Soil Nitrate and the Response of Sugarbeets To Fertilizer Nitrogen

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The efficient use of nitrogen fertilizer in sugarbeet (*Beta Vulgaris* L.) culture is an important factor in maximizing sugar production, conserving fertilizer supplies, and minimizing the pollution of ground water by the downward movement of nitrate. Fields on which sugar beets are grown differ markedly in the amount of fertilizer nitrogen required for maximum sugar yield. Some need none while others require up to 240 lb N per acre. Thus, efficient fertilization requires a specific recommendation for each field.

Procedures for estimating fertilizer nitrogen from soil nitrate early in the growing season have been advanced. James et al. (4)[2] summed the concentration of soil nitrate to a depth of 6 feet and found only one responsive site where this index exceeded 30 (ca. 120 lb NO_3-N/acre). Giles et al. (2) concluded that sugar responses to fertilizer N are unlikely when soil NO_3-N to a depth of 2 feet exceeds ca. 120 lb N/acre. Carter and his colleagues (1) improved on the fertilizer recommendations of fieldmen which were based on field history by determining mineralizable NO_3 in addition to residual NO_3 to a depth of 3 feet; modifying both determinations by factors to reflect efficiency of uptake; subtracting the sum of these quantities from the amount estimated to be needed by the expected crop to obtain the amount of fertilizer N needed; and then increasing this amount by a factor to reflect efficiency of fertilizer N uptake.

One objective for conducting the field trials reported here was to assess and, if possible, calibrate soil analyses for NO_3-N to use in predicting the needs of crops for fertilizer nitrogen in the sugar beet growing areas of California.

Materials and Methods

Twenty field trials were conducted from 1971 through 1974. Phosphorus was applied to all plots at all locations where this nutrient may have been needed. Ammonium nitrate was applied after seedlings had emerged but not later than thinning time, usually at rates of 0, 60, 120, 180, 240, and 300 lb N/acre. The fertilizer was sidedressed 8 to 10 inches from the sugar beet rows, usually on both sides. Plots were six rows wide and at least 50 feet long. Rates were replicated five or six times. At harvest, plants of the center two rows of each plot were dug

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[2]Numbers in parentheses refer to literature cited.

and topped below the oldest living leaf. Roots were counted and two samples, of about 10 roots each, were taken for tare and sucrose analyses by sugar factory tare laboratories.

Soil cores were taken just prior to fertilization, usually with a soil tube about 1 inch in diameter. At least three cores were taken from each of at least four nonfertilized plots and composited by foot depths to at least 4 feet. Soil samples were frozen or oven dried within 24 hours of collection. Five grams of dry soil were extracted by shaking with 25 ml silver sulfate solution (3.5 g Ag_2SO_4/liter), filtered, and the extract analyzed for NO_3 by the phenoldisulfonic acid method (5). Frozen samples were thawed and water added with stirring to form a saturated paste. Nitrate was determined in the extract as for dry samples. Results were reported on a dry soil basis.

Results and Discussion

In 5 of the 20 trials there were factors other than nitrogen nutrition which obviously affected yield and, therefore, the results could not be used for calibration purposes. These 5 trials have been omitted from this summary.

The root yield of each trial giving maximum sugar production and the associated fertilization rate was determined by fitting root and sugar yield response curves to the mean values observed for each rate of nitrogen fertilizer as illustrated in Figure 1. Root yields giving maximum sugar production varied from 27 to 46 tons/acre and the fertilizer N required to produce these yields varied from 0 to 240 lb N/acre. Data from all fifteen trials are summarized in Table 1.

