Residual Soil Nitrate Measurement as a Basis for Managing Nitrogen Fertilizer Practices for Sugarbeets[1]

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Received for publication November 9, 1970

Control of the amount of nitrogen that is available to sugarbeets is critical in the production of high sugar-yielding beet crops. The problem has two aspects: if nitrogen is insufficient root yield is reduced; if nitrogen is superabundant sucrose percent is reduced. Coupled with excessive nitrogen also is the problem of increased levels of soluble nitrogen compounds in the extracted beet juice. These materials interfere with the crystallization of sucrose during milling and result in decreases in the net yield of refined sugar.

Various attempts have been made to optimize nitrogen availability to sugar beets. Cropping and fertilizer history have been used as guides but experience has shown that these are very imprecise and therefore have very limited utility. Plant tissue analysis has been done to assay the crop's nitrogen status but while this is a good diagnostic tool, it is limited as a guide to fertilization since the information usually becomes available too late in the season to effectively alter either nitrogen deficiency or excess.

Ideally, soil analysis would be most effective in guiding fertilizer practices since the information could be used at the beginning of the season. This method depends, of course, on the availability of soil test correlation data for nitrogen. The interpretation of soil tests for nitrogen is made difficult by the many factors that regulate nitrogen availability. In particular, nitrate mobility, nitrogen mineralization, nitrification and immobilization, organic matter content (both fresh plant residue and humus) and the method and amount of irrigation affect nitrogen availability. These factors interact with each other and with the growing crop as it extracts nitrogen from the soil.

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Despite the many ramifications, soil analysis for nitrate-nitrogen has been successfully adapted in the state of Washington as a fertilizer guide. In 1959 Leggett (5)[5] demonstrated a correlation between nitrate-nitrogen in the root zone and yield of winter wheat under dry-land conditions. Subsequently, Nelson *et al.* (6,7), demonstrated a correlation between soil nitrate concentration and yield and quality of corn and wheat on irrigated land.

In 1967 a 3-year program was initiated to evaluate the adaptability of the soil test for nitrates to sugarbeet production management. The purpose of this report is to summarize some of the results.

In the past one of the main limitations to soil sampling and testing for nitrogen has been the mobility of nitrates; extreme differences in concentration in the soil can occur within very short distances. With furrow irrigation for example, the soil under the furrow can be very low in nitrates. At the same time the soil in the ridge between furrows can be extremely high in nitrates because of the surface isolation of soluble constituents brought about by upward movement and evaporation of capillary water. In addition, nitrate concentration will vary with depth depending on soil texture (water holding capacity), the rate and frequency of irrigation and the existence of soil layers which limit the root zone. Soil sampling technique *per se* does not receive special attention in this report but cognizance should be taken of the fact that the aquisition of meaningful soil test nitrogen data is highly dependent on the sampling procedure.

Procedure

Commercial sugarbeet fields were soil sampled which had not been fertilized since the previous spring. After soil analysis (see below) fields were selected from among those sampled so as to provide a wide range of residual nitrate-nitrogen levels. A total of five fertilizer treatments were applied in a randomized complete block design in four replications. The fertilizer treatments consisted of three rates of nitrogen—zero, 100 and 200 pounds of N per acre as ammonium nitrate (N-O, N-100 and N-200)—plus a check treatment each for phosphorus and potassium both at N-200. The fertilizers were generally applied broadcast-plowdown but in a few instances they were applied sidedress at thinning time.

Petiole samples (about 30 petioles per sample) were taken from each plot at each experiment and were analyzed for nitrates according to the scheme suggested by Ulrich *et. al.* (9).

Just prior to commercial harvest test samples of roots were

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[5] Numbers in parentheses refer to literature cited.

taken from the plots for estimates on yield of roots, percentage sucrose and impurity index. The root sample consisted of all beets in a measured 15-foot section of row selected so that there was a near perfect stand of beets in the sample row and in the two adjacent rows. Attempts were made to obtain three subsamples of roots per plot but this was not always feasible. The impurity index is the sum of weighted values for potassium, sodium and amino-nitrogen in the clarified beet thin juice (2).

