Sugarbeet Productivity as Influenced By Fertilizer Band Depth and Nitrogen Rate in Strip Tillage

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ABSTRACT

Most modern strip tillage (ST) implements are capable of banding fertilizer below the seed. For sugarbeet (*Beta vulgaris L.*), placement either too close or too far away from the seed may be detrimental. A field study was conducted at Sidney, MT to determine (1) the optimum depth of the fertilizer band for fall ST and (2) if the optimum band depth is affected by N application rate. Strip tillage was performed in the fall using a shank-type implement. Nitrogen and P were banded below the seed row at depths of 2.5, 7.5, or 12.5 cm from the soil surface. Nitrogen was applied as dry urea at 78, 146, or 212 kg N ha^{-1} and P as monoammonium phosphate at 24.4 kg P ha^{-1}. Interactions between band depth and N rate were not significant. Fertilizer band depth affected plant population in one of two years resulting in reductions of 7 to 13% when fertilizer was 2.5 or 7.5 cm deep compared to the 12.5-cm band depth. Nitrogen content of above-ground biomass (AGBM-N) was greatest with the 7.5-cm depth. Plant population was somewhat lower when N was applied at 212 kg N ha^{-1} resulting in a harvest population that was 7% less than when N was applied at 78 or 146 kg ha^{-1}. Fertilizer band depth did not affect root sucrose content, root yield or recoverable sucrose yield. It was concluded that fertilizer band placement between 7.5 and 12.5 cm deep (5 to 10 cm below the seed) resulted in the best combination of N uptake and seedling emergence. Caution is warranted when banding N shallower than 12.5 cm and/or at rates greater than 145 kg N ha^{-1} where conditions maximize the risk of seedling injury (e.g., dry climate, sandy textured soil, spring ST).

Additional Key Words: fertilizer management, fertilizer placement, urea, monoammonium phosphate, reduced tillage, zone tillage, *Beta vulgaris*, seedling injury

Strip tillage provides a viable means to implement reduced tillage practices in sugarbeet production (Evans et al., 2010; Overstreet, 2009). Most ST equipment currently available is equipped to apply fertilizer in a band at varying depths below the seed row. Banding N and P can improve fertilizer uptake efficiency because nutrients are close to the developing root system (Anderson and Peterson, 1978); immobilization is reduced (Tomar and Soper, 1987); and surface runoff, leaching and volatilization losses are minimized (Malhi et al., 2001; Timmons et al., 1973). Moreover, placement directly under the seed has been shown to be particularly beneficial for sugarbeet since early root growth is almost entirely in a downward rather than lateral direction (Anderson and Peterson, 1978). Fertilizer application rate and band depth can both influence early-season sugarbeet growth. If the band is placed too far away from the seed or the application rate too low, seedlings may suffer early-season nutrient deficiency and reduced yield.

In a recent field study, Stevens et al. (2010) monitored sugarbeet N status in both ST and conventional tillage and found in two of three years that N uptake early in the growing season under ST was less than with conventional tillage and suggested excessively deep fertilizer placement as a possible cause. Under furrow irrigation and conventional tillage in Wyoming, N placed 8 cm to the side of and 8 cm below the seed row resulted in greater N use efficiency than when banded 18 cm to the side of and 8 cm below the seed row or broadcast and incorporated (Stevens et al., 2007). The authors attributed this benefit at least partially to greater N availability during early growth stages when fertilizer was placed closer to the seed row. Conversely, under moisture-limited conditions, it has been noted that fertilizer applied too close to germinating corn seed or in excessive amounts may cause seedling injury and reduce plant population (Rehm and Lamb, 2009; Raun et al., 1986). Sugarbeet is reported to tolerate soil salinity levels up to 7.0 dS m^{-1} with little yield loss (Maas, 1987), but has been shown to be sensitive during germination (Ayers, 1952).

With interest in ST for sugarbeet production increasing more information is needed regarding fertilizer management. A field study was conducted to evaluate the effect of fertilizer placement on sugarbeet seedling emergence, N uptake and yield under fall ST and sprinkler irrigation. Specific objectives were to determine (1) the optimum depth of the fertilizer band for fall ST under overhead sprinkler irrigation and (2) if the optimum band depth is affected by N fertilizer application rate.

MATERIALS AND METHODS

The study was conducted from 2007 to 2008 at the Montana State University Eastern Agricultural Research Center approximately 2 km north of Sidney, MT (47.7255 N, 104.1514 W). The soil is a deep, well drained, nearly level Savage clay loam (fine, smectitic, frigid vertic Argiustolls) with 209 g kg^{-1} sand, 463 g kg^{-1} silt, and 328 g kg^{-1} clay; soil pH 7.8; organic C 8.9 g kg^{-1}, and total N 0.65 g kg^{-1} in the top 20 cm as determined from a composite sample collected from the study site. Growing season average monthly air temperatures range from 7.2 to 21.1ºC and average annual rainfall is about 330 mm, with approximately 190 mm occurring during the growing season. Thirty-year average precipitation was estimated by interpolating the 1971-2000 daily normal values based on data from the nearest National Weather Service (NWS) cooperative station (North Dakota Agricultural Weather Network; http://ndawn.ndsu.nodak.edu).

