The Influence of Residual Deep Soil Nitrate on Sugarbeet Production*

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INTRODUCTION

Sampling soils for nitrate (NO_3) before planting is of particular importance for efficient sugarbeet production (7, 14). High levels of available soil N late in the growing season detrimentally affect sugar recovery and purity (6). The soil NO_3 test, in addition to providing a rational basis for determing adequate rates of N fertilizer, can also help growers avoid fields with excessive levels of NO_3.

Storage of sucrose by beets is minimal until an adequate leaf area is developed (12). Stout (13) stressed that an abundance of available N was needed early in the growing season to produce such a canopy. The development of an effective leaf canopy early in the growing season was a partial cause for the beneficial effect of N fertilizer under dryland conditions in the Red River Vally (9). Utilization of soil water and presumably NO_3 below 60 cm was not extensive until later in the growing season. However, water and apparently NO_3 had been utilized to at least 150 cm by harvest (8). Residual NO_3 in the upper 60 or 90 cm would thus seem especially important for efficient N nutrition.

Anderson et al. (1) used ^{15}N to show uptake by irrigated beets of NO_3 located at depths up to 135 cm. Data from recent irrigated experiments in Texas demonstrated apparent uptake of NO_3 late in the growing season from depths in excess of 2m (14). Total N uptake by irrigated sugarbeets in Colorado was significantly correlated with soil NO_3-N to a depth of 150 cm (at planting) plus applied fertilizer N (10).

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In the absence of topdressing with N fertilizer most research has indicated that the NO_3 content of petioles from recently mature leaves decreases during the growing season (6). Carter et al. (5) used an exponential decay-type equation to represent mathematically such decreases. Winter (14) found that late-season petiole NO_3 increased when beets were grown on a soil with large reserves of subsoil NO_3.

The objective of this research was to study the influence of high levels of soil NO_3-N in the upper 150 cm on N nutrition and sugar production under dryland conditions in the Red River Valley. At one of six sites NO_3-N in the upper 60 cm was considered marginal for optimal early canopy development. The effect of various rates of anhydrous ammonia for sugar production at this site was investigated.

MATERIAL AND METHODS

Sites, containing in the spring of 1979 high levels of soil NO_3 in the upper 150 cm, were selected within six different fields (Table 1). Site 6, located at East Grand Forks, Minnesota, was of particular interest since it contained 106 and 348 kg NO_3-N/ha in the 0 to 60 and 60 to 120-cm depth increments, respectively. Sites 1 through 5, in the Perley, Minnesota area, contained greater than 171 kg NO_3-N/ha in the upper 60 cm, a level at which N deficiency would be unlikely to restrict early canopy development.

Five rates of anhydrous ammonia-N (0, 56, 112, 168 and 224 kg N/ha) were applied at Site 6 to 12-m long plots in four bands, 0.56 m apart. The plots were arranged in a randomized block design with six replicates. Three 150-cm cores were taken from each plot on June 1 and October 2, 1979 to study soil NO_3 use. Access tubes for determination of soil moisture by a neutron probe procedure were placed in plots treated with 0 and 224 kg NO_3-N/ha. The sugarbeet variety ACS ACH 17 was planted on May 15 and subsequently thinned to an intrarow spacing of 30 cm. Petiole samples were taken at regular intervals and analyzed for NO_3. The final root harvest was completed on September 28; roots from 6.7-m lengths of the two center rows were harvested.

Table 1. Pertinent information concerning six experimental sites used to study the influence of soil nitrate on sugarbeet production.

	Site[a]					
Characteristic	1	2	3	4	5	6
Soil series	Fargo-Hegne c.	Fargo-Hegne c.	Fargo s.c.	Fargo s.c.	Hegne c	Glyndon s.l.
Previous crop	Fallow	Fallow	Fallow	Fallow	Barley	Potatoes
NO_3-N, 0-60 cm, kg/ha (a)	318 (31)	310 (33)	242 (28)	171 (5)	181 (25)	106 (9)
NO_3-N, 0-120 cm, kg/ha (b)	534 (46)	508 (46)	364 (30)	260 (18)	330 (40)	454 (28)
NO_3-N, 0-150 cm, kg/ha (c)	582 (49)	549 (49)	403 (31)	283 (21)	352 (39)	514 (30)
a/b	0.60	0.61	0.67	0.66	0.55	0.24
a/c	0.55	0.57	0.60	0.60	0.52	0.21

[a] Numbers in parentheses represent standard errors.