Soil sampling and analysis

The sampling procedure used here was the three-point group sampling outlined by Nelson *et al.* (6,7) and by James *et al.* (4). Briefly it was as follows: Three cores of soil were taken across a distance equal to one-half the row spacing. (The previous crop's furrow may be obscured. It is not necessary to know the exact location of the furrow but the distance between furrows is important). Assume for example, that corn was the previous crop and the rows were 36 inches apart. Take a soil core from any point selected at random then take a second core nine inches from the first and another core 18 inches from the first such that the cores are oriented in a straight line at right angles to the direction of the furrow.

The vertical variation in nitrates was evaluated by taking cores from the three-point group by one-foot increments to the depth of the limiting layer or to six feet, whichever occurred first.

The three-point group sampling was repeated at random until the whole experimental area was well represented—18 to 36 cores per sampling unit. (The sampling unit was based on areas of the fertilizer replicates). The soil cores were composited for each one-foot depth increment for each field sampling unit. Thus, the number of soil samples for each unit corresponded to the depth of soil.

For sprinkler irrigated fields, where horizontal nitrate concentration does not vary cyclically, the three-point core grouping was not followed. The total number of cores per sampling unit was the same regardless of the irrigation method, however.

After thorough mixing and disposition of the excess soil the sample was placed in a plastic-lined bag and then put as soon as possible in a forced air drier at 60°C. The soil was then put through a 2 mm sieve. Extraction of soil nitrate was with distilled water which had been saturated with calcium hydroxide. The soil-solution ratio was 1:10. The extracted nitrate was measured with phenoldisulfonic acid.

A soil test nitrate-nitrogen index (STN) was calculated for each experimental site. STN is simply the sum of the nitrate-nitrogen parts per million in the soil for all foot-depth increments, averaged for all sampling units at each site.

All soil sampling in this research program was done from late January to early March of each year.

Results

Soil test nitrogen index

The frequency distribution of soil test nitrogen indexes (STN) for all fields examined is given in Table 1. STN categories, on 10-unit intervals, and the number of fields in each cateogry are shown. Category 60 includes all sites having STN above 50. The lowest and highest STN values observed from all sites were 5.9 and 166.1, respectively. The lowest value came from a new irrigation project (land formerly in dry-land wheat) and the highest STN came from a field which had been heavily fertilized for potatoes the previous two years. The actual amount of nitrate-nitrogen on a per acre basis can be estimated by multiplying STN by 3.94. This value is computed from the average bulk density of soils in the area. Thus, the range of nitrate-nitrogen was approximately 23 to 654 pounds of N per acre in the samples included in Table 1.

Table 1.—Frequency distribution of fields among soil test nitrogen categories—total of all fields sampled in three-year program.

STN Category	Number of sites
10	10
20	23
30	20
40	12
50	8
60	13
Total	86

Root yield

The relation between STN and sugarbeet yield performance is given in Table 2 in the form of frequency distributions. The numbers under 'successes' refer to the number of experiments in the respective categories that were carried to completion. The numbers under 'N-responsive' refer to the experiments where a real response to N fertilizer was measured based on analysis of variance. Thus, out of the 39 experiments that were completed there were seven that gave a root yield response to added N. Two out of three experiments in category 10 and three out of nine in category 20 showed yield responses to fertilizer. The one experiment in category 30 that was N-responsive was on a valley-floor alluvial soil that was relatively high in organic matter—2.4%. Most of the other sites involved loessal or colluvial soils containing moderate to low levels or organic matter—ranging from 1.8 to 0.6% and averaging 0.94%.

Table 2.—Soil test nitrogen correlation with sugarbeet responses to fertilization: Frequency distributions of successful experiments, nitrogen fertilizer responsive sites and experiments which failed because of poor stand.

	Number of experiments		
Category	Successes	N-responsive	Stand failure
10	3	2	4
20	9	3	8
30	9	1	1
40	7		1
50	6	1	
60	5		
Total	39	7	14

The experiment in category 50 that was N-responsive involved a very sandy soil. It was apparent during the season that leaching of N was taking place at this site. Accordingly, the fertilizer response in category 50 serves only to emphasize the need to control both soil moisture and fertility and this particular result is not directly applicable in the correlation of STN.