Sugarbeet was planted following barley in each of the two study years requiring that the study be moved to a different but adjacent location in 2008. All barley residues remained on the field following harvest, with some lying on the soil surface and the remainder standing 15 to 20 cm in height. Barley residues were spread as evenly as possible over the soil surface using straw and chaff spreaders attached to the combine.

Plots were arranged in a split-plot arrangement of a randomized complete block design with three fertilizer band depths (2.5, 7.5 and 12.5 cm below the soil surface) and three N application rates (78, 146 and 212 kg N ha^{-1}). In all cases, the fertilizer band was located directly below the seed row. A 55-m x 55-m experimental area was divided into 15 main plot strips each 3.7 m wide and running the entire length of the study area. Fertilizer band depth was the main plot treatment assigned randomly to each 3.7-m x 55.0-m main plot strip. Three 3.7-m wide × 18.3-m long subplots were established along the length of each main plot strip to which the three N application rate treatments were randomly assigned. Each treatment combination was replicated five times.

All plots were irrigated with a self-propelled linear move sprinkler irrigation system (Valmont Industries, Inc., Valley, NE) fitted with mid-elevation spray application heads suspended about 1 m above the canopy and spaced 3 m apart. The irrigation system was described in detail by Evans and Iversen (2005). The depth of irrigation water applied was based on soil moisture content determined weekly to a depth of 1.2 m by neutron attenuation (Hignett and Evett, 2002) and visual evaluations of crop moisture status.

Strip tillage was accomplished using a custom-built, six-row ST machine (Schlagel Mfg., Torrington, WY) described in detail by Evans et al. (2010). The implement leaves alternating 30-cm strips of tilled and undisturbed soil, leaving standing crop residue in the undisturbed inter-row areas. Fertilizer was applied in a band during the tillage operation via a tube attached to the back of the tillage shank. Tillage operations and fertilizer application were done in the fall. Nitrogen was applied as prilled urea [$(NH_2)_2CO$] at the application rates specified previously and monoammonium phosphate ($NH_4H_2PO_4$) was applied at 24.4 kg P ha^{-1}. Soil NO_3-N carried over from the previous crop was estimated based on a composite sample collected the previous fall. Values were 43 and 37 kg N ha^{-1} for 2007 and 2008, respectively. No other nutrients were applied due to soil test levels that were deemed non-limiting according to Montana State University recommendations (Jacobsen et al., 2005). Strip tillage was performed on October 6, 2006 and September 5, 2007. Sugarbeet seed (cv. ACH 927 large bare, American Crystal Co., Eden Prairie, MN) was planted in the spring at 135 000 seeds ha^{-1} at a 60 cm row spacing to a depth of 2.5 cm using a John Deere 1700 MaxEmerge Plus (Deere & Company, Moline, IL) machine equipped with toothed-wheel row cleaners (Model Dawn TrashWheel2®, Dawn Equipment Co, Sycamore, IL USA). Planting dates were April 23, 2007 and April 28, 2008.

Petiole samples were collected by removing the petiole of one recently-expanded leaf from each of 30 random plants within a plot. Petioles were oven-dried at 60ºC, ground to pass through a 1-mm screen, extracted with deionized water, and analyzed for NO_3-N using an automated flow analyzer (model QuikChem 8000; Lachat Instruments, Milwaukee, WI).

Root samples were collected in late September by hand-digging 1.5 m of row from two different rows randomly selected in the center of each plot. This procedure was repeated a second time in each plot resulting in two subsamples of 3 m each that were averaged prior to data analysis. Tops were removed by manually slicing through the crown tissue at about the first leaf scar. Roots that were less than 5.7 cm in diameter were determined to be non-harvestable because of the likelihood that they would fall through mechanical harvesting equipment. Non-harvestable beets were counted and discarded. Samples made up of harvestable roots were transported to the Sidney Sugars tare laboratory in Sidney MT where they were cleaned, weighed and analyzed for sucrose content. 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). Above-ground biomass samples consisting of leaves, petioles and crowns were collected at the same time as were root samples, but only from one of the two subsampling areas in each plot. Beet tops were placed into plastic tubs and weighed. A sub-sample from each tub was also weighed immediately, dried for 72 hours at 60ºC then weighed again so that above-ground dry matter (AGDM) production could be calculated. Sub-samples were ground using a Willey mill grinder fitted with a 1-mm sieve, then analyzed for total N and total C using the Dumas combustion technique (Edeling, 1968). Nitrogen uptake (kg N ha^{-1}) was calculated by multiplying total N concentration (kg N Mg^{-1} AGDM) by above-ground biomass (Mg ha^{-1}). The ratio of C to N (C:N) in the AGDM was calculated by dividing total C by total N.

