counter insecticide and 3 gals of 10-34-0 mixed with 3 gallons of water as a started at both sites. Quadris was applied twice during the growing season to control Rhizoctonia Root Rot.

Soil samples were collected from the allies between the individual replications within a couple of days of the fall fertilizer applications. Four cores to a depth of 4 ft were taken from each alley and divided into 0-6, 6-24, and 24-48 inch segment and composited within a given alley. These soils samples were analyzed for residual soil nitrate-N. Soil sample analysis was conducted in the NWROC soils analytical laboratory using KCl extraction procedures.

Twice during the latter half of the growing season, once in mid-July and again in early-August, petiole samples were collected for nitrate analysis. Petiole samples were collected on 21 July and 4 August at the NWROC Site and 24 July and 7 August at the North Site. Twelve most recently matured petioles from rows 3 and 4 of each 6-row plot were collected, placed in coolers for transport back to the NWROC soils laboratory and frozen. At a later date these petioles were heat dried and ground to a powder and nitrate was extracted using a KCl extraction procedure.

Final harvest occurred 15 September at the North Site and 19 September at the NWROC site. The middle four rows of the 6-row plot were detopped and the middle two rows harvested using a mechanical lifter. All the lifted beets were weighed and 10 random, but representative beets were sent to the American Crystal Sugar Company Quality Laboratory in East Grand Forks, Minnesota for tare, impurity, and sugar analysis.

For statistical analysis, the trials were divided into two experiments, Expt 1 tested N rates and methods of application that included Broadcast, Band, and Mixed application methods. Expt 2 tested N rates with Broadcast and Band pre-plant applications with or without in-season sidedress N applications. Analysis was conducted on each site separately. Tables 1 and 2 include significance to the 0.05 level.

Results:

The growing season of the two experimental sites was substantially different from each other. Later than normal or desired planting occurred at both sites, but was nearly a week later at the North Site than the NWROC Site. Once planted, the NWROC Site growth was reasonably good throughout most the growing season. But at the North Site, the sugar beets grew very slowly and were quite yellow for much of the early growing season. Cold wet soil conditions seemed to stunt the small plants and they just could not grow sufficiently through the first half the growing season. Comparisons of the 2014 root yield and quality with those of previous years indicates this prolonged stress conditions greatly reduced root yields and quality from what would normally have been expected.

Table 1 and 2 indicate there was no sugar beet root yield or quality response to N rates at the NWROC Site in 2014. The only response that was significant was whether N was sidedressed or not. There was very little response of petiole nitrates to the treatment factors in either experiment. For this reason and because the NWROC was mainly established for demonstration purposes, results from the site will not be further discussed in this report. Instead this report will focus on the North Site.

Fall applications of N fertilizer occurred in the late fall of 2013 when soil temperatures at the North Site were about 40^{o} F (Warren NDAWN Station) on the day fertilizer was applied. Conversion of the N fertilizer to nitrate was expected to be very slow at these temperatures and the loss of nitrate-N through denitrification in the spring was expected to be low. Residual nitrate-N at this experimental site was about 13 lbs. nitrate-N Ac^{-1}. Therefore, a response to N fertilizer rates was expected, but I was not sure if we would see the same type of N rate response I had observed in this same area in previous years.

In the last couple of years, there has been very little response to N fertilizer rates above 90 lbs. N Ac^{-1}. Part of this was relatively high residual soil nitrate-N at the experimental sites, 50 to 60 lbs. N Ac^{-1}. Even though soil conditions were frequently quite wet early in the growing season, N loss through denitrification was apparently minimal (verified by Dr. Katy Smith on a different trial adjacent to the one reported here). Prior to that, however, I had observed root yield response and sometimes a root quality response to increasing N rates as high as 210 lbs. applied N Ac^{-1} with a pre-crop soil residual nitrate-N of about 25 lbs. N Ac^{-1}.

