Nitrate-Nitrogen Accumulation in Furrow Irrigated Fields and Effects on Sugarbeet Production*

S. R. Winter

Received for Publication June 13, 1986

INTRODUCTION

Nitrogen (N) management is one of the most difficult production problems for sugarbeet (*Beta vulgaris* L.) growers. The ideal N regime for sugarbeets provides adequate N early in the growing season for high root yield (4,5,6,7,12) followed by a 4-to 9-week period of N deficiency prior to harvest to maximize sucrose content (2,5,7). Achieving the delicate balance between adequate N early and deficits late in the season, requires N management of rotation crops grown prior to sugarbeets to minimize excessive nitrate-nitrogen (NO_3-N) accumulation in the soil profile. Providing the proper period of N deficiency before harvest can be very difficult under commercial field conditions.

Difficult N management problems occur on deep soils that are not easily leached of excessive NO_3-N by rainfall or irrigation. Sugarbeets in Texas are grown on deep, slowly permeable soils that accumulate NO_3-N in amounts exceeding those reported elsewhere (8,11,12). The accumulated NO_3-N may be highly variable in both horizontal and vertical directions in the soil. Reuss et al. (10), working in Colorado on soils generally more permeable than those used in Texas for sugarbeet production, reported that 20 and 82 cores per field gave 90% confidence intervals of $\pm$26% and $\pm$15% for NO_3-N, respectively. Of all fields sampled, 54% had a significant directional gradient in NO_3-N, but there appeared to be no predictable pattern to the gradients.

---

*Contribution from the Texas Agri. Exp. Stn., Texas A&M Univ. System as Tech. Article No. 21697 in cooperation with USDA-ARS. The author is Associate Professor, P. O. Drawer 10, Bushland, Texas 79012.

Sugarbeets root deeper than most annual crops. This is probably related to their long period of vegetative growth. Early reports indicated NO_3-N uptake to a 5-ft depth (1). Peterson et al. (9), using ^{15}N-labeled NO_3-N, detected uptake from the 6- to 7-ft depth beginning in August for sugarbeets planted in mid-April. They state that "in climates where longer growing seasons exist and where soil permeabilities permit, sugarbeet root penetration may be to depths even greater than 7 ft". Sugarbeets in Texas with a 7 to 8 month growing season can use NO_3-N from at least 10 ft (12). Where deep residual NO_3-N interacts with the deep rooting habit of sugarbeets, the effect will be equivalent to a late-season side-dressing of N which has been shown to be detrimental to sucrose content and purity (2,3,7).

Previous work in Texas (12) suggested potentially serious problems due to deep (below 4 ft) residual NO_3-N and systematic NO_3-N variability related to furrow irrigation. The objectives of this study were to delineate the extent of these problems and to determine the consequences for production of commercially grown sugarbeets.

MATERIALS AND METHODS

Twenty-five commercial, furrow-irrigated fields within 50 miles of Hereford, Texas were chosen at random for study. Nineteen fields were sampled in 1981, 2 in 1983, and 4 in 1984. All fields were approximately 2500 ft long and were sampled 250 ft from both the upper (where water was applied) and lower ends. Soil types ranged from slowly permeable loams to very slowly permeable clay loams. All tillage and production operations were performed by the farmer cooperators.

Soil samples were taken in May when the sugarbeets had 6 to 10 true leaves. Soil sampling was delayed until spring so that an area with good stand could be selected and the exact location flagged for later data collection. Soil cores (three per site) were taken to a 12-ft depth by 2-ft increments. Soil samples were dried at 70C, ground, extracted with water, and NO_3-N was determined on the extract using a nitrate ion electrode. While we cannot be certain, it is believed that no additional N was applied after the soil samples were taken. The farmer's normal fertilizer applications were made before soil sampling.

Two additional fields were sampled for NO_3-N and yield at 100-ft intervals from top to bottom. These fields were 2,500 and 2,700 ft long, had very slowly permeable Pullman clay loam soil, and uniform slope of about 0.25%.