Analysis of variance was performed using the MIXED procedure of SAS (SAS Institute, 2008) treating band depth as a main plot effect and N rate as a split-plot effect. Year, DAE, band depth, and N rate were considered fixed effects, while block and block interactions were considered random effects. Year was considered fixed rather than random due to notable weather differences between the two 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. Relationships between response variable means and continuous independent variables were modeled using the non-linear regression procedure of SigmaPlot software (Systat Software, Chicago, IL). Models were selected to obtain the best fit as indicated by r^2 and P values.

RESULTS AND DISCUSSION

Plant Population

Weather and soil conditions were generally favorable during seedling emergence in both 2007 and 2008. Mean daily temperatures in 2007 were warmer than average during the germination and early emergence growth periods and were cooler than average during the late emergence period resulting in a hyperbolic relationship between plant population and days after emergence (DAE) as depicted in Figures 1a and 2a. The pattern of mean daily temperatures in 2008 was the inverse of that observed in 2007 with cooler than average temperatures during germination and early emergence and warmer than average temperatures as emergence progressed. This resulted in a sigmoidal relationship between plant population and DAE (Figs. 1b and 2b). In both years plant population reached an average of about 98 800 plants ha^{-1}. While 90% of the final population was achieved by 9 DAE in 2008 the cooler conditions during late emergence in 2007 delayed this until about 13 DAE (Figs. 1a, b).

Differences in plant population among fertilizer band depth treatment means in 2007 ranged from 358 to 7711 plants ha^{-1} and were not significant; however, the interaction between band depth and DAE was significant (P=0.048) indicating that the emergence pattern over time was affected by band depth. Plant population was highest during the early emergence period with the 12.5-cm band depth, but the 7.5-cm band depth produced the highest population as emergence was completed (Fig. 1a). The fertilizer band depth significantly (P=0.017) affected emergence in 2008 (Fig. 1b) resulting in plant populations of 67 262, 70 050, 76 192 plants ha^{-1} for the 2.5, 7.5, and 12.5 cm depths, respectively, averaged over DAE and N rate. While plant population

Figure 1. Strip tillage sugarbeet plant population as affected by fertilizer band depth in 2007 (a) and 2008 (b) beginning with the day emergence began (0 days after emergence). Lower case letters beneath data points for a given day indicate means separation ($P<0.05$) for the corresponding three treatment means. Mean final population is plant population at 30 days after emergence averaged across all band depth treatments.

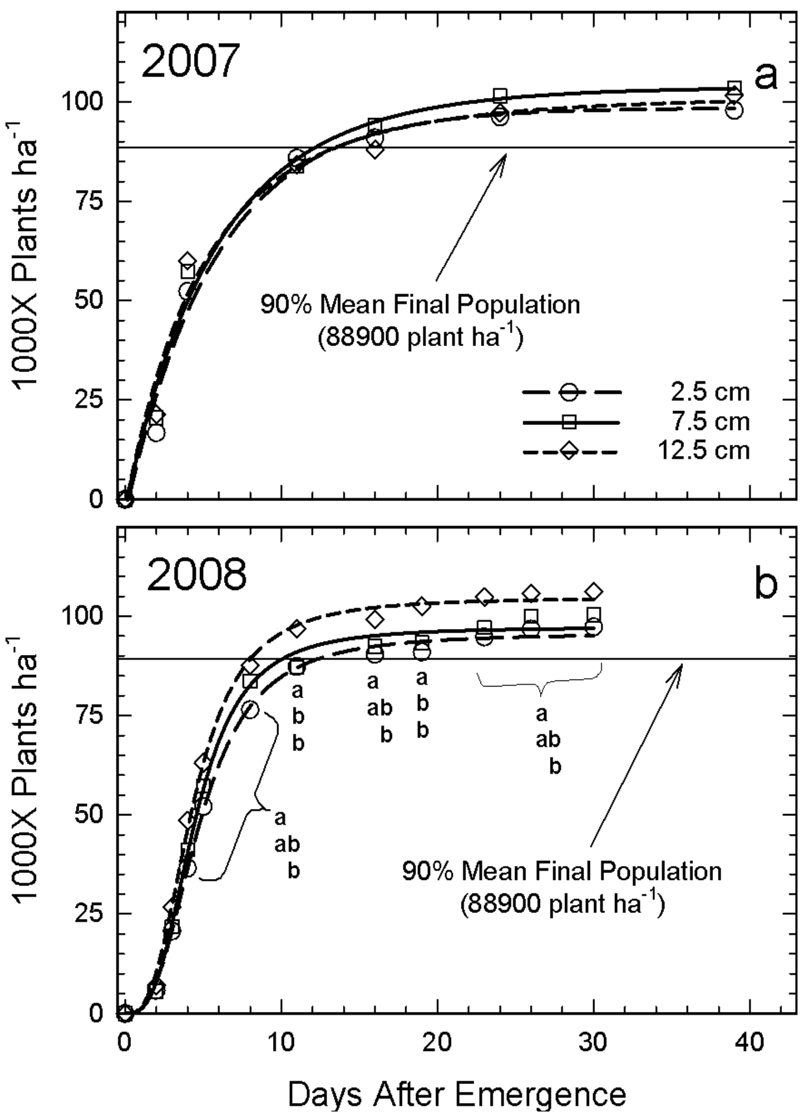


Figure 2. Strip tillage sugarbeet plant population as affected by N application rate in 2007 (a) and 2008 (b) beginning with the day emergence began (0 days after emergence). Lower case letters under data points for a given day indicate means separation (*P*<0.05) for the corresponding three treatment means. Mean final population is plant population at 30 days after emergence averaged across all band depth treatments.

