Redistribution of Nitrate in Soils and Its Effects on Sugar Beet Nutrition[1]

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Introduction

Nitrogen nutrition has been shown to be an important factor in sugar beet yield and quality (2,3,5,6,7,8)[3]. If nitrogtn is too low, unprofitable yields result, but if it is too high at harvest, beets are low in sucrose and purity. Thus timing of nitrogen uptake, as well as the total amount, is essential in successful sugar beet production.

Nitrate nutrition is one of the more difficult production variables to control because it is influenced by so many environmental conditions. The incorporation into soil of previous crop residues, time of application of organic or inorganic forms of nitrogen, temperature, and the method and amount of water application affect the availability of nitrate to growing crop plants.

Table 1.—Precipitation and Evaporation, Salt Lake Valley, 1959-1960 and Cache Valley, 1961.

	Precipitation (inches)			Evaporation (inches)		
Month	1959[1]	1960[2]	1961[3]	1959[4]	1960[4]	1961[3]
April	1.61	0.40	0.69	7.34	7.42	3.96
May	2.05	1.09	0.66	8.71	10.31	5.65
June	1.38	0.30	0.59	12.95	13.65	6.59
July	0.19	0.10	0.53	14.12	16.16	7.53
August	1.76	0.66	0.72	12.94	13.11	6.65
September	1.66	0.70	1.89	8.09	9.76	3.87
October	0.22	1.23	1.64	4.94	5.37	no data
Total	8.87	4.48	6.72	69.09	75.81	34.25

[1] Salt Lake Airport W. B. (Salt Lake Valley)
[2] Midvale Station (Salt Lake Valley)
[3] Greenville Farm, U.S.U. (Cache Valley)
[4] Morton Salt Company (Salt Lake Valley)

The wide discrepancy between amounts of rainfall and evaporation (Table 1) causes the redistribution of soluble salts in soils. This results in the build-up of high surface concentrations and is the primary cause of salinity problems in arid climates. Extensive research has resulted in some ingenious practical

[1] The field studies involving deep vs. shallow furrowing were done in cooperation with members of the Research Staff of the Utah-Idaho Sugar Co.

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[3] Numbers in parentheses refer to literature cited.

measures for manipulating the localization of high salt concentrations (1). Soluble plant nutrients, especially nitrate, follow the same general patterns of movement and concentration in soils. The movement and localized patterns of redistribution of nitrate strongly affect nutrition of the sugar beet crop.

The purpose of this report is to provide additional information on the extent of nitrate movement in soils and to suggest some cultural practices that may alleviate some undesirable effects from excess nitrate supply at the wrong time.

Chemical and Soil-Sampling Methods

Chemical. The colorimetric phenoldisulphonic acid method described by M. L. Jackson (1958 edition) was used for soil nitrate analyses. Eight grams of screened (20 Mesh), well-mixed soil were leached for 20 minutes by end-over-end rotation in 50-ml test tubes with 40 ml of dilute $CuSO_4$ solution and a small amount of $Ca(OH)_2$. The soil suspension was then filtered through close-textured filter paper and an aliquot of filtrate used for nitrate estimation.

Soil sampling and preparation. Extreme gradients in concentration of nitrate usually encountered in cultivated, arid soils make sampling and sample handling unusually subject to errors (4,5). To reduce errors, it was found convenient to lightly press irregular soil surfaces and then to use a flat-bottom scoop with sides ½ inch high to take the 0 to ½-inch surface samples. The soil tube was then inserted to the 6-inch depth and any dry surface soil scraped away with the scoop. The soil tube was then rotated and pressed against the top sides of the hole to insure a rather conical-shaped, firm top before withdrawing the tube. If dry soil fell into the hole, another ½-inch of core was removed and discarded before taking the next sample.

