# The Effect of Ammonic-N or Nitrate-N Dominated Fertilizer Programs on the Nitrogen and Sucrose Content of Sugar Beet Tissues and Yields of Sugar Beets

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Sugar beet production is predicated upon a compromise involving an apparent inverse relationship between root yields and the sucrose concentration in the root. It is well documented that additions of nitrogen from any source can, and usually do, increase root and sucrose yields, and may decrease the juice purity and sucrose percentage in the roots (4, 6, 9, 14, 20, 22, 23, 24, 28, 29, 34, 36, 39, 40)[2]. While the sugar beet processor is not without his problems (41), his continued existence is testimony to the fact that there must be some degree of compatibility between high yields, high sucrose content, high quality, and the use of nitrogen fertilizers (2, 14, 18, 26, 29, 34, 41).

Many researchers have investigated the use of petiole analyses as a means of monitoring the nitrogen status of the plant in relation to rates of nitrogen fertilization, sugar beet yields, sucrose content, and quality (5, 13, 15, 23, 28, 29, 36, 38, 39, 40). While the research in general now makes it possible to predict yield responses to additions of nitrogen fertilizer, it is still difficult to predict sucrose concentrations, juice purity percentages, and brei nitrate readings at the time of harvest. In addition, it is still difficult to apply this research as a means of gaining some insight as to the nature of such problems as low nitrate-N levels in the petioles with accompanying low sucrose percentage in the beet root at harvest; or low petiole and brei nitrate-N levels with acceptably high sucrose concentrations, but with low crystaline sugar recovery. These problems are very real ones to the beet processor. In an attempt to identify some of the factors responsible for these problems, Holly Sugar Company in Brawley, California, and the writer conducted a survey on beets grown under ammonic-N- or nitrate-N-dominated fertilizer programs. The decision to use this approach was influenced by Viet's discussion of the plant's need for, and utilization of, nitrogen (43). He indicated that certain plants may have the capacity to store for future use large amounts of soluble nitrogen as amino acids and acid amides. The decision was further influenced by Alexander's comments regarding factors that affect

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[1] Agronomist, Chevron Chemical Company.

[2] Numbers in parentheses refer to literature cited.

quality (2). He pointed out that soluble nitrogenous compounds and organic acids are among the non-sucrose substances that prevent crystalization to the greatest extent.

While the data obtained in the survey represent only one growing season, they nevertheless provide an indication as to the possible causes of low sucrose concentrations in beet roots, and low sugar-recovery problems, in the Imperial Valley. They also may indicate the need to develop research from a new or different approach that will permit more accurate interpretations of nitrogen constituents and nitrogen concentrations within the beet plant in terms of nitrogen fertilization rates, nitrogen sources, sucrose content, quality, and most important of all, crystaline sugar recovery.

## Methods

Ten sugar beet fields were selected for petiole and root sampling by the Holly Sugar Company. The selection was made on the basis of the managerial capabilities of growers and kinds of nitrogen fertilizer programs being used on the fields. Total amounts of nitrogen applied per acre and nitrogen source distribution are shown in Table 1. Six fields received all ammonic-N fertilizer as dry 11-48-0 preplant and supplemental aqua and/or anhydrous ammonia. Six different growers were represented by the six ammonic-N fields located at different points in the north end of the Imperial Valley. Four other fields received a combination of ammonic nitrogen and nitrate nitrogen in the form of liquid 10-34-0 preplant, and liquid calcium ammonium nitrate side dressings. Although these fields were managed by only one grower, they were widely separated within the central portion of the Imperial Valley. Two ammonic-N fields were dropped from the survey: one because of erratic petiole root and sucrose analysis data

**Table 1.—Nitrogen fertilizer rates and nitrogen source distribution in fertilizer programs on sugar beets in the Imperial Valley, California, 1973.**

| Field Number | Total N in Fertilizer Program | $NH_4^+$-N in Fertilizer Program | $NO_3^-$-N in Fertilizer Program |
|---|---|---|---|
| | (Lbs/A) | (%) | (%) |
| $NH_4^+$-N Programs | | | |
| 1 | 155 | 100 | 0 |
| 2 | 247 | 100 | 0 |
| 3 | 283 | 100 | 0 |
| 4 | 280 | 100 | 0 |
| Average | 241 | 100 | 0 |
| $NO_3^-$-N Programs | | | |
| 5 | 293 | 42 | 58 |
| 6 | 285 | 43 | 57 |
| 7 | 325 | 41 | 59 |
| 8 | 293 | 42 | 58 |
| Average | 299 | 42 | 58 |

that indicated extremely high residual soil nitrogen levels, the other because it was harvested early without petiole and root samples taken prior to harvest.

Root and petiole samples were taken at approximately one month intervals, except for the last sampling date. A shorter interval was necessary because each of the fields under observation was scheduled to be harvested shortly thereafter. Holly Sugar Agriculture Department personnel collected petiole samples according to prescribed methods (38). Roots of the plants from which the petioles were taken were also taken. On the first sampling date the entire root was taken as a sample; on subsequent sampling dates only a ¼″ longitudinal slice was taken from the root for analysis. Petioles were dried and ground at the Holly Sugar Company laboratory. Part of the petiole sample was also analyzed in the company laboratory for $NO_3^-$-N by the specific ion electrode method. The remainder of the sample was sent to the Chevron Chemical Company Agronomy Laboratory for total nitrogen analysis by the Kjehdal method that reduces nitrites and nitrates to ammonia. Sucrose concentration of the root samples was determined by the Holly Sugar Company laboratory. The root samples were then sent to the Chevron laboratory for drying, grinding and analysis for total nitrogen by the modified Kjehdal method, and $NO_3^-$-N by the phenoldisulfonic acid method.

"Other nitrogen" concentrations were determined by the difference between total nitrogen and $NO_3^-$-N concentrations for both petiole and root samples.

Yield data were obtained by the Holly Sugar Company Agriculture Department. Final sucrose concentrations in the beets were the average field run concentrations determined from tear samples at the time of harvest. Juice purity information was not obtained.