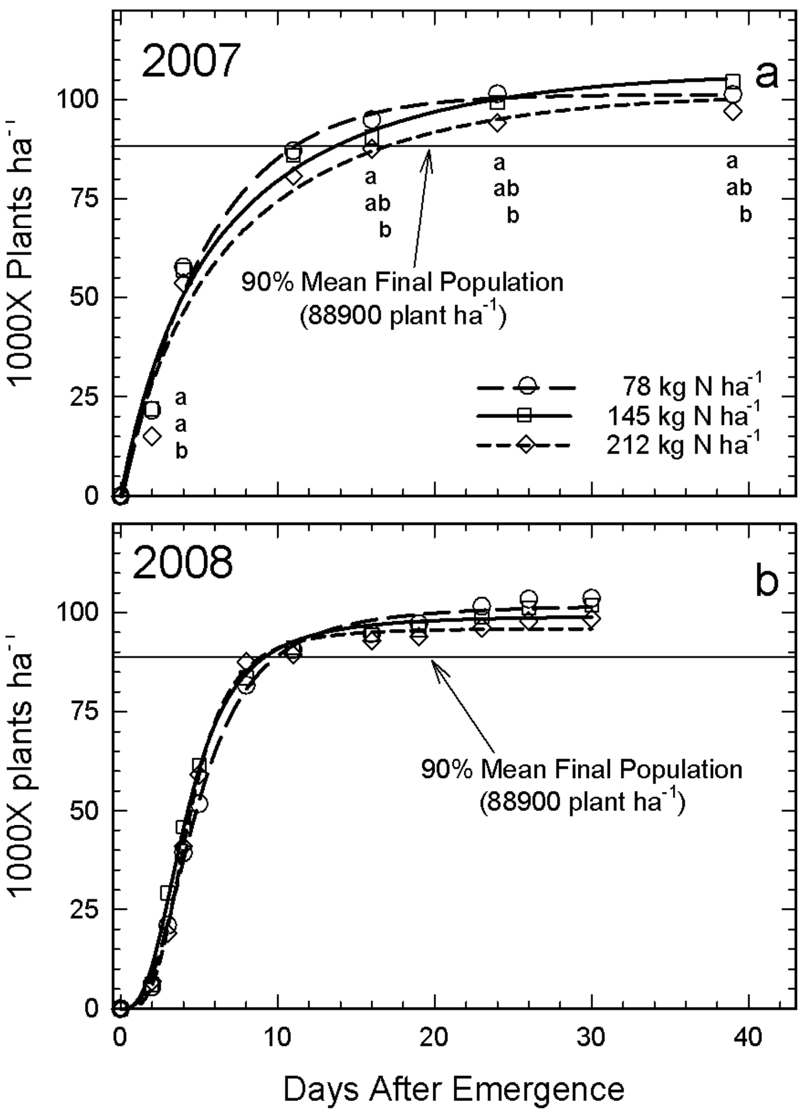


Table 1. Monthly precipitation values (cm) for Sidney, MT during a 2-year study on the effect of fertilizer placement on sugarbeet under strip tillage production.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Off-season[†]	Germination[‡]
	cm													
2006	--	--	--	--	--	--	--	--	--	0.7	0.1	0.0	--	--
2007	0.2	0.4	2.0	1.5	12.2	4.0	2.5	0.7	4.6	2.8	0.1	0.1	4.1 (10.2)[§]	12.7 (6.3)
2008	0.0	0.1	0.1	0.4	2.8	2.8	1.9	2.4	2.0	--	--	--	8.2 (14.8)	2.8 (5.6)
Average[¶]	1.2	0.9	1.6	2.9	5.3	6.9	6.2	4.1	4.0	2.4	1.5	1.1	--	--

[†]Off-season is the period between fertilizer application (10/6/2006 and 9/5/2007) and planting (4/23/2007 and 4/28/2008).
[‡]Germination period was from planting to May 31.
[§]Values in parentheses show the 30-year average precipitation for the corresponding off-season and germination time periods.
[¶]Thirty-year average precipitation values obtained from the North Dakota Agricultural Weather Network (NDAWN) website (http://ndawn.ndsu.nodak.edu).

tended to be highest when the fertilizer band was placed 12.5 cm deep throughout the emergence period, differences were significant only after 5 DAE. Stand reduction when fertilizer was placed shallower than 12.5 cm ranged from 7 to 13% after 5 DAE relative to the 12.5-cm band depth. Plant population was lowest with the 2.5-cm band depth, but could be differentiated from the 7.5-cm depth only at 6 and 8 DAE and only at $P<0.10$.