The soil was mixed in pans (a separate pan for each depth increment) and a sample of about 60 to 100 grams was sealed in small, wide-mouth bottles with 2 to 3 ml of toluene. Soil samples were dried in metal dishes at 65°C overnight, then passed between steel surfaced rolls and lightly rubbed through a 20-mesh screen by means of a large rubber stopper. The screened soil was then rolled thoroughly and stored in paper bags for analysis. The rather extreme precautions in sampling and sample preparation were taken because more than thousand-fold differences in nitrate concentrations may be encountered between surface ½-inch and lower layers of soil. For this reason, similar depth-increments of different soil samples were usually grouped and processed. The equipment was thoroughly cleaned before preparation of another depth-increment group of samples. Depth of samples was uniform in all tests. Therefore, to simplify presentation a depth code is used in presenting data. Depth increments were as follows: A, 0" to ½"; B, ½" to 6"; C, 6" to 12"; D, 12" to 24" and E, 24" to 36".

Experimental Results

Holden Plot Studies, 1959-1960

Both vertical and lateral movement of nitrate were studied on 40-inch double-row beds under frequent irrigations during late summer in 1959 and 1960. Studies were made on a fine sandy loam prepared and planted to sugar beet seed during August. Irrigation furrows were 40 inches apart and about 2 to 3 inches deep. The plot was usually irrigated at intervals of about five days with a small stream of water. There was no flooding of beds where nitrate studies were made. After preliminary observations showed a marked lateral movement of nitrate in the surface, samples were taken to a depth of 36 inches across the beds at frequent spacings as shown in tables 2 and 3.

Preliminary samples indicated more than a fourfold increase in nitrate concentration in the center of the bed where moist surface zones barely coalesced in contrast to a similar location where moisture did not traverse so far. Data (Table 2) also

Table 2.—Vertical and lateral movement of nitrate in relation to irrigation, rainfall and evaporation. Fine sandy loam; 40-inch double beds. Holden plot, 1959.

Date	Rainfall[1] inches	Depth code	Distance from Furrow (inches) 0	7	14	20
			Nitrate N			
			ppm	ppm	ppm	ppm
Sept. 10		A	3	525	1570	1800
13	0.03					
14	0.60					
15	0.19	A	3	2	8	6
		B	10	1	88	57
		C	9	2	25	29
		D	7	2	11	12
		E	4	4	7	8
19	0.19					
20	0.05					
21	0.18					
23	0.03	A	22	188	460	1900
		B	22	19	66	118
25	0.27	C	11	1	15	18
26	0.01	D	5	2	10	10
27	0.29	E	4	4	6	4
28	0.05					
30		A	2	5	550	170
		B	3	5	186	69
		C	3	3	25	16
		D	2	4	7	7
		E	2	4	7	5

[1] Rainfall 7200 South 3rd East — 1.4 miles from plots

Irrigations September 1, 5, 9, and 14

indicate a pronounced lateral movement of nitrate toward the centers of beds below the surface. Rainfall and evaporation produced strong effects on vertical movement of nitrate. Surface concentrations of nitrate in furrows were probably more dependent on length of time of sampling after irrigation than on other variables.

Table 3.—Vertical and lateral movement of nitrate in relation to irrigation, rainfall and evaporation. Fine sandy loan; 40-inch double beds. Holden plot, 1960.

Date	Rainfall[1] inches	Depth code	Distance from Furrow (inches) 0	10	20	10	0
			Nitrate N				
			ppm	ppm	ppm	ppm	ppm
Aug. 12		A	1	370	230	210	1
		B	1	9	12	6	1
		C	4	6	10	4	3
		D	11	10	13	18	15
		E	16	11	11	17	13
Aug. 19		A	3	340	700	510	3
		B	1	7	11	2	1
		C	3	5	8	3	2
		D	11	13	18	18	11
		E	15	13	18	21	10
Aug. 22	0.66						
Aug. 23		A	1	43	108	50	1
		B	2	38	90	12	1
		C	2	14	15	4	1
		D	11	18	26	16	7
		E	4	19	20	16	19
Aug. 28 Fertilized in bottom of furrows with ammonium nitrate; then irrigated							
Aug. 30		A	5	368	464	504	3
		B	32	7	37	4	11
		C	27	10	11	5	5
		D	19	17	20	18	6
		E	13	14	16	15	10
Sept. 1	0.13						
3	0.39						
6	0.01						
12	0.04	A	21	350	1210	470	6
		B	12	9	28	2	4
		C	32	19	22	4	10
		D	20	24	18	14	12
		E	16	12	17	17	14