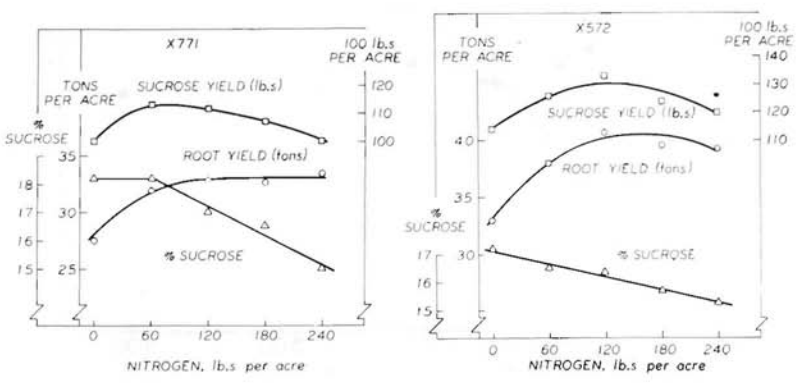

Figure 1.—Fertilizer nitrogen required for maximum sugar yield was estimated for each of the 15 trials of Table 1 as illustrated here. For these two trials, maximum sucrose yield was achieved with 60 (left) and 120 lb N/acre.

In Figure 2 the average root yield of unfertilized plots at each location is expressed as a percent of the average root yield of plots fertilized for maximum sugar production and plotted against soil

Table 1. Soil nitrate at the start of the growing season and crop response to nitrogen fertilizer for 15 California locations. Values are means of four or more replications.

Trial	NO_3-N/foot soil depth (Ns)				Nf[2]	Root Yield	
	0-1	1-2	2-3	3-4		Yo[3]	Ye[4]
	lb/acre[1]				lb/acre	tons/acre	
771	84	37	32	30	60	27.5	32.0
172	94	34	18	14	240	20.4	35.9
372	35	29	23	23	60	28.2	32.2
472	88	75	45	53	60	28.6	33.5
572	56	59	43	31	120	33.2	40.8
672	162	115	85	62	0	45.6	45.6
772	104	154	147	96	180	34.3	43.6
173	191	23	70	82	0	33.5	33.5
273	96	28	14	19	240	24.7	39.5
573	94	29	28	17	120	27.6	34.0
1273	62	68	46	42	60	24.3	28.2
174	190	173	65	13	0	39.4	39.4
274	21	6	5	6	240	24.6	35.5
374	46	35	27	22	60	22.7	27.1
474	124	123	77	52	0	32.1	32.1

[1]Ppm dry soil × 4.
[2]Fertilizer N giving maximum sugar production.
[3]Yield without fertilizer N.
[4]Yield with fertilizer N giving maximum sugar production.

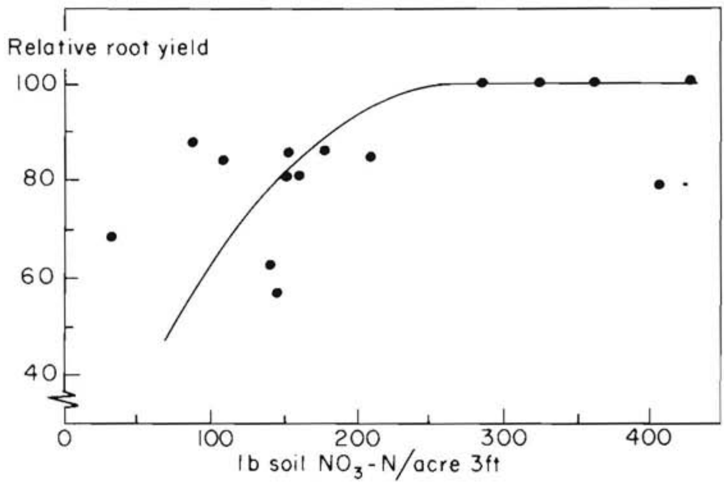

Figure 2. — Relation of crop response to fertilizer nitrogen to soil nitrate determined early in the growing season for 15 locations. Relative root yield = [(root yield without fertilizer N)/root yield with fertilizer N giving maximum sugar yield)]100.

nitrate. There is little basis for quantifying the response to nitrogen fertilizer to the level of soil nitrate, as implied by the eye fitted curve, except to note a possible critical value of about 250 lb NO_3-N per acre 3 feet of soil. Only one of five crops responded to fertilizer N when soil nitrate exceeded this level. For soil NO_3-N/acre 2 feet, the comparable critical value was about 200 lb.