Nitrogen rate had a small effect on plant population in 2007. The main N rate effect was not significant ($P=0.088$), but there was a significant interaction between N rate and DAE. Nitrogen applied at 212 kg ha^{-1} reduced plant population by 30, 7.6, 7.2, and 7.1% compared to one or both of the lower N rates on 2, 16, 24, and 39 DAE, respectively (Fig. 2a). Trend analysis indicated that 90% of the final population was reached 2 to 6 days earlier when 78 kg N ha^{-1} was applied compared to the higher application rates indicating that the higher application rates delayed emergence somewhat. Plant population was not affected by N rate in 2008 (Fig. 2b) and there was no depth × N rate interaction in either year.

It is unclear why fertilizer treatments affected plant population differently in 2007 than in 2008. One possible explanation is that weather conditions affected the chemical makeup and spatial position of the fertilizer band differently in the two study years. In 2007 there was a small N rate effect while the band depth effect was not significant. The injury was likely caused by free NH_3 in the soil derived from urea (Creamer and Fox, 1980). An unusually dry fall in 2006 (Table 1) may have prevented the urea from dissolving and hydrolyzing until spring 2007, which in turn may have resulted in sufficiently high NH_3 in the soil to injure seedlings during germination, especially at the higher application rates (Fig. 2a). Ammonia injury may also have been exacerbated by cool soil temperatures during germination (Creamer and Fox, 1980). Conversely, precipitation during the germination period was 230% of normal in 2007 (Table 1), which likely leached the fertilizer enough so that band depth had little effect on emergence. The precipitation pattern for the second study year was opposite of that of the first. Fall precipitation 2007 totaling 7.2 cm (Table 1) likely allowed the urea to dissolve and hydrolyze in the fall, thus reducing the amount of free NH_3 in the soil during germination and minimizing the N rate effect. However, below-average precipitation during germination (Table 1) may have minimized movement of the fertilizer band, resulting in a slight reduction in plant population when fertilizer placed shallower than 12.5 cm below the soil surface (Fig. 1b).

Plant population at harvest was not affected by fertilizer band depth (data not shown) but decreased as the N rate increased from 146 to 212 kg ha^{-1} (Table 2). The total number of roots ha^{-1} at harvest (i.e., harvest plant population) was 7% less when N was applied at 212 kg ha^{-1} than at 146 kg ha^{-1}. The same pattern was observed in the number of harvestable (diameter ≥ 5.7 cm) roots ha^{-1}, but the effect was not significant (Table 2). This is likely because harvestable roots were 13% larger where N was applied at 212 kg ha^{-1} which in turn was due, not only to the higher N rate, but also to the lower plant population which reduced the competition for space, nutrients and water. Results from Lauer (1995) also suggest that sugarbeet compensates for reductions in plant population by producing a larger root. In that study, root yield did not vary significantly across population treatments ranging from 40,000 to 111,000 plants ha^{-1}.