Five 9-m length plots with six 0.56-m rows were marked out at Sites 1 through 5 after the farmers had planted beets in late May. Soil NO_3 at the beginning and end of the growing season was determined in composite 30-cm samples, to a depth of 150 cm, from each plot. Petioles from young but recently mature sugarbeet leaves were analyzed periodically for NO_3. Root and sugar yields were estimated by harvesting 7.6-m lengths of two rows on September 20.

Soil nitrate was determined by an electrode procedure (3). Petiole nitrate analyses were made on aqueous extracts by a steam distillation technique using MgO and Devarda's alloy (2). Recoverable sugar was determined by the American Crystal Tare Laboratory, East Grand Forks using the Carruthers and Oldfield approach (4).

RESULTS AND DISCUSSION

Changes in Soil NO_3

Changes in soil NO_3 between early in the growing season and the final harvest are given in Table 2. These data show that decreases occurred at all sites and in all depth increments.

Table 2. Decreases in soil nitrate-N at six sites during the growing season.

Depth increment cm	Site[a] 1	2	3	4	5	6
	ΔNO_3-N, kg/ha					
0–30	193 (13)	190 (19)	156 (25)	108 (3)	101 (22)	41 (6)
30–60	90 (16)	88 (9)	73 (8)	49 (2)	63 (3)	15 (4)
60–90	115 (13)	82 (9)	56 (2)	48 (7)	91 (27)	48 (8)
90–120	58 (12)	64 (9)	41 (3)	29 (9)	39 (3)	118 (19)
120–150	32 (–)	9 (–)	22 (3)	18 (5)	11 (2)	38 (8)
0–150	488 (28)	433 (40)	348 (22)	252 (17)	305 (25)	260 (18)

[a] Nitrate decreases between June 1 and October 2 for Sites 1 through 5 and between June 6 and September 21 for Site 6. The data for Site 6 were obtained from non-fertilized plots. Numbers in parentheses represent standard errors.

Plant uptake undoubtedly contributed to the decreases in soil NO_3, but changes due to soil microbial transformations may have been important. Leaching losses during the growing season were unlikely to have affected overall NO_3 changes in the fine-textured soils at Sites 1 through 5 where precipitation ranged between 25 and 29 cm. Precipitation at Site 6 was 24 cm between June 1 and September 25. Little soil moisture was utilized from below 60 cm at Site 6 until late July when a complete canopy cover was present. However, by the end of September a decrease of 1 cm of water had occurred between 150 and 165 cm. This agrees with previous data showing the deep rooting habit of sugarbeets in the Red River Valley (8).

Of particular interest at Site 6 was the decrease of 118 kg NO_3-N/ha from the 90 to 120-cm depth increment. Soil water only commenced to decrease appreciably at this depth between August 3 and August 16. During this period petiole NO_3 values increased.

Changes in Petiole NO_3

Petiole NO_3 data for selected samplings at Sites 1 through 5 and at Site 6 are given in Tables 3 and 4, repectively. As expected, petiole NO_3 values in September were directly proportional to early season soil NO_3 values. Excessively high values

Table 3. Petiole nitrate during the growing season at five sites with high levels of soil nitrate and with greater than 50 per cent of the nitrate in the upper 60 cm of soil.

	Date of sampling[a]			
Site	7/16	7/30	8/14	9/4
	NO_3-N, ppm			
1	25,650 (1,180)	19,780 (830)	13,200 (640)	10,380 (610)
2	27,780 (880)	22,650 (890)	17,520 (510)	10,390 (1,160)
3	27,300 (4,340)	14,650 (2,120)	10,000 (1,290)	5,750 (640)
4	26,470 (760)	13,900 (1,850)	6,730 (1,690)	2,390 (1,140)
5	16,860 (2,540)	6,320 (1,010)	5,130 (640)	3,900 (730)

[a] Numbers in parentheses are standard errors.

of petiole NO_3 were present at Sites 1 and 2 at the final sampling.

Table 4. Influence of nitrogen fertilizer on petiole nitrate during the growing season at Site 6 where 21 per cent (106 kg/ha) of the nitrate-N was in the upper 60 cm of soil.