Three root samples were harvested from each site in late September or early October to determine root yield, brei nitrate, tare, and sucrose percent. Each root sample consisted of 9 ft of 30-inch row. The entire sample was weighed to determine yield and then used to determine sucrose. Root samples were analyzed by Holly Sugar Corporation.

RESULTS AND DISCUSSION

The amount of soil nitrate-nitrogen (NO_3-N) was highly dependent on field position and this appeared to influence sugarbeet quality. Soil NO_3-N averaged nearly twice as high on the lower end of the field as on the upper end whether measured to 4 or 12 ft (Table 1). Only three fields (numbers 8, 12, and 13; Table 1) of 25 sampled had greater NO_3-N on the upper than the lower end. Sucrose in sugarbeets averaged 14.37 and 12.95% on upper and lower field positions, respectively (Table 1). Four fields (numbers 7,8,10, and 12) had higher sucrose on the lower than on the upper end (Table 1). Only two fields (numbers 8 and 12) had sugarbeets with higher brei nitrate from the upper field position. While other factors may be involved in the quality differences between upper and lower ends of these fields, the difference in NO_3-N must be of paramount significance.

Field position had no effect on mean root yield but effects were apparent in some individual fields. Average root yields were 26.0 and 26.4 t/A on upper and lower positions, respectively. Somewhat less yield, on the average, could be expected on the lower position due to less water. More yield might be expected on the lower po-

Table 1. Sugarbeet quality, yield, and soil NO_3-N in 25 furrow irrigated fields as affected by field position.

Field number	Field position[a/] Sucrose upper	Sucrose lower	Root yield upper	Root yield lower	Brei nitrate upper	Brei nitrate lower	NO_3-N (0-4 ft) upper	NO_3-N (0-4 ft) lower	NO_3-N (0-12 ft) upper	NO_3-N (0-12 ft) lower
	--%--		--t/A--				------lb/A		------	
1	14.96	12.39	30.0	28.7	2.3	4.3	136	460	315	917
2	12.51	11.20	33.9	31.6	4.7	5.3	189	300	776	1056
3	15.69	12.70	24.0	21.1	2.3	5.0	158	301	331	618
4	15.68	12.62	23.0	25.6	2.0	6.0	97	336	249	786
5	13.22	10.85	24.9	24.2	3.3	6.0	201	842	501	1528
6	15.21	12.53	25.3	41.4	2.3	5.0	68	104	220	455
7	13.30	13.33	19.1	32.9	3.0	3.3	108	137	160	277
8	12.14	12.90	26.3	20.6	3.0	2.3	90	66	255	139
9	15.79	15.04	20.0	21.0	3.0	3.7	89	163	157	258
10	9.82	10.61	27.9	25.3	5.7	5.7	454	776	959	1331
11	13.72	13.19	25.2	23.7	3.0	4.7	104	286	297	412
12	13.36	14.26	25.6	20.9	3.7	3.0	275	211	456	340
13	15.22	15.11	20.2	20.7	2.7	2.7	109	63	254	114
14	14.78	10.79	22.0	15.3	2.3	6.0	151	207	197	388
15	14.63	13.74	27.8	33.9	2.3	3.3	136	315	200	385
16	15.42	12.49	23.1	35.9	2.7	5.0	129	295	269	910
17	15.35	13.84	23.8	21.3	2.7	5.0	195	316	238	496
18	13.76	12.13	23.9	17.8	4.0	5.3	138	290	488	638
19	14.70	11.86	26.2	26.2	2.7	5.0	160	292	280	649
20	15.75	14.64	24.0	23.2	2.8	4.7	121	183	182	391
21	14.45	14.20	34.5	26.6	4.7	5.2	117	252	367	737
22	15.11	13.87	37.6	36.7	4.6	5.3	100	155	178	415
23	15.44	13.67	28.4	29.2	3.1	4.4	155	156	403	428
24	13.84	11.79	24.3	24.0	3.9	5.8	76	275	217	503
25	15.49	13.90	28.4	31.1	4.3	5.0	148	196	244	388
Mean	14.37	12.95	26.0	26.4	3.2	4.7	148	279	328	582

a/Upper refers to the end of the field where water is applied.