Petiole NO_3-N Concentration

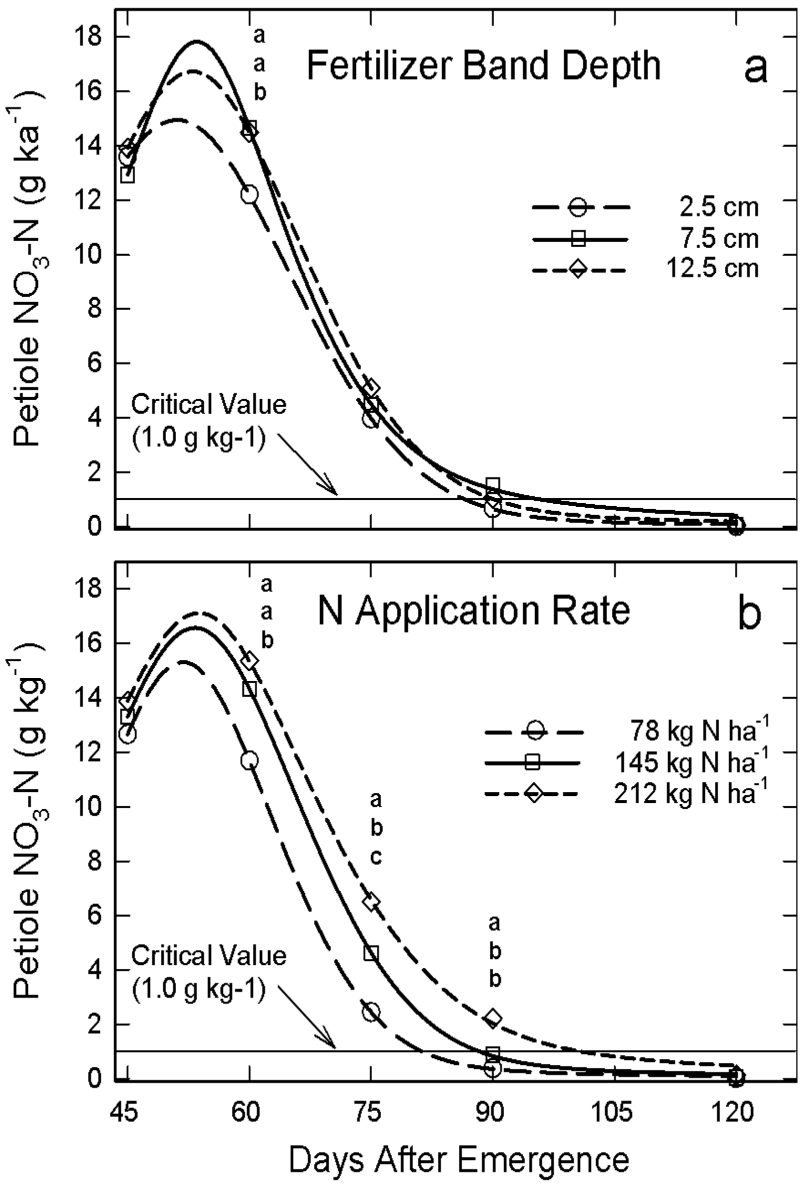
Fertilizer band depth had only a small effect on petiole NO_3-N concentration. On the first sample date in late June (45 DAE), petiole NO^3-N concentration was similar among the three band depth treatments. At 60 DAE, petiole NO_3-N concentration was lower when fertilizer was placed 2.5 cm deep compared to the two deeper band placements (Fig. 3a), but differences among band depth treatments were not significant at subsequent sample dates. Pseudo-Voigt models fit to the treatment means estimated that NO_3-N concentration was highest between 57 and 60 DAE and that fertilizer placed 7.5 cm deep maximized early-season N uptake. It is unclear why at 60 DAE petiole NO_3-N concentration was lowest when placed 2.5 cm deep. This is the same depth at which the seed was planted and it is plausible that the close proximity of the fertilizer band to the seed may have reduced N uptake because developing roots were injured by free NH_3 derived from urea fertilizer (Creamer and Fox, 1980). An alternative explanation is that the root of the developing sugarbeet seedling either grew below the majority of the fertilizer or bypassed the band due to im-

Table 2. Effect of fertilizer N application rate on the number of sugarbeet roots and beet fresh weight at harvest. Sidney, MT. Data are averaged across three fertilizer band depths (2.5, 7.5 and 12.5 cm) and two years (2007 and 2008).

N Rate	Number of Roots			Root Fresh Weight‡
	Non-Harvestable†	Harvestable	Total	
kg ha⁻¹	------------------------	*roots ha⁻¹*	--------------------	*g root⁻¹*
78	17,216a§	75,943a	93,159a	714b
146	17,752a	74,868a	92,620a	727b
212	14,615a	71,729a	86,344b	814a

†Non-harvestable roots are those with a diameter < 5.7 cm.
‡Root fresh weight is the weight of washed roots at harvest moisture content.
§Means in a column followed by the same letter are not significantly different ($p<0.05$).

Figure 3. Sugarbeet petiole NO_3-N concentration as affected by fertilizer band depth (a) and N application rate (b). Emergence refers to the day seedlings first began to emerge. Lower case letters above data points for a given day indicate means separation (P<0.05) for the corresponding three treatment means.



precise lateral seed placement relative to the fertilizer band. Regardless of the mechanism, the effect was small and temporary.

Stevens et al. (2010) compared N availability in ST sugarbeet and conventional tillage (CT) sugarbeet and reported that petiole NO_3-N concentration was sometimes lower when N was banded (ST) than when it was broadcast and incorporated (CT). In one year of the three-year study petiole NO_3-N concentration was about 50% less 80 days after planting with ST than with CT. The authors proposed as a possible reason for the observed difference that the fertilizer band depth was not optimal. However, the minimal effect of band depth on petiole NO3-N concentration reported herein suggests that fertilizer placement depth was not likely responsible for the differences reported by Stevens et al. (2010).

As expected, petiole NO_3-N concentration increased as more N was applied. While the three N treatment means were similar at 45 and 120 DAE, petiole NO_3-N concentration increased with increasing N application rate at 60, 75, and 90 DAE (Fig 3b). Petiole NO_3-N concentration dropped below the critical value of 1.0 g kg^{-1} defined by Ulrich and Hills (1990) at 81, 89, and 101 DAE for the 78, 146, and 212 kg ha^{-1} treatments, respectively. Ulrich and Hills (1990) further suggested that, for optimum sucrose yield, petiole NO_3-N concentration enter the critical range 56 days prior to harvest. For emergence on May 7 and harvest on September 30, petiole NO_3-N concentration should decrease to < 1.0 g kg^{-1} by about 90 DAE, which corresponds to the 146 kg ha^{-1} N rate.