## Results

### *Sucrose*

On the first sampling date, sucrose concentrations in beets grown with 58% nitrate-N in the fertilizer program were 2.7% higher than beets grown with all ammonic-N (Fig. 1). Sucrose concentrations in nitrate-N beets remained higher than those in ammonic-N beets until near the end of the sampling period. It is quite probable, however, that the sucrose concentration in the nitrate-N beets would have been equal to or slightly higher than those in ammonic-N beets on June 4, had sucrose concentration data been obtained from Field 7. (Field 7 had the second highest sucrose content in this survey at harvest time, Table 2.)

Sucrose accumulation was quite rapid in nitrate-N fertilized beets until about the end of the second week of April. At this time, accumu-

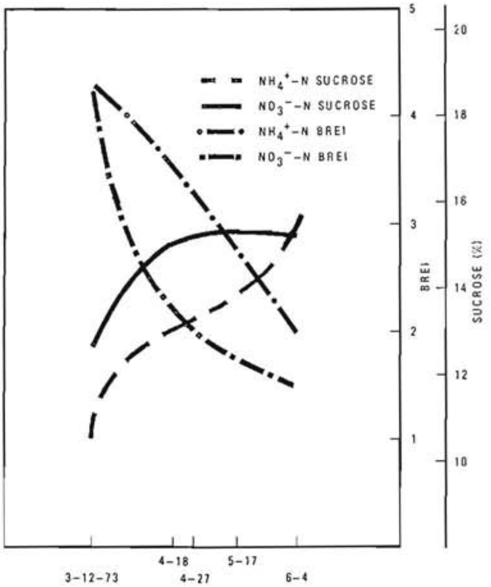

**Figure 1.—Sucrose content and diphenylamine ratings of sugar beets grown under $NH_4^+$-N and $NO_3^-$-N dominated fertilizer programs.**

lation began to taper off, and finally leveled off about May 1. ("Leveling off" may not be an accurate term because of the lack of sucrose data for Field 7 on June 4.) Sucrose accumulation was also rapid in all ammonic-N fertilized beets during the first half of the sampling period, and was even more rapid during the latter half.

**Table 2.—Yields of sugar beets and final sucrose concentration as affected by ammonic-N or nitrate-N dominated fertilizer programs, Imperial Valley, California, 1973.**

| Field Number | Total N in Fertilizer Program | Yield of Beet Roots | Sucrose Concentration At Harvest |
|---|---|---|---|
| | (Lbs/A) | (T./A.) | (Av. %) |
| $NH_4^+$-N Programs | | | |
| 1 | 155 | 23.5 | 16.20 |
| 2 | 247 | 31.1 | 15.58 |
| 3 | 283 | 17.3* | 16.52 |
| 4 | 280 | 27.0 | 14.30 |
| Average | 241 | 24.7 | 15.65 |
| $NO_3^-$-N Programs | | | |
| 5 | 293 | 29.6 | 17.31 |
| 6 | 295 | 41.7 | 15.69 |
| 7 | 325 | 30.4 | 17.04 |
| 8 | 293 | 34.7 | 14.09 |
| Average | 299 | 34.7 | 16.03 |

*Field replanted.

*Brei nitrate ratings*

Beets grown with either fertilizer program had high $NO_3^-$ levels in the brei on the first sampling date (Fig. 1). Nitrate concentrations in beets grown with either fertilizer program decreased throughout the sampling period. Brei nitrate in beets receiving some nitrate-N in the fertilizer program decreased rapidly. Beets grown with some nitrate-N also were consistently lower in brei $NO_3^-$ than were beets grown with ammonic-N throughout the sampling period.

*Average nitrogen content of petioles and roots*

The average $NO_3^-$-N concentration in petioles of beets grown with ammonic-N fertilizer was greater on all sampling dates than it was in beets grown with 58% nitrate-N in the fertilizer program (Fig. 2). On the second sampling date (4/18 for ammonic-N beets; 4/27 for nitrate-N beets) the average $NO_3^-$-N concentration in ammonic-N beets was double that of nitrate-N beets.

Both ammonic-N and nitrate-N fertilized beets reached their lowest $NO_3^-$-N concentration on May 17. The average $NO_3^-$-N level in petioles thereafter remained constant in ammonic-N fertilized beets, but more than doubled in nitrate-N fertilized beets. This occurred because the grower applied additional nitrogen to Field 8 when the petiole $NO_3^-$-N concentration began to fall off sharply after the first sampling date.

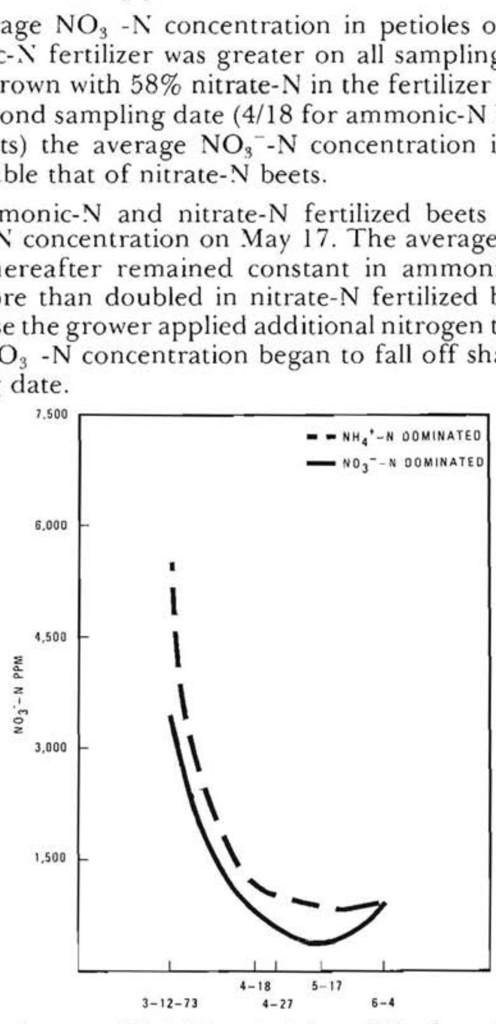

**Figure 2.—Average $NO_3^-$-N content in petiole tissue in $NH_4^+$-N and $NO_3^-$-N dominated fertilizer programs.**

The average $NO_3^-$-N content in root tissue was lower than that found in petiole tissue.