An emperical nitrogen requirement (Nr) based on soil and fertilizer N can be determined from experiments where there are responses to fertilizer as the amount of nitrogen required per unit of root yield for the crop that produces maximum sugar. For example, referring to Table 1, Nr = (Ns + Nf)/Ye. Thus for trial 771, Nr = (153 lb soil NO_3/acre 3 ft + 60 lb fertilizer N/acre)/32.0 tons/acre = 6.7 lb N/ton of roots. Nr reflects the efficiency of uptake of both soil and fertilizer N. If these efficiencies do not vary too greatly among fields, an average Nr can be used to determine the demand for soil plus fertilizer N for any given field by multiplying Nr by the root yield expected for maximum sugar yield. Then, fertilizer N, (Nf) can be determined by subtracting soil N. Thus Nf = Ye(Nr) − Ns. For the 11 trials of Table 1 where there was a response to fertilizer, the calculated Nr ranged from 4.56 to 13.42 with mean 8.49 (±0.56)[3] lb N/ton. This mean value for Nr was used to determine the soil NO_3-N plus fertilizer N needed for maximum sugar yield for each trial. Subtracting soil NO_3-N/acre 3 feet gave an estimate of fertilizer N, e.g. for trial 771, Nf = 32.0(8.49) − 153 = 119 lb fertilizer N. Estimates of fertilizer N were within what might be considered an acceptable deviation of ± 20 lb/acre in only 4 trials. Though this procedure does not appear to be satisfactory, it might be improved by determining mineralizable N, as proposed by Carter et al. (1).

From the data of Table 1 the amount of fertilizer nitrogen required per ton of increase in root yield was estimated for each trial where there was a response to fertilizer by dividing the amount of fertilizer N required for maximum sucrose yield by the difference between the root yield producing maximum sucrose and the root yield with no fertilizer to give lb fertilizer N/ton of root yield increase (Nfr). Thus Nfr = Nf/(Ye − Yo). For the 11 trials this fertilizer N requirement ranged from 12.24 to 22.02 and averaged 16.1(±0.87) lb N/ton root yield increase.

Using 16.1 lb fertilizer N per ton of root yield increase and the known response to fertilizer for the trials of Table 1, the fertilizer N required to produce maximum sugar can be predicted to within ±20 lb in 87% of the trials (13 out of 15). Thus, for a given field, if root yield can be estimated for nonfertilized beets and for beets fertilized to produce maximum sugar, the difference in root yield multiplied by 16 lb N/ton gives an estimate of fertilizer N needed, i.e. Nf = (Ye − Yo)Nfr.

[3]Standard error of the mean.

Rough estimates of root yield to be expected when a crop is not fertilized might be determined from soil nitrate at the beginning of the growing season. Coefficients of linear determination (r^2) relating mean root yields of nonfertilized plots to soil NO_3-N to a particular depth of sampling were: 0-1 foot, 0.47; 0-2 feet, 0.62; 0-3 feet, 0.63; and 0-4 feet, 0.61. The failure to improve the coefficient of determination by sampling below 3 feet suggests there is little to gain by deeper sampling. In fact, sampling to 2 feet gave nearly as good a correlation but since sugar beet roots readily penetrate 3 feet in a deep, well-drained soil, it appears reasonable to sample to this depth.

Based on these 15 fields, an equation to predict root yeild from soil nitrate is Yo = 20.5 + 0.044 (lb NO_3-N/acre 3 feet), where Yo = root yield without fertilizer N, r = 0.794***, (Figure 3). The fact that this relationship accounted for 63% of the variation among root yields of different fields is evidence that the amount of soil nitrate early in the season is an important factor affecting production. To estimate root yield based on soil nitrate to a depth of 2 feet, the regression equation is: Yo = 20.4 + 0.058 (lb NO_3-N/acre 2 feet), r = 0.785***. The two equations estimate comparable root yields at low levels of soil nitrate but, due to a steeper slope, the latter predicts higher root yields as soil NO_3-N increases, particularly above 100 lb/acre 2 feet.