<u>Expt 1 (North Site)</u>

Petiole Nitrate:
Nitrate-N can be stored in the sugar beet petiole and is an indication of the nitrogen availability to the sugar beet plant or reflects the ability of the plant to acquire soil N. Nitrate concentrations of 750 to 1000 ppm in the petiole of the most recently fully expanded leaf are considered sufficient. The ideal time for petiole sampling is thought to be between the hours of 10:00 a.m. and 2:00 p.m. After that time, the plant begins to reduce the nitrate stored in the petiole and incorporates it into amino-sugars and amino-acids for the production of proteins and enzymes. In this study, all samples were collected between the hours of 8:30 a.m. and 10:30 a.m.. I was more interested in measuring petiole nitrates near where I thought the peak accumulation might be and I wanted to make sure all samples were collected within a short amount of time so that direct comparisons among treatments would be valid. A difficulty in petiole sampling is determining the most recently fully expanded leaf blade. Usually it can be narrowed to two or three possibilities. Without destroying all the possible candidates and making a direct comparison of leaf size, a certain amount of subjectivity is necessary. I instructed my crews to narrow the possible candidates to a maximum of three and select the middle one. It is presumed that this systematic approach to the leaf-petiole selection process collected within a very short period of time for each sampling event will provide the best opportunity for comparisons across trials, treatments, and sampling times.

Nitrate levels in the most recently mature petiole were significantly responsive to applied N fertilizer rates in both the July and August petiole sampling (Table 1a). In the July sampling there was no difference among the three N fertilizer application methods. In Fig 1 July, a linear response to N fertilizer rates across all application methods, as suggested in Table 1a, is illustrated. As N rates increased petiole nitrate increased. However, at all N rates, petiole nitrates were greater than 3500 ppm, which suggests the sugar beet crop was not N deficient at this stage of growth.

In the August petiole sampling not only did petiole nitrate increase as N rates increased, there was a differential effect of N fertilizer application method (Table 1a and Fig 1 August). In all application methods, petiole nitrates increased as N rates increased. However the rate of increase was significantly less when N fertilizer was applied as a band. There was little difference between Mixed and broadcast. It was also apparent at this latter sampling that the 90 lbs. N Ac^{-1} rate treatments may be starting to approach N deficiency levels with the relatively low petiole nitrate levels. Still petiole nitrate levels, though low, at this lower N rate suggest there the crop still has sufficient N available to it.

These results are substantially different that was observed and reported previously (Sims, 2010). In that report it appeared the sugar beet crop was having difficulty accessing sufficient N even at high applied N rates. In 2014, and in the previous two years, this seems not to be the case.

Quality Parameters:

Sugar beet quality was reduced in 2014 relative to previous years. It is suspected this is partly due to the excess stress this sugar beet crop experienced throughout much of the early growing season. The was no effect on root quality due to N rates or method of fertilizer application (Table 1a)

Yield:

The root yield response to applied N rates was not significant except for an interaction between the linear response to N rates and the method of application associated with the Mixed verse the all Band or Broadcast (Table 1a). When all the fall N was Banded or Broadcast there was no response to applied N rates (Fig 2). That is, maximum root yield occurred with 90 lbs. applied N ac^{-1}. Yield was greater with the Broadcast application at all N rates. The interaction term was significant because of the increasing root yield with increasing N rates in the Mixed treatment (Fig 2). It is difficult to determine why this result occurred. However, there is sufficient noise in the data, this result could be an artifact of the data and may not be real. When averaged across all N rates, there was little difference in root yield between the Broadcast and Mixed and yields were lower in the Band treatments.

<u>Expt 2 (North Site)</u>

Petiole Nitrate:

In July, petiole nitrates were not responsive to N rates or fall method of applications (Table 2a). However, applying some of the N as a sidedress increased petiole nitrates compared to all the N applied the previous fall (Fig 4). This occurred whether the fall applied N was Banded or Broadcasted.

In August, petiole nitrates were responsive to more of the treatment factors (Table 2a). In all treatments, petiole nitrates, for the most part, increased as N rates increased, though the response to N rates was curvilinear and not linear. That is, petiole nitrates increased substantially at the higher N rates and not in the middle N rates (Fig 5). The lowest petiole nitrates occurred when all the N was fall Banded. Sidedressing some N when the rest of fall Banded increased petiole nitrates. However, when fall N was Broadcast, there was no difference in petiole nitrates between when some N was sidedressed or all N was fall applied.

Root Yield:

As in Experiment 1, there was no response to N rates when all the N was applied in the fall as either Band or Broadcast (Table 2a and Fig 6). Yields were greater with Broadcast applications. But, if some of the N was applied as in-season sidedress, yields increased as N rates increased when fall N was Banded. When fall N was Broadcast, this did not occur. Though root yields with sidedress N when fall N was Broadcast was slightly greater than those of no sidedress and fall N was Broadcast applied, the difference was very minor and not significant.