The average $NO_3^-$-N content with respect to the different fertilizer programs maintained the same relative position in roots as it did in petioles (Fig. 3). The average $NO_3^-$-N content remained consistently higher in the roots of beets grown with ammonic-N fertilizer than it did in roots of beets that received some nitrate-N in the fertilizer. On the first sampling date, the average $NO_3^-$-N content in the ammonic-N roots was more than 85% higher than that in the nitrate-N roots. The average $NO_3^-$-N levels in roots of beets grown with ammonic-N dropped off more sharply during the first three harvest dates than it did in the nitrate-N beet roots. Beets grown under both fertilizer programs reached their lowest average $NO_3^-$-N content on May 17.

Of special interest is the comparison of the configuration of petiole (Fig. 2) and root (Fig. 3) $NO_3^-$-N curves. Both $NO_3^-$-N curves in Figure 2 are concave, but in Figure 3, only the $NO_3^-$-N curve for ammonic-N grown beets remained slightly concave until May 17. The $NO_3^-$-N curve for beets grown with some nitrate-N in the fertilizer program is distinctly convex until May 17. Additionally, on May 17, when the $NO_3^-$-N concentration in both roots and petioles began to increase, there appeared to be a lag in the increase of $NO_3^-$-N concentration in the petioles of beets grown with either fertilization program.

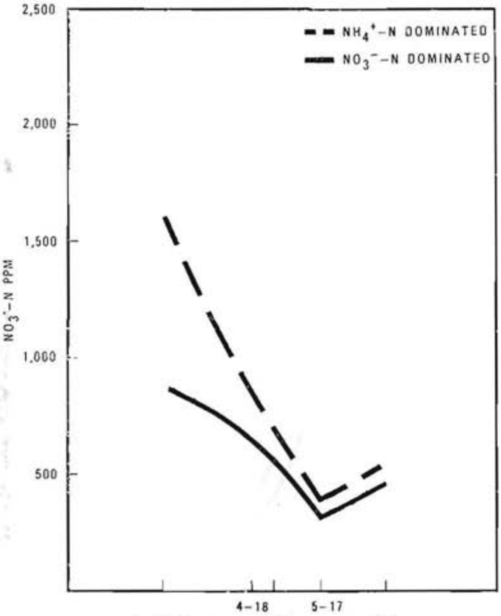

**Figure 3.—Average $NO_3^-$-N content in root tissue in $NH_4^+$-N and $NO_3^-$-N dominated fertilizer programs.**

The increase in $NO_3^-$-N content in the petioles in the beet plants grown with ammonic-N was quite small. Increases in the $NO_3^-$-N concentration in roots of beets grown with either program were very rapid after May 17.

The total N content in petiole tissue was higher throughout the sampling period in ammonic-N grown beets than it was in beets fertilized with some nitrate-N (Fig. 4). Total N concentrations in petioles taken from beets grown with ammonic-N did not drop as rapidly as it did in petioles of beets that received some nitrate-N in the fertilizer program. The total N in petioles of ammonic-N fertilized beets dropped to a level of 1.58% on May 18 and remained at that point for the remainder of the sampling period. Total N in petioles from nitrate-N fertilized beets dropped to an average of 1.20% on May 18, but increased sharply by June 4 to an average of 1.47%. On June 4 there was only a slight difference in total N content in the petioles of beets grown under either fertilizer program.

The total N content in root tissue was lower than that found in petiole tissue (Fig. 5).

Total N content in roots of beets grown with some nitrate-N in the fertilizer program was slightly higher than that in the ammonic-N fertilized beet roots on the first sampling date. Thereafter, the am-

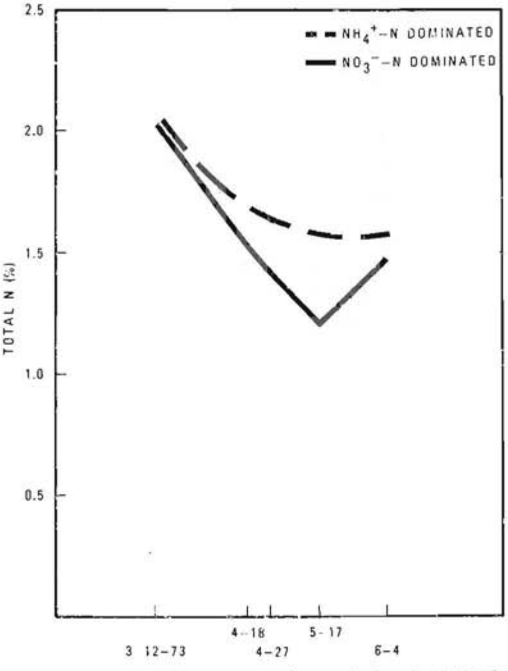

**Figure 4.—Average total N content in petioles in $NH_4^+$-N and $NO_3^-$-N dominated fertilizer programs.**

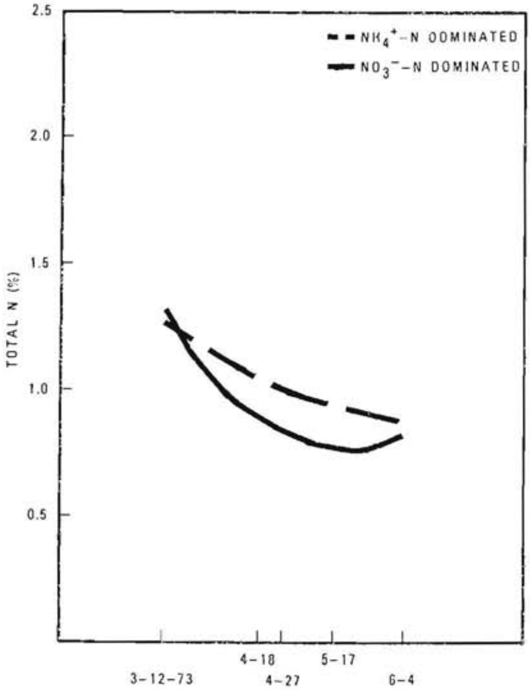

**Figure 5.—Average total N content in root tissue in $NH_4^+$-N and $NO_3^-$-N dominated fertilizer programs.**

monic-N fertilized beet roots consistently contained the greater amount of total N. Differences in total N content in roots of beets grown under either fertilizer program were very slight at the end of the sampling period.