Based on these results, a procedure for estimating fertilizer N is the following. 1) Estimate expected root yield for maximum sugar production (Ye) from crop history. 2) Estimate root yield without N fertilizer (Yo) from the equation Yo = 20.5 + 0.044 Ns, where Ns = lb soil NO_3-N/acre 3 feet early in the season. 3) Estimate fertilizer N (Nf) by Nf = (Ye-Yo)Nfr, where Nfr = 16 lb fertilizer N/ton of root yield

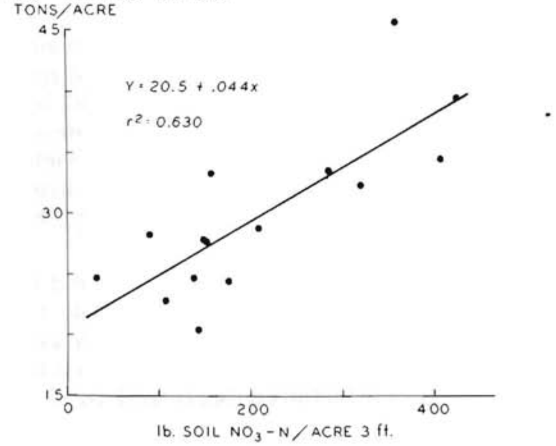

Figure 3. — Relation of root yield in unfertilized plots to soil nitrate-nitrogen determined early in the growing season for 15 locations.

increase. Utilizing this procedure, Table 2 gives estimates of fertilizer N based on varying levels of soil NO_3 and expected root yields of 30 and 35 tons/acre.

It should be noted that estimated fertilizer N can and will vary considerably from the actual requirement due to the variability not accounted for by the regression for estimating yield without fertilizer from soil nitrate, the failure of a sampling procedure to estimate the amount of soil nitrate actually present, and a poor estimate of root yield for the fertilized crop due to unexpected changes in weather, pest and disease infestation, or other unforeseen factors.

Regardless of the procedure used to estimate fertilizer N, it is important to evaluate how well applied fertilizer meets the needs of the crop. This can best be done by a plant analysis program and reference to a well-defined critical level to determine the adequacy of nitrogen supply and when plants become deficient (6). Anticipated early season deficiencies may be corrected and a knowledge of late season deficiencies can aid in deciding which fields are to be harvested first (6, 3). In addition, plant samples can be analyzed to determine if the fertilizer program is also meeting the needs for other nutrients known to affect sugar beet growth (6, 7).

Table 2. Nitrogen fertilizer rates estimated from soil nitrate and expected root yield.

lb soil NO_3-N per care 3 ft	Root yield no N	Root yield (tons/acre) with fertilizer	
		30	35
	tons/acre	lb fertilizer N/acre	
0	20[1]	160[2]	240
50	23	110	190
100	25	80	160
150	27	50	130
200	29	20	100
250	32	0	50

[1]Calculated from root yield = 20.5 + 0.044 (lb soil NO_3-N/acre 3 feet).

[2](Expected root yield with fertilizer − root yield with no fertilizer) 16 lb N/ton.

Summary

Field trials to determine fertilizer N required for maximum sucrose yield were conducted at 15 locations throughout the beet growing areas of California. The root yield to be expected without fertilization (Yo) can be estimated from the equation $Yo = 20.5 + 0.044\ Ns$, where Ns = NO_3-N/acre 3 feet of soil early in the growing season. The amount of fertilizer N required per ton of increase in root yield averaged about 16 lb N per ton. Fertilizer nitrogen (Nf) for maximum sugar production can be estimated by $Nf = (Ye\text{-}Yo)\ Nfr$; where Ye = expected root yield based on field history, Yo = root yield expected without N fertilizer based on soil nitrate, and Nfr = fertilizer N required/unit of root yield increase from Yo to Ye.

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