[1] Rainfall, Midvale, Utah

Data (Table 3) indicate essentially the same patterns of movement in 1960 as those in table 2 except that surface nitrate concentrations were higher in 1959. Field laborers applied ammonium nitrate to the plot on August 28. It is evident that the unauthorized addition of nitrate to one furrow was twice as much as in the other. The rainfall of 0.66 inch, August 22 occurred during a very short period. This heavy shower did not leach nitrate from the surface nearly so completely as the less rapid rainfall of September 13-15, 1959 (Table 2) or that of October 8-12, 1960 (Table 6). Studies reported in Table 3 were terminated by the accidental cultivation of surface soil after samples were taken September 12.

Effect of deep vs. shallow furrows on nitrate redistribution, yield and quality

Deep vs. shallow-cultivated strips were compared on two fields in 1959. Until about July 1, the fields were uniformly fertilized, cultivated and irrigated. Deep-furrowed strips were made about July 1 at the time of final cultivation. Both fields were irrigated in the same alternate furrows all summer. The soil was hard and relatively dry after August 11. No flooding occurred near any sampled areas but there was little difference in depth of irrigation furrows at harvest due to washing and silting of soil. Soil and beet sampling sites were chosen about 1/4 the distance from the top and 1/4 the distance from the bottom of each field. Because of usual differences in yield and quality between top and bottom of irrigated fields, comparisons are possible only between adjacent positions.

Soil below the surface was consistently more moist and sampling was easier in deeply-furrowed strips where water penetration was better. These differences are believed to be significant at least with respect to differences in yield at harvest.

Presence of an average of nearly 400 ppm of nitrate nitrogen in relatively dry surface soil after a series of rains that occurred during the sampling period seems very significant (Table 4). Foliar protection of this excess nitrate in the surface during precipitations totaling 3.25 inches may be an important factor in reducing hazards of late rainfall in some relatively dry climates provided that soils are not flooded by precipitation.

Soil samples were taken in ridged soil between furrows and between approximately normally spaced beets. Data (Table 5) indicate that there was a fairly consistent difference in both yield and quality of beets between deep and shallow-furrowed strips of each field. There were also consistent differences in yield, sugar percentage, and purity in favor of deeply-furrowed strips. Differences in amino nitrogen, sodium, and potassium were not sufficiently consistent to justify any definite conclusions.

Two tests on the effect of deep vs. normal cultivation were run in Cache Valley in 1961. Surface concentrations of nitrate were not so great as they were in Salt Lake Valley in 1959 because the evaporation rates and temperatures were lower. Surface-nitrate concentration was greater in deeply-furrowed strips. Average yield of sugar per acre, tons of beets per acre, sugar percentage, and purity values were higher in deeply cultivated strips.

Table 4.—Nitrate nitrogen content of soil on two farms, deep vs. shallow furrows. All samples taken between beets in the beds between furrows, 1959.

LESLIE JONES FARM

Furrows	Position in field	Depth code	8/11	8/31	9/17	9/28	10/8
			ppm	ppm	ppm	ppm	ppm
1. Shallow	Bottom	A	825	890	290	550	410
		B	27	35	5	41	2
		C	10	1	7	1	1
		D	5	10	1	1	1
		E	1	2	------	------	------
2. Deep	Bottom	A	370	450	1010	560	300
		B	8	2	45	3	1
		C	1	1	2	1	1
		D	5	1	3	0	1
		E	2	1	------	------	------
3. Shallow	Top	A	475	440	190	270	310
		B	2	34	3	1	1
		C	2	1	0	1	1
		D	1	2	1	1	1
		E	1	1	------	------	------
4. Deep	Top	A	360	440	230	640	320
		B	26	15	1	1	1
		C	9	2	0	1	1
		D	7	1	0	0	1
		E	2	1	------	------	------
		MELVIN JONES FARM					
5. Shallow	Top	A	290	390	990	1030	640
		B	21	1	32	1	1
		C	15	1	1	1	1
		D	7	1	1	0	1
		E	3	------	------	------	------
6. Deep	Top	A	400	810	260	570	550
		B	12	3	2	11	1
		C	6	1	1	1	1
		D	1	1	1	1	1
		E	1	------	------	------	------
7. Shallow	Bottom	A	260	730	1020	125	150
		B	21	1	1	1	1
		C	26	1	1	1	1
		D	6	1	0	1	1
		E	1	------	------	------	------
8. Deep	Bottom	A	300	650	120	21	430
		B	55	1	1	1	1
		C	55	1	1	1	1
		D	43	1	1	0	1
		E	6		------	------	------