Total N concentrations in the roots of beets fertilized with some nitrate-N dropped lower and faster than the total N in roots of beets fertilized with ammonic-N, but had increased more sharply by June 4. Total N content in roots of beets receiving ammonic-N also decreased throughout the sampling period.

The "other-N" concentrations in petioles of beets fertilized with ammonic-N produced an unusual curve configuration over the sampling period (Fig. 6). Starting much lower than the content in petioles of beets fertilized with some nitrate-N, petiole "other-N" from ammonic-N beets increased sharply, peaked out on April 18, dropped sharply until May 17, and then declined very slightly toward the end of the sampling period. "Other-N" concentrations in the petioles of beets fertilized with some nitrate-N, on the other hand, dropped sharply until May 15, then increased sharply toward the end of the sampling period. While the "other-N" content of petioles for beets fertilized with ammonic-N never fell below 14,925 ppm, the

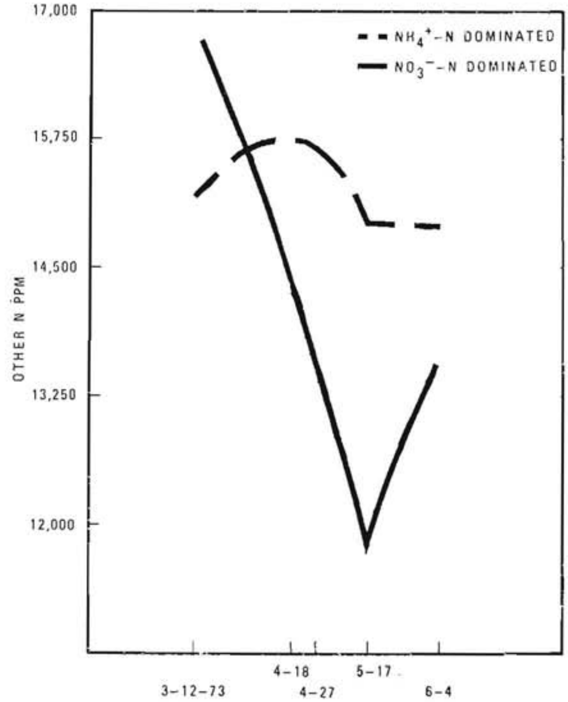

**Figure 6.—Average "other-N" in petiole tissue in $NH_4^+$-N and $NH_3$ -N dominated fertilizer programs.**

"other-N" content in petioles of beets with the 58% nitrate-N fertilizer program dropped to 11,713 ppm, but rose to 13,813 ppm by June 4.

Average "other-N" in root tissue was lower than that found in petiole tissue (Fig. 7).

On the first sampling date the "other-N" concentration in roots of beets grown with 58% nitrate-N in the fertilizer program was considerably higher than that found in roots of beets grown with ammonic-N. On March 12, however, the decrease in "other-N" concentration in nitrate-N beet roots dropped sharply and continually throughout the sampling period. On the other hand, while the "other-N" concentration was initially lower in ammonic-N fertilized beets, the decrease in "other-N" concentration was slow and remained considerably higher than that in the nitrate-N fertilized beets. At the end of the sampling period, ammonic-N beet roots contained 1,732 ppm more "other-N" than beets grown with some nitrate-N in the fertilizer program.

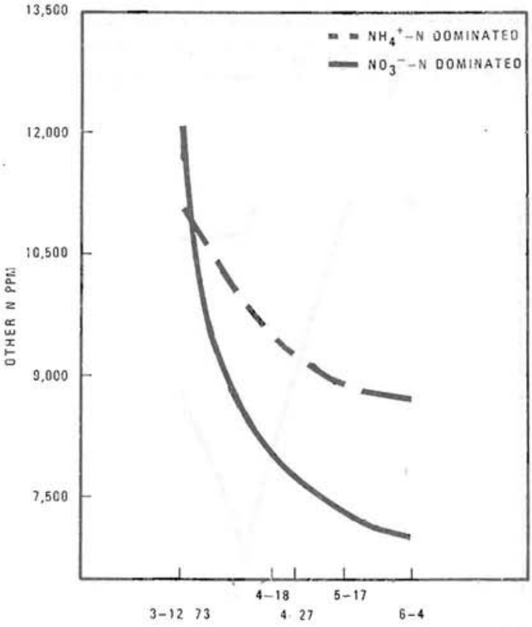

Figure 7.—Average "other-N" in root tissue in NH$_4^+$-N and NH$_3^-$-N dominated fertilizer programs.

*Harvest results*

Yields of beets grown with 58% nitrate-N in the fertilizer program were 10 tons higher than the yields produced with ammonic-N fertilizers (Table 2). There was also a trend toward higher sucrose concentration with the fertilizer programs containing an average of 58% of the total nitrogen as nitrate-N.

## Implications

It is believed that NO$_3^-$-N and "other-N" data more clearly reflect responses to the two fertilizer programs than do total-N data. Total-N data are included in this report for those who may desire reference points. The following discussion, then, will interpret the responses to the fertilizer programs in terms of NO$_3^-$-N and "other-N" content of the petioles and roots.

The survey tends to agree with the conclusions of Ulrich and others (1, 16, 18, 21, 37) that there are no important differences between yields of beets fertilized with different sources of nitrogen. Although there appeared to be a difference in beet root yields as a result of nitrogen source differences in the fertilizer programs, the yield loss from replanting Field 3 penalized yield data for ammonic-N fertilizer programs. It would therefore be difficult to state in terms of yields that one fertilizer source is superior to the other.

Since replanting Field 3 would be expected to have the effect of yield reduction, as did occur, it would also be expected that there should be an increase in sucrose content in the roots. This effect on sucrose content did occur, but not to the extent anticipated. The average sucrose content for beets harvested from Field 3 was only 2.22% higher than the lowest concentration found in Field 4 and only 0.32% higher than the second highest concentration found in Field 1. On the other hand, the average sucrose concentration in beets receiving 58% of the total nitrogen as nitrate-N surpassed that contained in ammonic-N fertilized beets. It appears, then, that the observations made in this survey do not fully agree with results found by various research workers.