Summary

Banding N seemed to be detrimental to sugar beet production compared to Broadcast applications. Petiole nitrates suggest that Banded N is not as readily available to the crop as Broadcast N. Sidedressing N during the growing season increased N availability, but only where fall N had been Banded. When sufficient N was Broadcast applied in the fall, sidedressing a portion of the total N had no effect on N availability or root yield.

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Table 1. Statistical analysis comparing nitrogen rates and method of pre-plant application for several measured variables at the North site (a) and NWROC site (b).

a). North site

	Variable§						
	Rtyld	RtQual	RecSuc	Sugar	LTM	JulPetN	AugPetN
Source§§	------------ PR>F§§§ ------------						
N rate	ns	ns	ns	ns	ns	*	***
Lin	ns	ns	ns	ns	ns	**	***
Quad	ns	ns	ns	ns	ns	ns	*
Method	**	ns	ns	ns	*	ns	***
Bdcst vs Band	**	ns	ns	ns	*	ns	***
One vs Mixed	*	ns	ns	ns	ns	ns	*
N rate X Method	ns	ns	ns	ns	ns	ns	ns
Lin by Bdcst vs Band	ns	ns	ns	ns	ns	ns	*
Quad by Bdcst vs Band	ns	ns	ns	ns	*	ns	ns
Lin by One vs Mixed	*	ns	*	ns	ns	ns	ns
Quad by One vs Mixed	ns	ns	ns	ns	ns	ns	ns

b). NWROC site

	Variable§						
	Rtyld	RtQual	RecSuc	Sugar	LTM	JulPetN	AugPetN
Source§§	------------ PR>F§§§ ------------						
N rate	ns	ns	ns	ns	ns	ns	ns
Lin	ns	ns	ns	ns	ns	ns	ns
Quad	ns	ns	ns	ns	ns	ns	ns
Method	ns	ns	ns	ns	ns	ns	ns
Bdcst vs Band	ns	ns	ns	ns	ns	ns	ns
One vs Mixed	ns	ns	ns	ns	ns	ns	ns
N rate X Method	ns	ns	ns	ns	ns	ns	ns
Lin by Bdcst vs Band	ns	ns	ns	ns	ns	ns	ns
Quad by Bdcst vs Band	ns	ns	ns	ns	ns	ns	ns
Lin by One vs Mixed	ns	ns	ns	ns	ns	ns	ns
Quad by One vs Mixed	ns	ns	ns	ns	ns	ns	ns

§ Rtyld, RtQual, RecSuc, Sugar, LTM, JulPetN, and AugPetN represent root yield (ton Ac^{-1}) , root quality (lbs. sucrose ton^{-1}), recoverable sucrose (%), Sugar (%), Loss-to-molasses (%), July Petiole NO_3 (ppm), and August Petiole NO_3 (ppm), respectivefully.

§§ Lin=linear regression; Quad=quadratic regression; Bdcst=broadcast; Mixed=50% broadcast and 50% banded; One=broadcast and band applications tested together against both applications mixed.

§§§ ***,**,*, and ns represent significance at the 0.001, 0.01, 0.05 levels, and non-significant, respectfully.

Table 2. Statistical analysis comparing nitrogen rates and method of pre-plant application with and without sidedress nitrogen application for several measured variables at the North site (a) and NWROC site (b).

a). North site

	Variable§						
	Rtyld	RtQual	RecSuc	Sugar	LTM	JulPetN	AugPetN
Source§§	------------ PR>F§§§ ------------						
N rate	ns	ns	ns	ns	*	ns	***
Lin	ns	ns	ns	ns	**	ns	***
Quad	ns	ns	ns	ns	ns	ns	**
Method	**	ns	*	ns	**	ns	***
N rate X Method	ns	ns	ns	ns	**	ns	ns
Lin by Method	ns	ns	ns	ns	ns	ns	ns
Quad by Method	ns	ns	ns	ns	**	ns	ns
Sidedress	.07	ns	ns	ns	ns	***	ns
N rate X Sidedress	ns	ns	ns	ns	ns	ns	ns
Lin by Sidedress	*	ns	ns	ns	ns	ns	ns
Quad by Sidedress	ns	ns	ns	ns	ns	ns	ns
Method X Sidedress	ns	ns	ns	ns	ns	ns	*
N rate X Method X Sidedress	ns	ns	ns	ns	ns	ns	ns
Lin by Method by Sidedress	ns	ns	ns	ns	ns	ns	ns