Anhydrous ammonia-N	Date of sampling					
	7/12	7/20	8/3	8/16	8/30	9/14
kg/ha	NO_3-N, ppm					
0	9,690	8,300	4,100	6,920	9,610	9,690
56	16,290	13,820	5,340	6,890	10,090	9,700
112	21,070	19,250	7,410	7,360	9,410	10,000
168	20,950	20,510	8,050	6,660	8,680	9,530
224	25,380	22,900	9,990	8,500	9,610	10,060
LSD (0.05)	3,130	2,240	1,270	1,640	1,260	1,230

The seasonal pattern for petiole NO_3 at Site 6 was different to that at the other sites. Values for check and low rates of fertilizer treatments reached a distinct minimum in August before increasing late in the season. As indicated in Table 1 this site had the smallest fraction of its soil NO_3, as well as the smallest absolute amount, in the upper 60 cm. The anomalous result resembled that reported by Winter (14) for a soil with a similar relative distribution of soil NO_3.

The exponential decay coefficients for petiole NO_3 disappearance (5) are given in Table 5. The anomalous situation at Site 6 is indicated by the very low coefficient of determination of 0.03 for the check-plot situation. The coefficient was only increased to 0.48 for plants treated with 200 kg NO_3-N/ha. The coefficient of determination for Sites 1 through 4 were reasonably high but was lower for Site 5, a non-fallow site where an appreciable barley straw residue was present. Immobilization may have detrimentally affected shallow soil NO_3 at this site and indirectly caused the poor fit of the decay equation. Petiole NO_3 in beets was reduced by approximately 50 per cent by application and incorporation of 6.7 tons/ha of wheat straw in Idaho (11).

Yield Data

The yield data for beets raised on the five fine-textured soils in the Perley area are illustrated in Table 6. The use-

Table 5. Effectiveness of the exponential decay equation to explain seasonal changes in petiole nitrate-N at several sites.

Regression coefficients[a]	Site[b] 1	2	3	4	5	6a	6b
No, ppm NO_3-N	24,600	29,200	23,700	27,800	12,000	7,200	19,000
C, day^{-1}	-0.0185	-0.0201	-0.0298	-0.0547	-0.0268	-0.0040	-0.0160
r^2	0.08	0.89	0.78	0.84	0.57	0.03	0.48

[a] No and C are the coefficients for the petiole nitrate "decay" equation, N = No exp (-Ct) (5), r = coefficient of determination.

[b] Sites 6 (a) and 6 (b) indicate values for plants from 1pots treated with 0 and 224 kg/ha of spring-applied ammonia-N, respectively.

fulness of the residual NO_3 test for predicting soils on which it would be difficult to raise quality beets is apparent. Correlation coefficients between sugar loss and sugar percentage and June NO_3-N (0 to 150 cm) were 0.98 ($P < 0.01$, n=5) and 0.95 (P x 0.05, n=5), respectively.

Table 6. Yield of roots and sugar at Sites 1 through 5 with high levels of soil nitrate and greater than 50 percent of the nitrate in upper 60 cm.

Site	Roots[a]	Sugar[a]	Rec. sugar[a]	Sugar loss[a]
	metric ton/ha	%	kg/ha	kg/ha
1	41.2 (0.9)	13.3 (0.3)	4280 (160)	1200 (45)
2	44.1 (1.3)	13.0 (0.3)	4520 (70)	1230 (60)
3	43.9 (1.1	14.6 (0.3)	5450 (160)	930 (50)
4	39.6 (0.7)	15.3 (0.3)	5250 (160)	790 (35)
5	39.6 (0.7)	15.5 (0.3)	5330 (190)	820 (30)

[a] Numbers in parentheses are standard errors.

The influence of N fertilizer on yield characteristics at Site 6 is given in Table 7. A small increase in recoverable sugar resulted from application of N fertilizer. Canopy development was slower in the check plots, and applied fertilizer increased early growth and intensity of the green leaf color until early August. At that time large quantities of subsoil NO_3 apparently became available, and an intense, dark green color then persisted in all plots for the rest of the growing season.