Table 5.—Comparative yield and quality of beets from deep vs. shallow furrows on two farms, harvested October 10, 1959. (Three 10-beet samples at each location)

Type of Furrows	Position in field	Weight per beet	Gross sugar per beet	Dry Substance	Sugar	Purity	Amino N	Na	K
	lbs	lbs	lbs	percent	percent	percent	percent	ppm	ppm
				LESLIE JONES FARM					
Shallow	Top	1.67	0.273	18.18	16.34	89.9	0.16	231	2622
Deep		1.79	0.332	20.48	18.53	90.5	0.18	172	2332
Shallow	Bottom	1.66	0.263	19.94	15.87	88.8	0.17	370	2614
Deep		2.11	0.374	19.67	17.72	90.1	0.26	330	2542
				MELVIN JONES FARM					
Shallow	Top	1.67	0.296	20.27	17.70	87.3	0.35	239	2731
Deep		2.04	0.375	20.83	18.40	88.4	0.30	295	2917
Shallow	Bottom	2.26	0.355	18.11	15.71	86.7	0.34	392	3210
Deep		2.76	0.471	19.29	17.07	88.5	0.29	311	2961

Table 6.—Nitrate nitrogen distribution in furrow-irrigated fields of sugar beets, Toppenish, Washington, 1960.

MACK HOUSTON FARM

Location	Position	Depth code	Nitrate N at dates indicated					
			5/14	6/30	7/19	8/5	9/8	10/17
			ppm	ppm	ppm	ppm	ppm	ppm
1	Beet row	A	340	840	3400	2700	4200	1720
		B	81	36	130	312	103	137
		C	82	133	32	71	71	38
		D	17	51	28	30	4	4
		E	6	39	10	12	2	4
	Furrow	A	370	260	320	99	78	170
		B	119	11	6	7	4	13
		C	90	15	17	2	1	3
		D	19	11	5	2	1	3
		E	8	7	4	2	1	2
2	Beet row	A	260	290	1650	1900	1110	710
		B	88	34	112	24	17	52
		C	68	76	56	107	11	102
		D	16	46	33	6	1	34
		E	7	16	53	7	1	15
	Furrow	A	620	160	33	81	94	32
		B	107	10	5	8	14	13
		C	65	10	3	3	1	2
		D	17	5	4	2	1	2
		E	14	4	2	25	1	1

BILL PARRISH FARM

Location	Position	Depth code	4/29	6/22	7/19	8/5	9/8
			ppm	ppm	ppm	ppm	ppm
1	Beet row	A	94	210	1250	1400	3650
		B	56	25	25	93	55
		C	31	24	19	21	6
		D	18	32	10	37	9
		E	12	16	4	18	6
	Furrow	A	99	128	240	90	36
		B	42	13	5	7	4
		C	35	9	3	3	2
		D	15	8	20	3	3
		E	6	6	4	7	5
2	Beet Row	A	55	84	1900	1700	1920
		B	52	69	200	43	126
		C	28	36	121	88	13
		D	15	32	59	23	23
		E	5	32	59	28	9
	Furrow	A	188	91	57	118	290
		B	48	20	7	10	13
		C	26	12	4	4	3
		D	14	14	4	4	6
		E	12	11	6	7	2

Table 7.—Nitrate nitrogen distribution in sprinkler—irrigated sugar beet fields, Walla Walla, Washington, 1960.