b). NWROC site

	Variable§						
	Rtyld	RtQual	RecSuc	Sugar	LTM	JulPetN	AugPetN
Source§§	------------ PR>F§§§ ------------						
N rate	ns	ns	Ns	ns	ns	ns	ns
Lin	ns	ns	ns	ns	ns	ns	ns
Quad	ns	ns	ns	ns	ns	ns	ns
Method	ns	ns	ns	ns	*	**	ns
N rate X Method	ns	ns	ns	ns	ns	ns	ns
Lin by Method	ns	ns	ns	ns	ns	ns	ns
Quad by Method	ns	ns	ns	ns	ns	ns	ns
Sidedress	*	ns	*	ns	**	***	***
N rate X Sidedress	ns	ns	ns	ns	ns	***	***
Lin by Sidedress	ns	ns	ns	ns	ns	***	ns
Quad by Sidedress	ns	ns	ns	ns	ns		***
Method X Sidedress	ns	ns	ns	ns	ns	ns	ns
N rate X Method X Sidedress	ns	ns	ns	ns	ns	ns	ns

§ Rtyld, RtQual, RecSuc, Sugar, LTM, JulPetN, and AugPetN represent root yield (ton Ac^{-1}) , root quality (lbs. sucrose ton^{-1}), recoverable sucrose (%), Sugar (%), Loss-to-molasses (%), July Petiole NO_3 (ppm), and August Petiole NO_3 (ppm), respectivefully.

§§ Lin=linear regression; Quad=quadratic regression; Bdcst=broadcast; Mixed=50% broadcast and 50% banded; One=broadcast and band applications tested together against both applications mixed.

§§§ ***,**,*, and ns represent significance at the 0.001, 0.01, 0.05 levels, and non-significant, respectfully.

a. North site

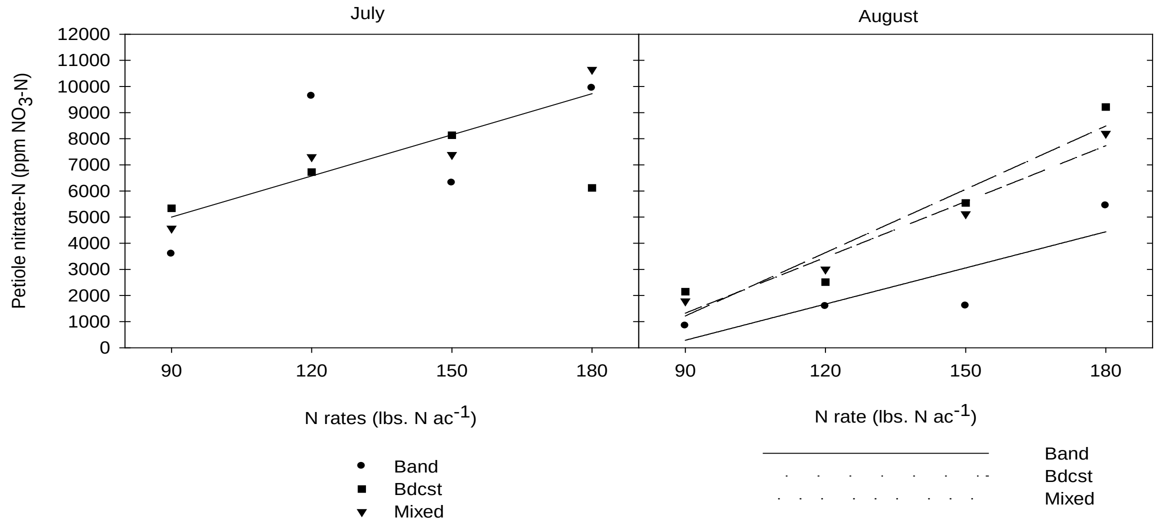

Figure 1. Petiole nitrates from most recently fully expanded leaf blade petiole at two sampling times and two experimental sites.