sition due to higher N so these two effects would tend to cancel out. In fields 6 and 16 and to a lesser extent in field 7, plant appearance during the growing season and harvest results indicate that root yield on the upper field position was probably limited by N deficiency. Fields 6 and 16 had high yields (41.4 and 35.9 t/A) and low sucrose (12.53 and 12.49%) on the lower ends of the fields compared to 25.3 and 23.1 t/A and 15.21 and 15.42% sucrose on the upper ends. These results indicate a high yield potential in fields 6 and 16 which was not realized on the upper end due to low ground cover resulting from N deficiency.

Two fields sampled every 100 ft had nearly linear changes in NO_3-N and sucrose from low NO_3-N:high sucrose on the upper end grading to high NO_3-N:low sucrose on the lower end. A linear change in vigor of top growth in many fields indicates that such patterns are common in fields with uniform soil and slope.

To investigate the relationship of soil NO_3-N in the 0-4 ft depth with that in the total profile, the 50 sampled sites were divided into five categories based on NO_3-N levels in the 0-4 ft depth (Table 2). Categories were based on 0-4 ft NO_3-N because Holly Sugar Corporation samples all Texas' sugarbeet fields to 4 ft. The ratio of 0-12 ft NO_3-N to 0-4 NO_3-N is 2.02 to 2.66 depending on soil NO3-N category. Since sugarbeets may root as deep

Table 2. Relationship between 0-4 ft and total profile NO_3-N. The categories are based on 0-4 ft NO_3-N. The 0-12 ft NO_3-N is given for the same sites.

Soil NO_3-N categorya/	0 to 4 ft NO_3-N Mean	0 to 4 ft NO_3-N Range	0 to 12 ft NO_3-N Mean	0 to 12 ft NO_3-N Range	Ratio of means 0-12ft/ 0-4 ft	Ratio of means 0-4 ft/ 4-12 ft
	-----	-----	lb/A	-----		
1	85.7	63-104	228.1	114-455	2.66	0.602
2	127.9	108-148	275.6	160-488	2.15	0.866
3	166.5	151-195	371.7	197-776	2.23	0.811
4	248.5	196-292	501.2	340-737	2.02	0.983
5	439.5	295-842	898.6	385-1528	2.04	0.957
Mean	213.6	-----	455.0	------	2.22	0.844

a/The 50 sites (25 fields, 2 sites/field) were divided into five categories with 10 sites/category based on 0-4 ft NO_3-N.

as 12 ft in Texas (12) potential available NO_3-N on the average is over twice the 0-4 ft NO_3-N.

The best NO_3-N distribution for sugarbeets would be adequate amounts in the surface and none in the deeper soil profile. Distribution of NO_3-N was somewhat better at high NO_3-N sites than at low NO_3-N sites (Table 2). The ratio of 0-4 ft NO_3-N to 4-12 ft NO_3-N was 0.957 for category 5 sites (high NO_3-N) and 0.602 for category 1 (low NO_3-N). On the other hand, the sites which averaged higher in sucrose tended to have a higher ratio of shallow to mid-depth NO_3-N (Table 3). The ratio of 0-2 ft/2-4 ft NO_3-N was 1.22, 1.19, 1.05, 0.86, and 0.76 where

Table 3. Characteristics of sites averaged by sucrose concentration.