Above-ground Dry Matter Yield and N Uptake

Nitrogen content of above-ground dry matter (AGDM-N) was similar in both 2007 and 2008 (p=0.849) while AGDM yield and N uptake

Table 3. Sugarbeet above-ground dry matter production (AGDM), above-ground dry matter N concentration (AGDM-N), C:N ratio, and N uptake by AGDM at different fertilizer placement depths in sugarbeet grown using strip tillage at Sidney MT. Data are averaged across three fertilizer N rates (78, 146 and 212 kg N ha^{-1}) and two years (2007 and 2008).

Band Depth	AGDM	AGDM-N	C:N	N Uptake
cm	*Mg ha⁻¹*	*g kg⁻¹*		*kg ha⁻¹*
2.5	5.64a†	18.5a	21.3ab	105ab
7.5	6.00a	18.9a	20.9b	114a
12.5	5.67a	17.4a	23.1a	99b

†Means in a column followed by the same letter are not significantly different (*P*<0.05).

were greater in 2008 than in 2007. Though AGDM-N was not significantly affected by band depth (*P*=0.173), the AGDM C:N ratio was lower when fertilizer was placed at 7.5 cm deep than when placed 12.5 cm deep (Table 3) indicating that ABDM was richer in N with the shallower band depth. While there was no difference in AGDM yield among the depths, slightly more N (15 kg ha^{-1}) was taken up into the AGDM when fertilizer was 7.5 cm deep than when it was 12.5 cm deep. These results suggest that placement at the 7.5-cm depth provided the best overall N availability. Placement at the 2.5- or 12.5-cm depths may have limited N uptake, most likely during early growth stages when differences in petiole NO_3 concentration were greatest (Fig. 3a) and when the root system was small and susceptible to positional unavailability of nutrients (Anderson and Peterson, 1978). However, differences in N uptake among band depth treatments were small and N uptake should be acceptable when fertilizer is banded anywhere within the range evaluated as long as management practices and climatic conditions are comparable.

Increasing N application rate increased AGDM-N in both years at an average rate of 2.25 g N kg^{-1} AGDM for each 67-kg ha^{-1} increase in N rate (Table 4). The same trend was observed in the AGDM C:N ratios, but the effect was stronger in 2008 than in 2007. While AGDM yield was not affected by N application rate in 2007, it increased in

Table 4. Sugarbeet above-ground dry matter production (AGDM), above-ground dry matter N concentration (AGDM-N), C:N ratio, and N uptake by AGDM at different N application rates in sugarbeet grown using strip tillage at Sidney MT. Data are averaged across three fertilizer band depths (2.5, 7.5 and 12.5 cm) and two years (2007 and 2008).

N Rate	**AGDM**	**AGDM-N**	**C:N**	**N Uptake**
kg ha⁻¹	*Mg ha⁻¹*	*g N kg⁻¹ AGDM*		*kg ha⁻¹*
		2007		
78	5.13a†	16.2b	25.4a	82b
146	4.95a	18.4ab	20.5b	91b
212	5.49a	20.0a	20.1b	111a
		2008		
78	5.33c	15.3c	24.8a	81c
146	6.09b	18.1b	21.6b	110b
212	7.59a	21.7a	19.1c	165a

†For a given year, means in a column followed by the same letter are not significantly different (*P*<0.05).

2008 by 0.76 Mg ha^{-1} as the N rate was increased from 78 to 146 kg ha^{-1} and 1.50 Mg ha^{-1} when the N rate was increased from 146 to 212 kg ha^{-1}. Nitrogen uptake by AGDM increased with increasing N rate in both years, but the response was greater in 2008 than in 2007. Band depth did not affect the AGDM N-uptake response to N application rate as indicated by nonsignificant depth × N rate interactions (P from 0.125 to 0.915).

Yield Components

Year affected (p from <0.0001 to 0.003) yield components, but because interactions between year and these factors were not significant, means from the two years were pooled. Root yield, sucrose content and SLM were not affected by fertilizer band depth (Table 5). Moreover, the offsetting trends in root sucrose concentration and root yield resulted in recoverable sucrose yield means that were very similar for the three band depth treatments.

Yield components were affected by N application rate. Root sucrose content decreased from 182.9 g kg^{-1} at 78 kg N ha^{-1} to 175.3 g kg^{-1} at 212 kg N ha^{-1} (Table 5). This decrease was further exacerbated by an

Table 5. Effect of fertilizer band depth and N application rate on recoverable sucrose yield components in sugarbeet grown using strip tillage at Sidney MT. Data are main effect means averaged over two years (2007 and 2008).