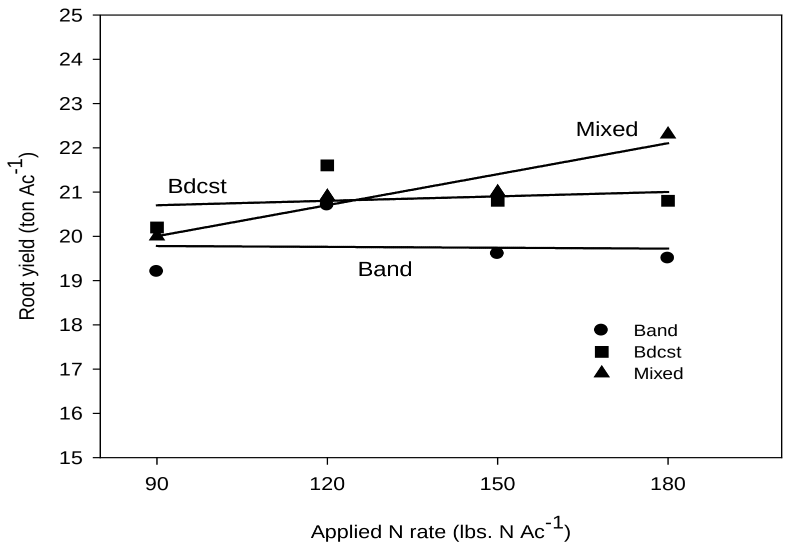

Figure 2. Root yield response to N rates for each N application method

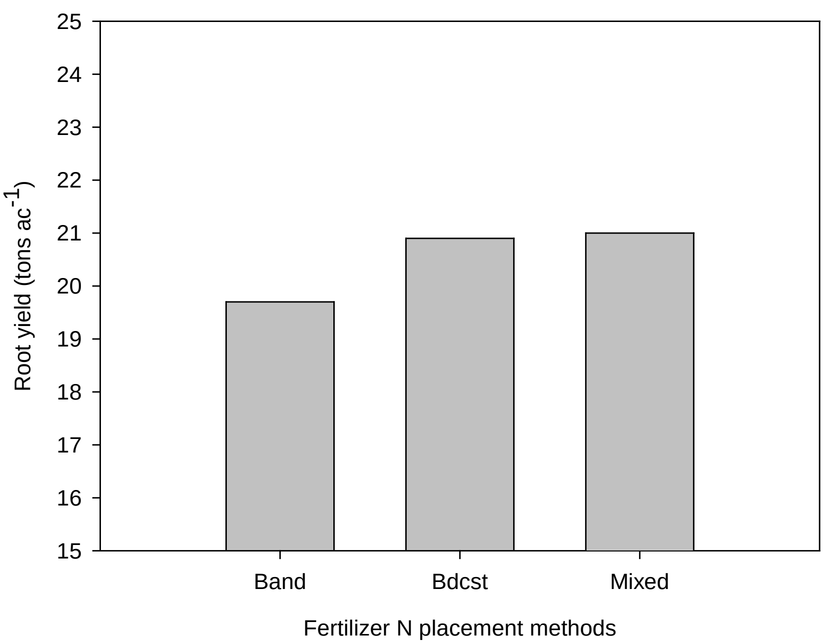

Figure 3. Root yield response to N application methods averaged across all N rates.

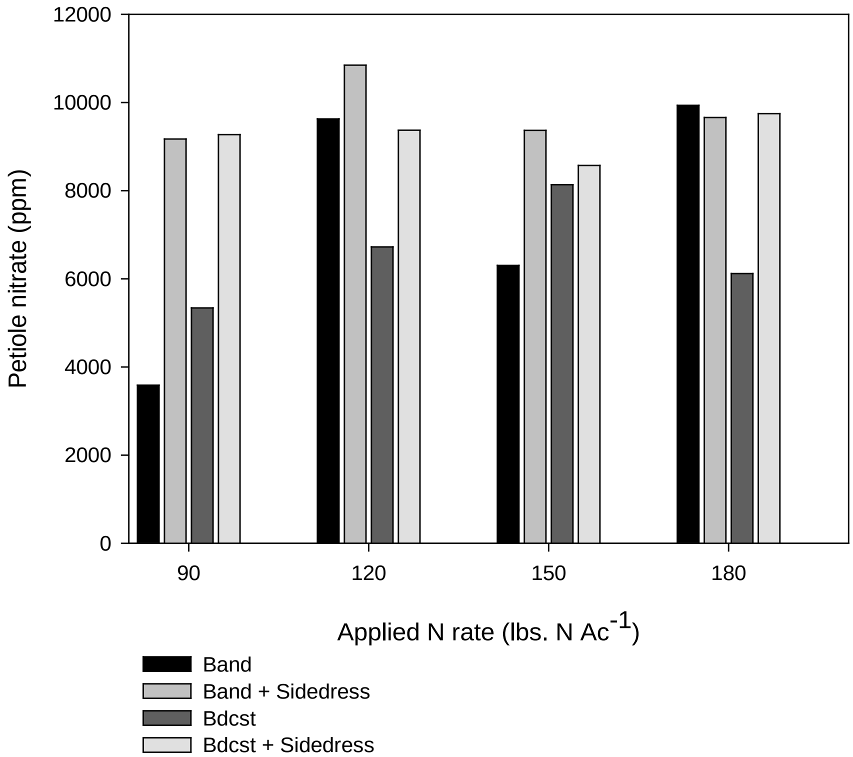

Figure 4. July sampled Petiole nitrate response to N rates for two fall N fertilizer applications methods with or without additional N applied as in-season sidedress.