	Sucrose, %				
	$\geq$ 15.00	14.00-14.99	13.00-13.99	12.00-12.99	$\leq$ 11.99
Total sites	13	8	13	9	7
Upper sites	11	5	6	2	1
Lower sites	2	3	7	7	6
Mean % sucrose	15.41	14.58	13.60	12.48	10.99
Mean root yield, t/A	24.6	26.4	27.1	27.9	24.9
Mean brei nitrate	2.99	3.40	3.99	4.51	5.64
Mean NO_3-N 0-2 ft	67.5	103.6	90.2	109.4	193.1
2-4 ft	55.2	87.0	85.5	127.3	254.9
0-4 ft	122.7	190.6	175.7	236.8	448.0
0-12 ft	238.2	376.5	364.2	610.4	916.3
Ratio 0-2/2-4 ft	1.22	1.19	1.05	0.86	0.76
0-4/4-12 ft	1.06	1.03	0.93	0.63	0.96

sucrose was 15.0, 14.0 to 14.99, 13.0 to 13.99, 12.0 to 12.99, and 11.99% or less, respectively. Consideration of this ratio might be a worthwhile addition to the evaluation factors for field selection. However, the major criteria of field selection should continue to be the absolute value of NO_3-N.

Soil samples should be taken as deep as possible because the correlation of sucrose to soil NO_3-N improved as sampling depth increased (Table 4). However, sampling below the present 4 ft will probably not be cost effective because 0-4 ft and 0-12 ft NO_3-N were highly correlated (Table 4). The correlation of brei nitrate to soil NO_3-N also increased as soil sampling depth increased (Table 4). These observations are evidence that NO_3-N below 4 ft was affecting sugarbeet quality by a measurable amount. Root yield was not correlated with measured NO_3-N at any depth (Table 4) which probably indicated that N was not generally limiting root yield.

High soil NO_3-N greatly decreased average and maximum attainable sucrose concentration. Soil NO_3-N below 200 lb/A in the 0-4 ft sample had little influence on average and maximum sucrose. For soil NO_3-N categories 1, 2, and 3 (Table 2), mean sucrose was 14.20, 14.63, and 14.57% respectively. Maximum sucrose was 15.79, 15.75,

Table 4. Correlation coefficients between yield, quality, and soil NO_3-N.

	Root yield, t.A	Brei nitrate	Soil NO_3-N 0-2 ft	2-4 ft	0-4 ft	0-12 ft
			correlation coefficients			
Sucrose %	-0.0645	-0.7088	-0.5712	-0.5884	-0.6406	-0.7269
Prob. > r	0.6564	0.0001	0.0001	0.0001	0.0001	0.0001
Root yield, t/A	---	0.2149	-0.0481	-0.0283	-0.0394	0.1603
Prob. > r		0.1340	0.7401	0.8452	0.7860	0.2660
Brei nitrate		---	0.4129	0.5972	0.5821	0.6899
Prob. > r			0.0029	0.0001	0.0001	0.0001
NO_3-N 0-2 ft			---	0.6255	0.8419	0.6872
Prob. > r				0.0001	0.0001	0.0001
NO_3-N 2-4 ft				---	0.9477	0.8913
Prob. > r					0.0001	0.0001
NO_3-N 0-4 ft					---	0.8977
Prob. > r						0.0001

and 15.69% for those categories. Mean sucrose fell to 12.87 and 12.03% for categories 4 and 5, respectively. The maximum sucrose achieved was only 14.26% in category 4 and 13.84% in category 5. Some low sucrose sugarbeets were produced with low soil NO_3-N. Thus, one can conclude that high sucrose will be achieved only with low NO_3-N; whereas, low sucrose can be produced with either low or high NO_3-N. The low sucrose associated with low NO_3-N could in some cases be due to sampling or analysis errors. However, most of the low sucrose:low NO_3-N observations are probably due to disease or other unfavorable factors which lowered sucrose concentration.

The effect of field position on NO_3-N content and its distribution with depth in the soil did not appear to be dependent on soil type or year. The results were consistent from year to year and are consistent with earlier observations in 1977 (12). The effect of furrow irrigation on NO_3-N distribution must be a widespread phenomenon and has implications for fertilizer management of crops other than sugarbeets.

SUMMARY

Soil nitrate-nitrogen (NO_3-N) was measured to 12 ft on the upper and lower ends of 25 furrow irrigated sugarbeet fields. Samples were taken 250 ft from each end of the 2,500 ft long fields. Root samples were harvested from the same locations to determine yield and sucrose. Two additional fields were sampled for NO_3-N and sucrose at 100 ft intervals from top to bottom.