Treatment	Root Yield‡	SLM†	Sucrose Content‡	Recoverable Sucrose
	Mg ha^{-1}	*g kg^{-1}*	*g kg^{-1}*	*kg ha^{-1}*
Band Depth Effect				
2.5 cm	54.9a§	8.2a	181.5a	9509a
7.5 cm	55.6a	8.9a	177.8a	9374a
12.5 cm	55.6a	8.5a	178.5a	9445a
N Rate Effect				
78 kg ha^{-1}	52.2b	8.0b	182.9a	9130a
146 kg ha^{-1}	54.9b	8.3b	179.5a	9417a
212 kg ha^{-1}	58.9a	9.2a	175.3b	9781a

†SLM, sugar loss to molasses for fresh weight roots at harvest moisture content.
‡Root yield and sucrose content are for fresh weight roots at harvest moisture content.
§For a given main effect, means in a column followed by the same letter are not significantly different (P<0.05).

accompanying increase in impurities as indicated by SLM values that increased from 8.0 g kg^{-1} at 78 kg N ha^{-1} to 9.2 g kg^{-1} at 212 kg N ha^{-1} resulting in extractable sucrose contents decreasing from 174.9 g kg^{-1} to 166.1 g kg^{-1} as N application rate increased. This decrease in extractable sucrose content was offset by root yields that increased from 52.2 to 58.9 Mg ha^{-1} as N application rate increased from 78 to 212 kg ha^{-1}. The offsetting effects resulted in recoverable sucrose yields that were similar (P=0.118) within the range of N rates evaluated. Given the well-documented relationship between N application rate and sugarbeet yield components, a response to increasing N was expected. In an Idaho field study, Carter and Traveller (1981) reported that excess N applications both reduced root sucrose concentration and increased impurities that cause more sucrose to be lost to molasses during the extraction process. In Wyoming, Lauer (1995) and Stevens et al. (2009) similarly reported that sucrose concentration decreased and SLM increased as N application rate increased from 0 to up to 358 kg ha^{-1}.

It is not surprising that band depth had little impact on yield components given that its impact on plant population was minimal (Figs. 1a and 1b). It was, however, somewhat unexpected that band depth did not have a greater impact on seedling emergence. One objective of this study was to evaluate the risk of seedling injury when using ST equipment that places the band directly below the seed row. The shallow band depth (2.5 cm below the soil surface) was included because it poses the greatest risk of seedling injury since seeds are planted in the same position (i.e., 2.5 cm below the soil surface) as fertilizer is placed, yet virtually no reductions in emergence were observed. A number of factors may have reduced the negative effects of fertilizer placed close to the seed. First, it is likely that during the ST operation some of the dry fertilizer pellets fell below the intended placement depth before the slot created by the tillage shank was completely closed. This would produce a more diffuse band extending from the intended placement depth to the bottom of the tillage slot (~20 cm deep). Second, because fertilizer was applied in September or early October, there was ample opportunity for rainfall and snowmelt to dissolve the fertilizer and leach it deeper into the soil before seeding occurred in late April. Third, the soil texture at the study site is classified as clay loam, which is less likely than sandy textured-soil to result in seedling injury (Rehm and Lamb, 2009). The greater cation exchange capacity of clay soils provides more reaction sites to neutralize the ionic effect of fertilizer ions. Moreover, soils high in clay tend to have a greater water holding capacity than soils low in clay which may further reduce the osmotic potential by diluting the fertilizer ions in the soil solution. Fourth, since ST and planting operations were performed at different times and without the aid of global positioning technology, seed may not have been placed precisely with respect to the fertilizer band causing the seed to sometimes be farther away from the fertilizer band than intended, thus reducing the negative effects of the fertilizer on seedling germination and emergence.

Another purpose for this study was to determine if placing the fertilizer band too deep might have caused reduced early petiole NO_3-N concentrations as reported in a previous ST sugarbeet study (Stevens et al., 2010). However, petiole NO_3-N concentration was virtually the same whether N was placed 7.5 or 12. 5 cm deep (i.e., 5.0 and 10.0 cm below the seed), suggesting that N placed within the range of depths evaluated will not reduce N uptake. This agrees with results reported by Anderson and Peterson (1978), which indicate that for fertilizer banded 5 or 10 cm directly below the seed, roots reach the fertilizer band 5 and 12 days after planting, respectively. They further suggested that the ideal location for the fertilizer band for sugarbeet was 5 cm directly below the seed but that 10 cm below the seed may be preferable because of a lower risk of seedling injury.

We conclude that under the conditions of this study, fertilizer banded between 7.5 and 12.5 cm deep (i.e., 5 to 10 cm below the seed) will maximize early season fertilizer uptake with minimal risk of seedling damage. While we also found little risk associated with placing the fertilizer band 2.5 cm deep under the conditions of this study; however, the potential for seedling injury at this depth will likely be greater in sandy textured soil, in drier conditions, or with spring N application. In most circumstances risk of seedling injury can be expected to increase as fertilizer N application rate increases. In this study fertilizer band depth did not affect any of the yield components while fertilizer N application rate had a modest affect on yield components, but did not significantly affect recoverable sucrose yield. The range of N application rates in this study does not allow determination of an optimum N rate, but we conservatively estimate that under similar conditions N banded with ST implements at 145 kg N ha^{-1} or less will result in efficient N uptake with a low risk of seedling injury. Where additional fertilizer N is required it may be applied in a separate operation.

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