The fact remains, however, that research reporting yields of roots and final sucrose concentrations apparently does not fully serve to provide logical explanations for the problems defined earlier in this report. Sugar beet processors are making a concerted effort to counsel their growers as to how much nitrogen should be applied. University Extension Agronomists, Farm Advisors, and Industrial Agronomists are also addressing themselves to the problem of the effect of nitrogen on yields and quality of sugar beets. Thousands of dollars are spent annually for soil nitrogen surveys and petiole testing programs to monitor nitrogen levels in the plant, but the problems remain. With operating costs increasing, net returns for processed sugar are diminishing.

It is not the intent of this report to even remotely infer that research data is inadequate. To the contrary, there is an abundance of information that does shed light on the source of the inplant problems encountered by the sugar beet processor. What appears to be overlooked are the inter-relationships between various areas of research.

Work by Benda and others (3, 7, 8, 10, 11, 12, 13, 15, 17, 19, 25, 27, 30, 31, 32, 33, 35, 43, 44, 45, 46) complements soil and plant nutrition research and assists in interpreting some of the information acquired in this survey.

If the responses to the two fertilizer programs are indeed real ones, then it would appear that growers, beet processors, and agronomists may have misinterpreted the meaning of petiole and brei $NO_3^-$-N tests. Because of the relative ease in determining $NO_3^-$-N in petiole tissue and brei, $NO_3^-$ ions appear to be the sole constituents responsible for low sucrose concentrations in the beet roots. While $NO_3^-$-N in the petiole does indicate the degree of nitrogen accumulation in the beet plant, it also represents only a portion of the total nitrogen content of the plant.

$NO_3^-$-N concentrations provide no indication of the other kinds of nitrogenous compounds in the plant that would affect sucrose recovery. The $NO_3^-$-N concentration in the brei similarly provides some indication as to the amount of crystaline sugar that may be recovered. It also does not, however, tell the processor what effect other soluble, non-nitrate, nitrogenous, organic compounds will have on sugar recovery. It is suggested that the misinterpretation of the significance of $NO_3^-$-N in petiole tissue and in the brei has resulted in the concept that $NO_3^-$-N in sugar beet fertilizer programs is something to be avoided. Yet, at least as indicated in this survey, the best pattern of sucrose accumulation, the highest sucrose content at harvest, and in both petioles and roots, the lowest $NO_3^-$-N, total N, and other N concentrations were found in beets fertilized with some nitrate N in the fertilizer program.

Research by Viets (43) and Vickery, et al. (42) appears to provide good reasons why $NO_3^-$-N should not be considered detrimental to sugar production. While it has been shown that some $NO_3^-$-N is reduced in the roots at the expense of sugars and organic acids, most of it is translocated to the tops. The researchers also state that $NH_4^+$ ions in the roots are quickly metabolized into amino acids or amides. It is then conceivable that beets fertilized with all ammonic-N could absorb $NH_4^+$ at rates high enough to accelerate the detoxification mechanism of combining oxidized $NH_4^-$ with sucrose to produce nitrogenous organic compounds such as amides and free amino acids. Since $NO_3^-$-N per se is usually not considered toxic to the plant, and since plants rapidly detoxify $NH_4^-$ oxidation products, it could be expected that $NO_3^-$-N, in the presence of excess $NH_4^+$ uptake, might not be as quickly reduced, and would have the tendency to accumulate. This conjecture seems to be supported by the data shown in Fig. 2, where $NO_3^-$-N is higher in petioles of ammonic-N fertilized beets; in Fig. 3, where $NO_3^-$-N apparently has accumulated in the roots of ammonic-N fertilized beets; and in Fig. 7, that shows "other-N" in roots of ammonic-N fertilized beets to be considerably higher than that in beets receiving some nitrate-N in the fertilizer program.

The concentration and rates of change in concentration in both the sucrose and brei $NO_3^-$-N in beets grown under each fertilizer program further supports this view (Fig. 1). It seems logical that sucrose concentrations in roots of beets grown with nitrate-N dominant fertilizer programs accumulated more rapidly and in greater amounts than the sucrose in beets fertilized with all ammonic-N nitrogen because excess $NH_4^+$ uptake did not occur. It also appears that $NO_3^-$-N fertilized beet plants may have absorbed and metabolized both $NH_4^+$ and $NO_3^-$ at rates that were not conducive to high $NO_3^-$ accumulation at the end of the sampling period. On the other hand, the $NH_4^-$ from the ammonic-N fertilizer programs apparently provided the greater portion of the plant's nitrogen needs. If this were so, nitrate reduction could be less rapid and this, then, could account for the nitrate accumulation in the beets grown with all ammonic-N.

The information obtained in this survey also raises some question as to the value of petiole analysis in predicting sucrose concentration accumulation and nitrogen depletion in the beet root. The curves in Fig. 8 show what would be expected to occur in terms of $NO_3^-$-N concentrations in the petiole with changes in sucrose concentrations in the root. As the sucrose concentration increases, petiole $NO_3^-$-Ndecreases. Similarly, the curves shown in Fig. 9 follow the expected pattern. As sucrose decreases, or remains static, petiole $NO_3^-$-N increases. Deviation from the expected pattern is apparent, however, in Fig. 10. As the sucrose concentration increases in the root, so does the $NO_3^-$-N concentration in the petioles. It is this example of disconformity that plagues sugar beet processors, their fieldmen, and agronomists.

Analysis for "other-N" in beet roots, while admittedly more laborious, time consuming, and costly, appears to provide a more accurate assessment of the sucrose nitrogen concentration relationship in the beet plant. Fig. 11 shows a definite decline in the "other-N" concentration in the roots as the sucrose concentration increases. Similarly, in Fig. 12, an increase in the "other-N" concentration in the root is reflected by a more or less static sucrose concentration accumulation. In Fig. 13, the "other-N" concentration is sharply decreasing while the sucrose content is increasing rapidly. Fig. 10 shows the corresponding petiole $NO_3^-$-N concentration changes for Field 7. This information