Soil NO_3-N averaged 148 and 279 lb/A in the 0-4 ft depth on the upper and lower ends, respectively, of 25 fields. As a result, sucrose in sugarbeets averaged 14.37 and 12.95% on the upper and lower ends, respectively. Field position had no effect on average root yield; however, three fields appeared to have considerably reduced root yields on the upper end due to N deficiency. On the average, NO_3-N concentration decreased with depth in the soil. Sites with high sucrose tended to have a higher ratio of shallow to mid-depth or deep NO_3-N than low sucrose sites.

Two fields sampled every 100 ft had linear changes in NO_3-N and sucrose from low NO_3-N:high sucrose on the upper end grading to high NO_3-N:low sucrose on the lower end.

Deep soil samples (up to 12 ft) gave better correlations of sucrose and brei nitrate with soil NO_3-N than shallow soil samples. Nitrate-N below 4 ft had measurable effects on sugarbeet quality. If soil NO_3-N was low, high sucrose was possible but some sites with low NO_3-N also had low sucrose. High NO_3-N sites never had high sucrose.

Results were consistent from year to year. The effect of furrow irrigation on NO_3-N distribution must be a widespread phenomenon and has implications for fertilizer management of other crops.

LITERATURE CITED

1. Anderson, F. N., G. A. Peterson, and R. A. Olson. 1972. Uptake patterns of ^{15}N tagged nitrate by sugarbeets as related to soil nitrate level and time. J. Am. Soc. Sugar Beet Technol. 17:42-48.

2. Carter, J. N. 1982. Effect of nitrogen and irrigation levels, location and year on sucrose concentration of sugarbeets in southern Idaho. J. Am. Soc. Sugar Beet Technol. 21:286-306.

3. Gilbert, W. A., A. E. Ludwick, and D. G. Westfall. 1981. Predicting in-season N requirements of sugarbeets based on soil and petiole nitrate. Agron. J. 73:1018-1023.

4. Giles, J. F., J. O. Reuss, and A. E. Ludwick. 1975. Prediction of nitrogen status of sugarbeets by soil analysis. Agron. J. 67:454-459.

5. Hills, F. J., G. V. Ferry, A. Ulrich, and R. S. Loomis. 1963. Marginal nitrogen deficiency of sugar beets and the problem of diagnosis. J. Am. Soc. Sugar Beet Technol. 12:476-484.

6. James, D. W., A. W. Richards, W. H. Weaver, and R. L. Reeder. 1971. Residual soil nitrate measurement as a basis for managing nitrogen fertilizer practices for sugarbeets. J. Am. Soc. Sugar Beet Technol. 16:313-322.

7. Loomis, R. S. and D. J. Nevins. 1963. Interrupted nitrogen nutrition effects on growth, sucrose accumulation and foliar development of the sugar beet plant. J. Am. Soc. Sugar Beet Technol. 12:309-322.

8. Ludwick, A. E., P. N. Soltanpour, and J. O. Reuss. 1977. Nitrate distribution and variability in irrigated fields of northeastern Colorado. Agron. J. 69:710-713.

9. Peterson, G. A., F. N. Anderson, G. E. Varvel, and R. A. Olson. 1979. Uptake of ^{15}N-labeled nitrate by sugar beets from depths greater than 180cm. Agron. J. 71:371-372.

10. Reuss, J. O., P. N., Soltanpour, and A. E. Ludwick. 1977. Sampling distribution of nitrates in irrigated fields. Agron. J. 69:588-592.

11. Westfall, D. G., W. J. Eitzman, D. R. Rademacker, and R. G. Vergara. 1979. Residual soil nitrogen and phosphorus in some sugarbeet fields in Montana and Wyoming. J. Am. Soc. Sugar Beet Technol. 20:217-232.

12. Winter, S. R. 1981. Nitrogen management for sugarbeets on Pullman soil with residual nitrate problems. J. Am. Soc. Sugar Beet Technol. 21:41-49.