FRANK RIZZUTE FARM

Location	Position	Depth code	Nitrate N at dates indicated 5/31	7/1	7/29	8/11	10/16
			ppm	ppm	ppm	ppm	ppm
1	Beet row	A	150	67	72	35	1
		B	54	22	3	2	1
		C	14	25	1	2	1
		D	4	14	1	1	1
		E	1	2	1	1	1
	Furrow	A	130	41	11	10	1
		B	94	69	2	1	3
		C	21	47	1	11	1
		D	4	3	1	1	1
		E	2	1	1	1	1
2	Beet Row	A	location not included	37	119	26	2
		B		12	2	2	1
		C		20	3	N.S.[1]	1
		D		3	1	1	1
		E		1	1	1	1
	Furrow	A		16	17	4	2
		B		2	2	1	2
		C		3	1	2	1
		D		4	1	1	1
		E		1	1	1	1

W. F. SCHIFFMAN FARM

Location	Position	Depth code	5/31	7/1	7/27	8/11	10/16
			ppm	ppm	ppm	ppm	ppm
1	Beet Row	A	35	35	36	21	6
		B	37	10	4	10	2
		C	13	43	2	5	1
		D	21	32	2	3	1
		E	11	9	2	25	1
	Furrow	A	11	25	16	10	1
		B	15	22	1	2	1
		C	5	6	1	2	1
		D	18	28	2	4	2
		E	9	8	4	31	1
2	Beet Row	A	location not included	15	27	54	18
		B		8	6	9	1
		C		19	11	20	1
		D		14	10	35	1
		E		10	9	25	1
	Furrow	A		11	15	23	3
		B		16	3	3	1
		C		22	17	10	1
		D		13	20	25	1
		E		10	16	23	3

[1] N.S. — no sample

Soil Nitrate Studies on Sprinkler vs. Furrow-irrigated Sugar beet Fields

Soil samples were taken during summer and early fall of 1960 on two furrow-irrigated and two sprinkler-irrigated sugar beet fields. The Mack Houston and Bill Parrish farms in Toppenish, Washington, were furrow-irrigated, while those of W. F. Schiffman and Frank Rizzuti in Walla Walla, Washington, were irrigated by sprinkling. Samples were taken in beet rows and in the furrows.

Data (Tables 6 and 7) indicate large differences in surface nitrate concentration resulting from the two methods of irrigation. Concentrations of nitrate in surface soils were low where beets were irrigated by sprinkling and nearly all nitrate in the soil was periodically leached to active root zones of plants.

Under furrow irrigation, high concentrations of nitrate were found in dry surface soil where beets could not use it. Concentrations of more than 4,000 ppm of nitrate nitrogen were observed on the Mack Houston Farm. Although surface concentrations were much greater where samples were taken than in furrows some idea of the amounts involved may be realized by the fact that only a little more than 600 ppm of nitrogen in a ½-inch layer of soil is equivalent to 100 pounds of nitrogen per acre. If we estimate sampled areas to represent ⅓ of the surface, more than 200 pounds of nitrogen per acre might be concentrated in this area where it is not available to beets unless a rain occurs to leach it into the root zone.

An extreme case of evaporative redistribution of nitrate in part of a 10-acre commercial field of beets was observed in 1960. The field had been planted to grain in 1959 and a fairly heavy cover of straw and stubble was plowed under. Nitrogen was applied as anhydrous ammonia at the rate of 135 pounds of N per acre. Phosphate was also applied in the fall with the anhydrous ammonia. An early planting of sugar beets was frozen and the field was replanted April 22. Although there was a good stand of sugar beets, they grew very slowly and were obviously very deficient in nitrogen as shown by tests with diphenylamine. The field was furrow-irrigated in the same alternate furrows all season. Although furrows were rather shallow, there was little or no flooding. A heavy surface application of ammonium nitrate was made to three strips, crosswise to the furrows, about July 2. These cross-strips were about 10-feet wide and 200-feet long. Response of beets to ammonium nitrate was very striking and sharply delineated (Figure 1). Foliage of sugar beets in the fertilized cross-strips was more than knee high and very dark green,

Figure 1.—Sugar beets on the Joseph J. Schmidt farm, West Jordan, Utah, October 17, 1960. Beets in foreground have been harvested. The cross strip received a heavy application of ammonium nitrate in July. At harvest there was more nitrate in the surface of the area where the beets were deficient but it was in the dry soil and unavailable to the plants.

while foliage of adjacent beets did not cover more than half the 22-inch rows and were only about ankle-high. Symptoms indicated an extreme nitrogen deficiency.