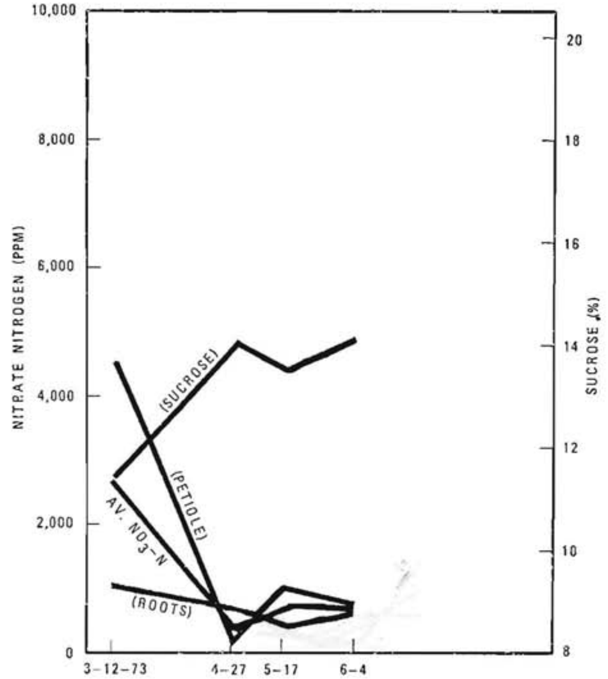

**Figure 8.—$NO_3^-$-N and sucrose content in sugar beet petioles and roots, field No. 6.**

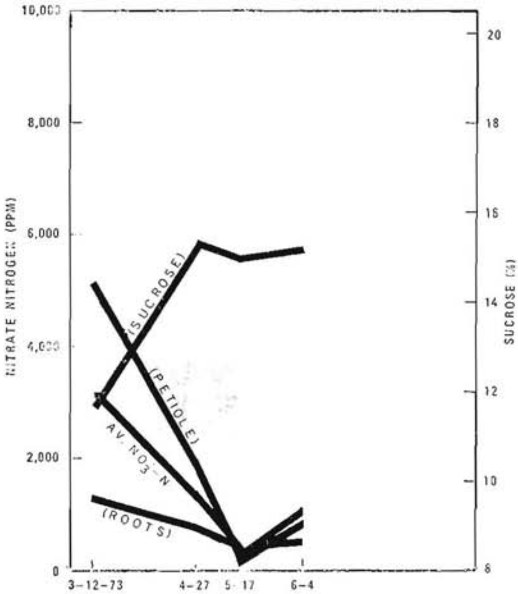

Figure 9.—$NO_3^-$-N and sucrose content in sugar beet petioles and roots, field No. 8.

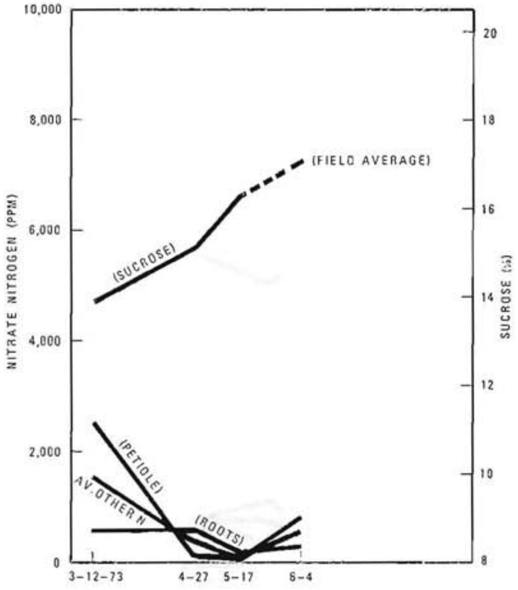

Figure 10.—$NO_3^-$-N and sucrose content in sugar beet petioles and roots, field No. 7.

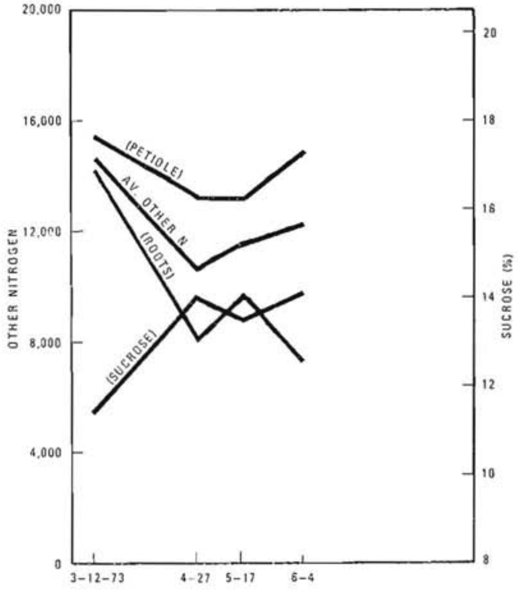

Figure 11.—"Other-N" and sucrose content in sugar beet petioles and roots, field No. 6.

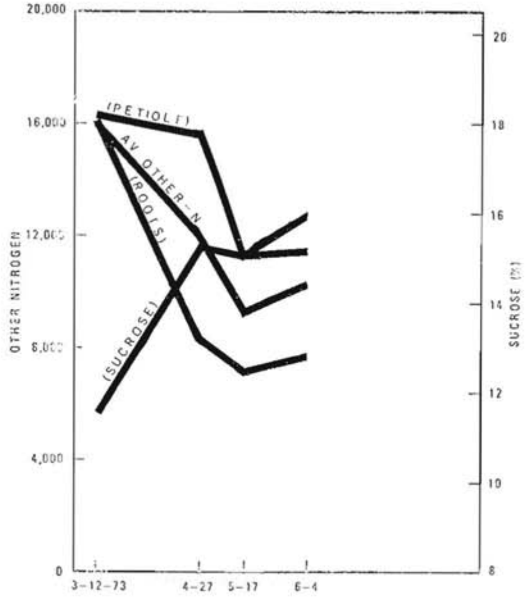

Figure 12.—"Other-N" and sucrose content in sugar beet petioles and roots, field No. 8.