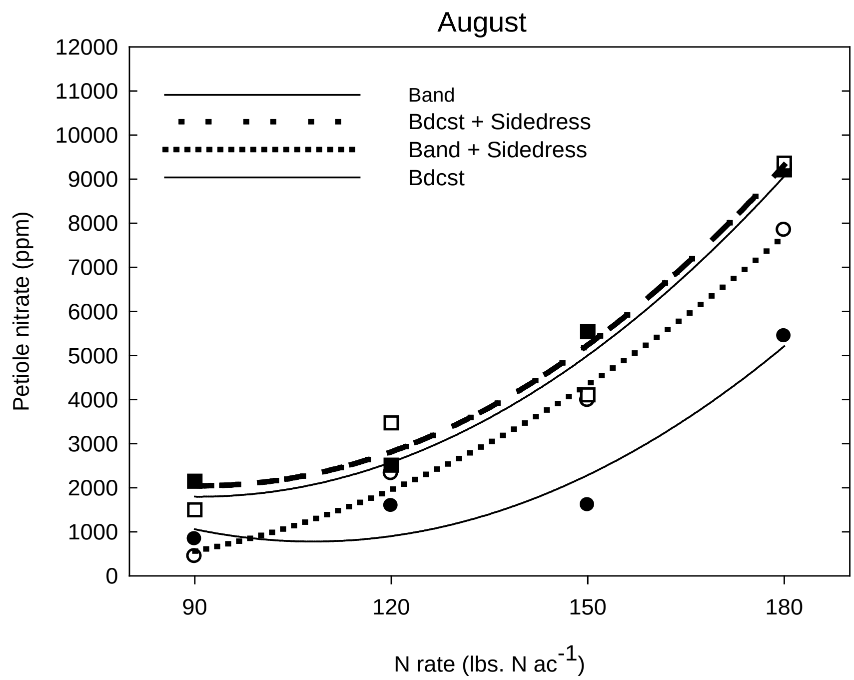

Figure 5. August sampled petiole nitrate response to N rates and two fall N fertilizer application method with and without additional N applied as in-season sidedress.

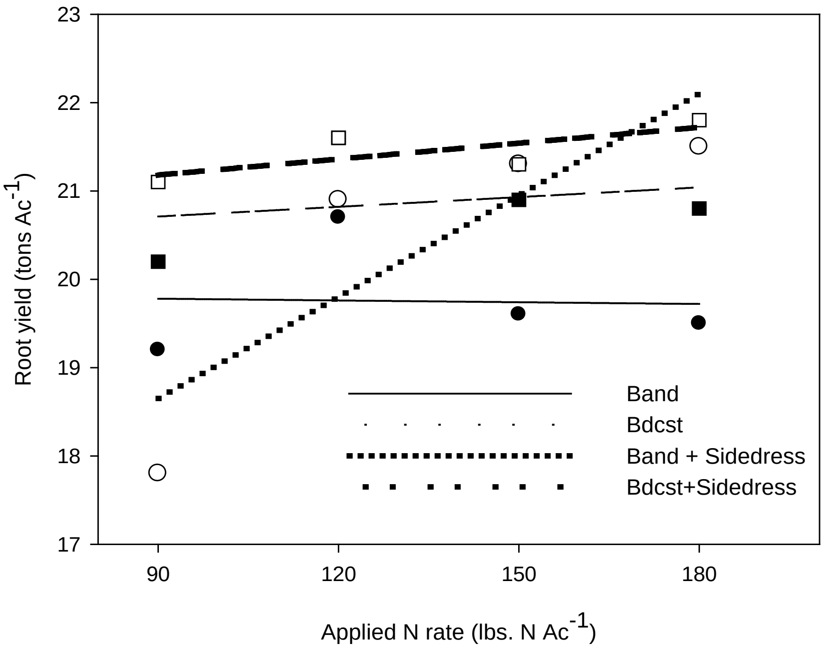

Figure 6. Root yield response to N rates and two methods of fall N fertilizer application with and without additional N applied as in-season sidedress.