On October 8, soil samples were taken to a depth of two feet in irrigated furrows and between furrows in fertilized cross-strips and in the nitrogen-deficient sugar beet area. The soil was moderately dry when sampled but a light, persistent rainfall, amounting to 1.23 inches, occurred during the period of October 8 to 12. The same areas were resampled on October 12. In addition to soil-profile samples, four surface samples were taken between furrows where nitrogen-deficient beets were located and five surface samples were taken in fertilized cross strips where heavy foliage had protected surface soil from rainfall. These

Table 8.—Nitrate nitrogen in soil profile before and after a prolonged light rainfall of 1.23 inches, J. J. Schmidt Farm, West Jordan, Utah, 1960.

Depth Code	Small foliage (field)		Large foliage (cross strip)	
	Between furrows	In furrows	Between furrows	In furrows
	ppm	ppm	ppm	ppm
	BEFORE RAINFALL — (OCTOBER 8)			
A	1260	2	610	28
B	1	1	1	1
C	0	0	1	0
D	1	0	2	0
	AFTER RAINFALL (OCTOBER 12)			
A	4	0	48	1
B	65	1	104	1
C	1	0	1	1
D	1	1	1	1

latter samples were not taken midway between rows, but closer to beet rows where foliar cover was better.

Data (Table 8) show that befort the rainfall there was more nitrate in surface soil where the deficient beets were located than in heavily fertilized cross strips. The 1260 ppm of nitrate nitrogen observed in surface soil, where the deficient beets were located, is equivalent to about 200 pounds of nitrogen per acre—in the top ½-inch of soil. Rainfall leached all but 4 ppm into lower layers of unprotected soil, but, where there was good foliar cover, 5 separate samples had an average of 372 ppm that remained in surface soil after precipitation. These observations, concerning protection by good foliar cover in preventing leaching surface nitrate to lower levels, were similar to observations in 1959 (Table 4).

Discussion

Application of the principles governing salt movement and zones of concentration in soils to plant nutrition has received little attention. Most concern has been directed toward solving adverse effects that threaten to cause abandonment of soils. However, some of this basic knowledge can be used in understanding seasonal variations in nutrient availability—and probably in developing techniques to modify nutrient uptake and to more nearly approach the optimum needs of sugar beets.

The extent of redistribution patterns observed in arid soils under furrow-irrigation or bed-planted beets offers a lucid explanation of the erratic sugar concentration and quality of sugar beets. Frequent heavy rains before harvest can depress quality of beets by causing an unfavorable abundance of nitrogen to become available at the wrong time. Dry preharvest conditions may result in sugar concentrations three or more percent higher than when wet weather occurs before harvest. These fluctuations in availability of nitrate make it difficult to estimate optimum amounts of nitrogen fertilizers to add to soil even though total amounts present may be determined before planting. However, knowledge of evaporative redistribution patterns, relative amounts, and extent of foliar protection from rain should be useful in developing cultural methods to utilize these phenomena to improve sugar beet culture. Sprinkler-irrigated beets and those in areas where frequent late-summer and fall rains occur should be handled so as to utilize nearly all nitrogen before harvest. In some of our arid climates excess nitrogen may be relatively immobilized in dry soil under an adequate protective foliar cover.

New products are being introduced to reduce mobility of nitrogen nutrients by either reducing the rate of nitrification of ammonium salts or by reducing solubility of nitrate by incorporating it into more slowly soluble forms. The author believes that the data presented on patterns of nitrate movement in the soil indicate that any supplemental nitrate added to row crops after the first irrigation should be placed below the bottom of irrigation furrows in order to lengthen the period of availability to plants before it reaches dry surface layers of soil.

Summary

The nitrate ion moves very freely with moisture in soils. It may be easily leached but in arid or semi-arid climates the movement is predominantly to the surface as sub-surface moisture moves upward and evaporates. Surface concentrations of nitrate may be as much as a thousand times that of subsurface concentrations under furrow irrigation. This redistribution has a profound effect on sugar beet nutrition. By decreasing nitrate availability late in the season, sugar concentration and quality of the roots is improved. Late-season rainfall or sprinkler irrigation usually results in lower sugar concentrations and quality.

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