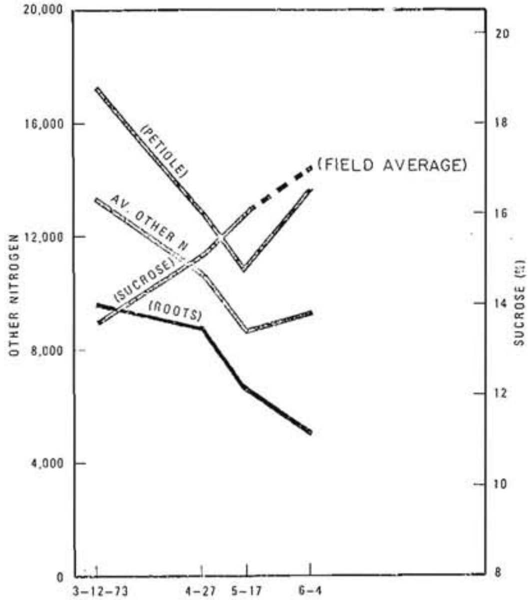

**Figure 13.—"Other-N" and sucrose content in sugar beet petioles and roots, field No. 7.**

suggests that there may be a need to re-evaluate the role of petiole analysis as a means of predicting nitrogen responses in terms of yield and quality factors in the sugar beet. Since the beet processor deals with the root portion of the beet plant, it would seem to be more logical to understand more clearly the biochemical relationships occurring within this organ.

It is suggested that attempts to suppress the formation of nitrogenous compounds in the beet root may not be an entirely desireable undertaking. With the world demand for food, particularly that of protein, increasing sharply, the nitrogenous compounds in sugar beets may afford an opportunity for beet processors to augment their income. Food technologists have developed texturized vegetable protein from soybeans. Wouldn't it be possible to do the same with amides, amines, and amino acids in sugar beets? Benda, et al. (3) attempted to obtain the required amino acid composition and mineral content of sugar beet roots used for animal feed by fertilization with nitrogen. But protein conversion by animals is inefficient. Why not prepare edible proteins from the sugar beet? Fowden (8) reports that the enormous scale of the sugar beet industry makes available very large quantities of nitrogenous compounds. One million metric tons of beets could yield about 500 metric tons of a mixture of free amino acids. Hac, et al. (11) studied the effect of fertilization on glutamic acid in beets in relation to sugar production. From their work it would appear that fertilizer programs could be established that would produce beets containing the optimum compromise of sucrose and free amino acids. Walker, et al. (44) studied rates of nitrogen fertilization in relation to glutamic acid and sucrose content. They observed an inverse relationship between glutamic acid and sucrose concentration with respect to nitrogen fertilization. They also observed that beets grown with $NH_4^+$ as the source of N in the presence of high sodium had a considerably greater increase in glutamic acid than those grown at equal nitrogen rates on nitrate. It is clear, then, that it is the nature of the sugar beet to store nitrogen. While beet processors view this characteristic as detrimental to the production of sugar, it also presents the sugar beet industry with a challenging and golden opportunity to investigate the merits of turning a lemon into lemonade: the profitable conversion of beet amino nitrogen into edible and nutritious vegetable protein.

## Literature Cited

(1) Adams, S. N. 1960. The value of calcium nitrate and urea for sugar beets and the effect of late nitrogenous top dressings. J. Agr. Sci. 54:395-398.

(2) Alexander, J. T. 1971. Factors affecting quality **In** Russell T. Johnson, John T. Alexander, George E. Rusch, George R. Hawkes, eds., *Advances in Sugar Beet Production: Principles and Practices.* The Iowa State University Press, Ames, Iowa.

(3) Benda, P., M. Dvorak, and J. Tusl. 1971. Influence of different nitrogen fertilizers on amino acids and minerals of sugar beet pulp. J. Sci. Food Agr. 22(5):221-222.

(4) Campbell, R. E. and F. G. Viets, Jr. 1967. Yield and sugar production by sugar beets as affected by leaf area variations induced by stand density and nitrogen fertilization. Agron. J. 59:349-354.

(5) Carter, J. N., M. E. Jensen, and S. M. Bosma. 1971. Interpreting the rate of change in nitrate nitrogen sugar beet petioles. Agron. J. 63:669-674.

(6) Ferry, G. V., F. J. Hills, R. S. Loomis, and A. Alred. 1963. Sugar in beet roots. Calif. Exp. Sta. in Calif. Agr. 17:8-9.

(7) Finkner, R. E., C. W. Doxtator, P. C. Hanzas, and R. H. Helmerick. 1962. Selection for low and high aspartic acid and glutamine in sugar beets. J. Am. Soc. Sugar Beet Technol. 12:152-162.

(8) Fowden, L. 1972. Amino acid complement of plants. Phytochem. 11:2271-2276.

(9) Gardner, R. and D. W. Robertson. 1942. Nitrogen requirement of sugar beets. Colo. Agr. Exp. Sta. Tech. Bull. 28.

(10) Hac, L. R., A. C. Walker, and B. B. Dowling. 1950. The effect of fertilization on the glutamic acid content of sugar beets in relation to sugar production. Proc. Am. Soc. Sugar Beet Technol. 6:401-411.

(11) Hac, L. R., A. C. Walker, and M. L. Long. 1954. I. The effect of fertilization on the glutamic acid content of sugar beets in relation to sugar production. II. Nitrogen fertilization in the Woodland, California area. Proc. Am. Soc. Sugar Beet Technol. 8:386-391.

(12) HADDOCK, J. L., B. C. LINTON, and R. L. HURST. 1956. Nitrogen constituents associated with reductions of sucrose percentage and purity of sugar beets. J. Am. Soc. Sugar Beet Technol. 9:110-117.

(13) HADDOCK, J. L. 1950. Nutritional status of sugar beets as revealed by chemical analysis of petioles. Proc. Am. Soc. Sugar Beet Technol.

(14) HADDOCK, J. L., P. B. SMITH, A. R. DOWNIE, J. T. ALEXANDER, B. E. EASTON, and B. JENSEN. 1959. The influence of cultural practices on the quality of sugar beets. J. Am. Soc. Sugar Beet Technol. 10:290-301.

(15) HARADA, TOGORO, HIROSHI TAKAKI, and YOSHIO YAMADA. 1968. The effect of nitrogen sources on the chemical components in young plants. Soil Sci. and Plant Nutr. 14(2):47-55.

(16) HILLS, F. J. and J. D. AXTELL. 1950. The effect of several nitrogen sources on beet sugar yields in Kern County, California. Proc. Am. Soc. Sugar Beet Technol. 6:356-361.

(17) HILLS, F. J., G. V. FERRY, A. ULRICH, and R. S. LOOMIS. 1963. Marginal nitrogen deficiency of sugar beets and the problems of diagnosis. J. Am. Soc. Sugar Beet Technol. 12:476-484.