The data under 'stand failure' (Table 2) indicate the number of experiments that failed because of poor stand. It was obvious in the field that under early spring growing conditions seedling vigor was greatly enhanced where fertilizer had been applied on sites where STN was low. It was unfortunate to have the high mortality among the sites low in residual or indigenous N because yield data from these sites would be most meaningful in the soil test correlation. The data do provide a commentary on the importance of having N readily available early in the season especially from the time of germination to the 4-6 leaf stage of the plants.

The actual yield data for the N-responsive sites are shown in Table 3. At the STN-5.9 site periodic failure of the sprinkler

Table 3.—Yield of sugarbeets for the N-responsive sites and the added effect of 100 pounds per acre of nitrogen fertilizer.

	Root yield—Tons/acre		
STN	N-0	N-100 increase[a]	LSD$_{05}$
5.9[b]	15.4	4.9	3.8
8.5	28.6	6.3	4.5
10.8	25.1	7.1	6.0
13.2	27.5	5.0	4.1
16.6	35.1	3.7	3.3
25.0	27.6	3.4	3.2
44.8	29.4	5.9	4.0

[a] N-O = zero fertilizer, N-100 = 100 pounds N per acre as ammonium nitrate. Yield increases were significant at the .05 level.

[b] Yield at this site was severely limited by irrigation problems (see text). Because this location was being newly irrigated the experimental design included an extra treatment of 300 pounds N per acre. Root yield increased regularly with each N increment and the 4.9 ton per acre increase was to the 300 lbs N level of fertilization.

irrigation system resulted in serious drought problems. Under proper water control the yield could have been double the amount shown. Despite the problems, the yield response to N was significant. In Table 3, the STN-25 site was on the high organic matter soil and the STN-44.8 site was the one that evidently suffered from N loss by leaching.

The added effect of 100 pounds of N per acre is also given in Table 3. With the one exception indicated, there was no additional benefit from the second 100-pound N increment.

Root yields at the non-responsive sites ranged from 20 to 40 tons per acre. The overall mean yield was 32 tons per acre.

Root quality

The results for percent sucrose and impurity index are given in Figures 1 and 2. As would be expected there was a regular decrease in sucrose percent with each fertilizer increment (Figure 1). The fertilizer effects were approximately the same in each STN category. It is apparent though, that the smallest decrease in sucrose occurred with the first N increment at the lowest category. Figure 1 indicates that, with the exception of category

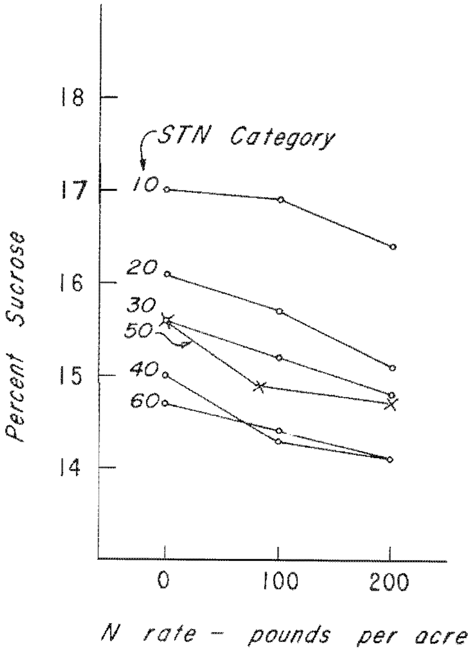

Figure 1.—Relationships between percent sucrose, N fertilizer rates and STN category levels. Date shown are category means. Effects of N fertilizer and STN categories were significant at the 1% level with no interaction between N and STN.

50, there was a successive decrease in sucrose percent from the lowest STN category to the highest. Three experiments in category 50 were exceptionally high in percent sucrose. It is believed that, with a larger sample, categories 40, 50 and 60 would be quite similar in terms of average sucrose content of the beets.

There was a regular increase in impurity index in each STN category with each N rate (Figure 2). At N-O there was also a regular increase in impurities with successive STN categories. The data indicate that there was fertilizer by STN interaction. It was expected that fertilizer rates and STN would be simply additive. The apparent interaction is probably a result of a significant location by category interaction.