Subsoil NO_3, rather than applied fertilizer, apparently dominated quality characteristics at Site 6. Fertilizer applied

Table 7. Influence of nitrogen fertilizer on yield of sugar and related characteristics at Site 6 where 21 per cent (106 kg/ha) of the soil nitrate was in the upper 60 cm.

Anhydrous ammonia-N	Roots	Sugar	Gross sugar	Rec. sugar	Impurities		
					Na	K	Amino-N
kg/ha	metric ton/ha	%	kg/ha	kg/ha	ppm		
0	44.1	14.1	6220	4950	1145	2173	882
56	48.2	14.3	6880	5500	1093	2183	902
112	46.1	14.1	6500	5130	1113	2153	952
168	47.5	14.1	6680	5280	1152	2130	948
224	46.1	14.2	6530	5200	1102	2092	928
LSD (0.05)	2.9	NS	430	390	NS	NS	NS

at rates up to 224 kg N/ha had no significant effect on percentage sugar or on levels of Na, K and amino-acid impurities. The petiole data in Table 4 suggest that fertilizer N had a large effect on N nutrition early in the growing season, but this effect was swamped by the availability of subsoil NO_3 in August. Restricted availability of soil moisture in the surface layers during the latter part of the growing season may also have reduced availability of the fertilizer N. The soil NO_3 at deeper depths probably contributed substantially to the low average sugar percentage at this site.

CONCLUSIONS

The value of the residual NO_3 test for predicting soils in the Red River Valley, on which the raising of quality beets would be difficult, is clearly indicated by this study. Soil sampling to 120 or 150 cm is needed for such diagnosis. However, the usual commercial situation is to sample soils to a depth of 60 cm. For many cases this practice is probably adequate. However, the identification of some soils on which quality beets cannot be raised will not be possible with this shallower sampling.

Deep soil sampling to 120 or 150 cm is a difficlt, time-consuming task and seems hardly justified on an area-wide basis unless large numbers of fields contain moderate or high levels of NO_3 below the customary sampling depth. A survey of soil test reports for 387 Red River Valley fields planted to beets in 1980 showed that only 16 and 7% contained in excess of 112 and 168 kg NO_3-N/ha, respectively, in the 60 to 120-cm depth increment. It seems appropriate to stress the need for moderate use of N fertilizer according to soil-test recommendations, not only for the sugarbeet crop, but for all crops in the rotation. Judicious use of N fertilizer should eventually decrease the incidence of high NO_3 soils.

The N fertilizer response obtained at Site 6 resembles a similar situation on a soil with a high level of deep-soil NO_3 in Texas (14). If soil NO_3-N in the upper 60 or possibly 90 cm is low, N fertilizer will probably be needed for maximum sugar production. Deeply located NO_3 in soils, because of possible water-pollution problems as well as its harmful effect on beet production, must be classed as a liability. Winter (14) suggested that growing alfalfa, a deeply rooted plant, in a cropping sequence may be the best way to remove excess profile NO_3.

SUMMARY

The influence of high levels of residual soil NO_3 on sugar production was studied in six field trials under dryland conditions in the Red River Valley. Soil NO_3-N varied between 106 and 318 kg/ha and 283 to 582 kg/ha in the 0 to 60 and 0 to 150-cm depth increments, respectively. The ratio of soil NO_3-N in the upper 60 cm to that in the upper 150 cm ranged between 0.52 and 0.60 for five soils (Sites 1-5) and was 0.21 (with 106 kg NO_3-N/ha in the upper 60 cm) at Site 6.

Percentage sugar and sugar losses were significantly correlated with soil NO_3-N at Sites 1-5. Petiole NO_3 was related to soil NO_3 and its disappearance tended to follow an exponential-type decay curve at these sites; there was no tendency for NO_3 to increase late in the growing season. The situation at Site 6 was more complex. Petiole NO_3 in unfertilized beets at this site was only moderate early in the season, decreased to a minimum at mid-season, and then increased later in the season with the delayed availability of subsoil NO_3. Consequently, petiole NO_3 disappearance could not be modelled by an exponential decay-type function. The deeply located NO_3 at Site 6 was ineffective at supporting rapid canopy growth early in the season, as a result of which a response to N fertilizer was obtained. The response was obtained in spite of petiole NO_3-N values of 9,690 ppm in unfertilized plants at the end of the season.

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