(18) HILLS, F. J. and ALBERT ULRICH. 1971. Nitrogen nutrition. **In** Russell T. Johnson, John T. Alexander, George E. Rusch, George R. Hawkes, eds., *Advances in Sugar Beet Production: Principles and Practices.* The Iowa State University Press, Ames, Iowa.

(19) HURST, C. T. and J. E. GREAVES. 1944. Noxious nitrogen in leaves, crowns and beet of sugar beets grown with various fertilizers. Soil Sci. 57:417-424.

(20) LAST, T. J. and P. V. H. TINKER. 1968. Nitrate nitrogen in leaves and petioles of sugar beets in relation to yield of sugar and juice purity. J. Agr. Sci. 71:383-392.

(21) LOOMIS, R. S., J. H. BRICKEY, F. E. BROADBENT, and G. F. WORKER, JR. 1960. Comparison of N source materials for mid-season fertilization of sugar beets. Agron. J. 52:97-101.

(22) LOOMIS, R. S. and G. F. WORKER, JR. 1963. Responses of the sugar beet to low soil moisture at two levels of nitrogen nutrition. Agron. J. 55:509-515.

(23) MACKENZIE, A. J., A. R. STOCKINGER, and B. A. KRANTZ. 1957. Growth and nutrient uptake of sugar beets in the Imperial Valley, California. J. Am. Soc. Sugar Beet Technol. 9:400-407.

(24) OGDEN, D. B., R. F. FINKER, R. F. OLSEN, and P. C. HANZAS. 1958. The effects of fertilizer treatment upon three different varieties in the Red River Valley of Minnesota. J. Am. Soc. Sugar Beet Technol. 10: 265-280.

(25) PAYNE, M. G., L. POWERS, and G. W. MAAG. 1964. Levels of total nitrogen, potassium and sodium in petioles and in thin juice of sugar beets. J. Am. Soc. Sugar Beet Technol. 13:127-137.

(26) PENDLETON, RAY A. and W. W. ROBBINS. 1945. Fertilizers for sugar beets on some California soils. Calif. Agr. Exp. Sta. Bull. 694.

(27) POWERS, L. and M. PAYNE. 1964. Associations of levels of total nitrogen, potassium and sodium in petioles and in thin juice with weight of roots per plot, percentage sucrose and percentage apparent purity in beets. J. Am. Soc. Sugar Beet Technol. 13:138-150.

(28) REUSS, J. O. and P. S. C. RAO. 1971. Soil nitrate nitrogen levels as an index of nitrogen fertilizers of sugar beets. J. Am. Soc. Sugar Beet Technol. 16: 461-470.

(29) RIRIE, D., A. ULRICH, and F. J. HILLS. 1954. The application of petiole analyses to sugar beet fertilization. Proc. Am. Soc. Sugar Beet Technol. 8:48-57.

(30) RORABAUGH, G. and L. W. NORMAN. 1956. The effect of various impurities on the crystallization of sucrose. J. Am. Soc. Sugar Beet Technol. 9:238-252.

(31) SINGH, B. 1972. Nitrogen metabolism of sugar beets: a recurring problem gets a fresh appraisal. Econ. Bot. 26(2):182-188.

(32) SNYDER, F. W. and N. E. TALBERT. 1966. The influence of nitrogen nutrition and season on photosynthic incorporation of $C^{14}O_2$ into sucrose and other soluble components of the sugar beet. Bot. Gaz. 27:164-170.

(33) SNYDER, F. W. 1971. Some agronomic factors affecting processing quality of sugar beets. J. Am. Soc. Sugar Beet Technol. 16:307-496.

(34) STOUT, M. 1961. A new look at some nitrogen relationships affecting the quality of sugar beets. J. Am. Soc. Sugar Beet Technol. 11:388-398.

(35) TROUGHTON, A. 1957. The underground organs of herbage grasses. Commonwealth Bureau of Pastures and Field Crops Bull. 44, Hurley, England.

(36) ULRICH, A. 1955. How much N for sugar beets? **In** *The Sugar Beet.* Amalgamated Sugar Company, Ogden, Utah. Summer publication, Vols. 6-9, No. 6.

(37) ULRICH, A. 1943. Beet sugar production from chemical forms of nitrogen. Spreckles Sugar Beet Bull. 7.

(38) ULRICH, A. and F. J. HILLS. 1952. Petiole sampling of sugar beet fields in relation to their nitrogen, phosphorus, potassium, and sodium status. Proc. Am. Soc. Sugar Beet Technol. 7:32-45.

(39) ULRICH, A. 1942. The relationship of nitrogen to the formation of sugar in beets. Proc. Am. Soc. Sugar Beet Technol. 3:66-80.

(40) ULRICH, A. 1950. Nitrogen fertilization of sugar beets in the Woodland area of California. II. Effect upon the Nitrate nitrogen of petioles and the relationship to sugar production. Proc. Am. Soc. Sugar Beet Technol. 6:372-389.

(41) 1973. *Upbeet.* Great Western Sugar Company. 61, (1):12-13, Winter.

(42) VICKERY, H. P., G. W. PUCHER, and H. E. CLARK. 1936. Glutamine metabolism of the beet. Plant Physiol. 11:413-420.

(43) VIETS, FRANK G., JR. 1965. The plant's need for and use of nitrogen. **In** W. B. Barthalamew and S. E. Clark *Soil Nitrogen.* Agron. Mono. No. 10, Am. Soc. Agron., Madison, Wisc.

(44) WALKER, A. C., L. M. LONG, and L. R. HAC. 1950. Sand culture experiments with sugar beets. Proc. Am. Soc. Sugar Beet Technol. 6:412-421.

(45) WALKER, A. C., L. R. HAC, A. ULRICH, and F. J. HILLS. 1950. Nitrogen fertilization of sugar beets in the Woodland area of California. I. Effects upon Glutamic acid, sucrose concentration and yield. Proc. Am. Soc. Sugar Beet Technol. 6:362-371.

(46) WOOLLEY, D. G. and W. H. BENNETT. 1959. Glutamic acid content of sugar beets as influenced by soil moisture, nitrogen fertilization, variety, and harvest date. J. Am. Soc. Sugar Beet Technol. 10:624-630.