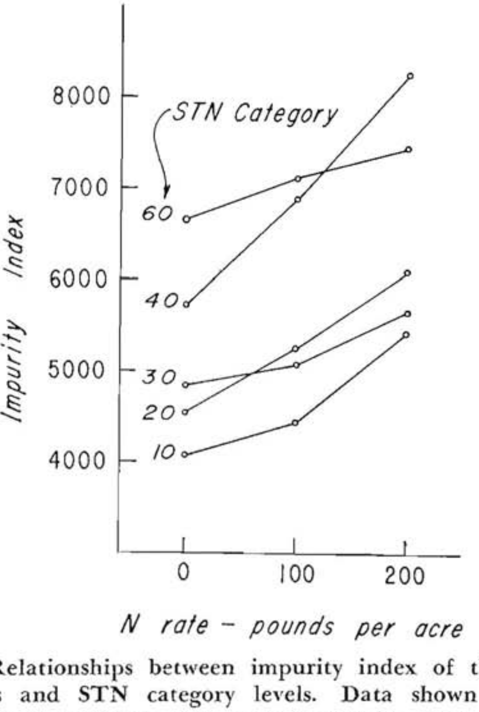

Figure 2.—Relationships between impurity index of the thin juice, N fertilizer rates and STN category levels. Data shown are category means. Effects of N fertilizer and STN categories were significant at the 1% level. The N by STN interaction was significant at 1% as also were the following: location within categories; treatment by location within categories.

Only three-fourths of all experiments was analyzed for impurity index. In the results there was only one representative for category 50 and since this was exceptionally low in impurities it was not included in Figure 2. Again, with a larger sample, category 50 would be expected to be similar to category 60.

interest to note that this particular location was lower in sucrose percent and higher in impurity index than the average of the next two higher categories. This indicates a possible error in sampling or analysis of the soil from this site. It is believed that soil tests as low as 10 will, in general, require added fertilizer N for best results.

The one N-responsive site in category 30 emphasizes the question of soil organic matter as it relates to N availability. The problem is brought into focus when it is realized that, at the site in question without nitrogen fertilizer, the crop was definitely limited in the early part of the season. This was apparent in terms of nitrogen deficiency symptoms as well as root yield reduction where no fertilizer was applied. But later in the season nitrogen was excessive as indicated by sugar percentages of 15.0, 14.8 and 14.0 corresponding to the three respective fertilizer rates (compare with Figure 1). Some combination of soil tests involving both inorganic and mineralizable N, as suggested by Reuss and Geist (8), should be investigated as a means of improving the predictive power of N soil tests.

Using inorganic soil N alone, it is believed that the pivotal category will be STN category 20 for basing fertilizer decisions. The N responsive sites were not predominant in this category (three out of nine, Table 2) but the problem with stand establishment is crucial as evidenced by the high frequency of poor stands in the lowest STN categories.

Considerable refinement in N soil tests undoubtedly will be forthcoming. In the meantime the index discussed here has immediate application. It is apparent that, except under special conditions,[6] fertilization of soils with STN greater than 30 is to be avoided. In addition, soils with STN greater than 50 should not be planted to sugarbeets if alternative fields are available to the grower.

Summary and Conclusions

A series of experiments in commercial sugarbeet fields were conducted to evaluate soil nitrate-nitrogen concentration as a predictor of soil N availability. An N index (STN), based on the sum of NO_3-N ppm in one-foot layers throughout the root zone, was used as the measure of soil fertility.

Some but not all field sites having low STN responded to N fertilization in terms of root yield increases. On the average, percent sucrose decreased with increasing STN levels and with increasing fertilizer rates. Also, the impurity index, based on

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[6] If less than half of the residual nitrate is in the upper foot of soil seedling vigor would probably be enhanced by supplemental nitrogen at planting time. Also, if soil conditions are conducive to nitrate leaching loss consideration should be given to nitrogen supplementation at planting and/or early mid-season.

the amount of Na, K and soluble N compounds in the thin juice, increased sharply with both STN and fertilizer rates. Some results which were out of line with the majority were explained on the basis of soil moisture and soil organic matter interactions with STN. Increased refinement of soil tests for N will require thorough evaluation of these factors.

The best control of root quality was obtained when the beets were planted on sites with minimal STN and which received N fertilizer. Under these conditions N availability was adequate for early season plant growth vigor. The N supply then reduced to the low levels in late season required for maximum sucrose assumulations.

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