A New Look at Some Nitrogen Relationships Affecting the Quality of Sugar Beets

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Nitrogen is an essential element for the growth of all plant life, including sugar beets. There has been a phenomenal increase in the rate of application of nitrogen fertilizers on sugar beets during the last two decades. Associated with this great increase in the use of nitrogen fertilizers and increased yields has been a decline in quality, and processing losses have increased. The term "quality" as used in this paper refers to the relative concentrations of impurities, with respect to sucrose, which interfere with the recovery of sugar. The influence of nitrogen fertilization on the decline in quality may be due more to the improper timing of nitrate uptake by the beet than by the total amount used in many cases.

The general trend of quality decline and its effect on processing losses were summarized at a general session of the American Society of Sugar Beet Technologists in 1958 and several reviews have been published since then (13, 22)[2]. Haddock, et al. (13) showed that the downward trend in sugar percentage of the sugar beet since 1937 was correlated with a much greater loss of sugar extracted from the beets. The average loss in extraction appears to have been more than five times as great as the decrease in sugar percentage. Although some increased losses in extraction are probably due to increases in the daily tonnage put through a given processing plant, the reduction in quality is undoubtedly the principal factor responsible for the decline in extraction.

The general trend toward higher yields with lower sugar percentage and lower quality suggests that yield and sugar percentage may be negatively correlated. On a given farm under uniform field practices other than nitrogen fertilization, this negative correlation is usually true; however, results between many farms within a district may not show this relationship. Frequently some farms having the highest yields produced sugar beets far above the average in sugar percentage. High yield, high sucrose percentage, and quality are evidently not incompatible but the factors responsible for their concomitant occurrence have not been clearly recognized.

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[2] Numbers in parentheses refer to literature cited.

A Major Cause of Low Quality

The depressing effect of high nitrogen nutrition on sugar beet quality was reported by Headden (14) as early as 1912. His report left little reason for doubt of the cause-and-effect relationship between high nitrate uptake and low quality. Later studies by Gardner and Robertson (9) also showed that excessive nitrogen reduced the sugar percentage and purity of sugar beets. Gardner and Robertson estimated that the reduction in sugar percentage was an approximately linear function of the nitrate nitrogen in the beet at harvest and that each 0.025 percent nitrate nitrogen in the beets reduced the sugar percentage by approximately 1 percent, which amounts to a 40 to 1 ratio between nitrate nitrogen and sugar percentage.

High nitrogen nutrition of sugar beets stimulates the growth of new leaves. Since leaves are the photosynthetic machinery that biochemically produces sugar from water and carbon dioxide for storage in the root, beets should have an abundant supply of nitrate to get them off to a good start early in their growth cycle (1, 25, 30, 33). Early development of a full canopy of foliage lengthens the time for the effective use of leaves for photosynthesis, thereby increasing sugar yields.

Nitrate uptake and metabolism require energy derived at the expense of sugar accumulation. First, energy is required to take nitrate into the roots (4, 5, 16, 20, 31) where its concentration is usually many times greater than that in the soil solution (4, 5). The energy for this accumulation of ions against a concentration gradient is derived from the respiratory metabolism of stored food, principally sugar. Second, nitrate must be reduced before it can be incorporated into usable compounds and this reduction requires eight hydrogen ions for each nitrate ion. Again the energy is derived at the expense of sugar accumulation, whether it is from the direct metabolism of sugar or from the photolysis of water (4, 5). Third, the ammonia formed by the reduction of nitrate, and possibly other partly reduced nitrate intermediates, is toxic to the plant (8, 23) and must be immediately combined with more than five times its weight (2) ($\%$ N $\times$ 6.25 = $\%$ protein) of photosynthesized sugar-forming intermediates to form amino acids which in turn are used for the synthesis of proteins and enzymes (4, 5, 24). Although these nitrogen-containing compounds are necessary for photosynthesis and other biochemical processes, they are impurities as far as the extraction of sugar is concerned (22) and sometimes they are produced in considerable excess of the amounts needed for optimum sugar production and storage.

Fife and Carsner (8) reported that "tip burn" occurs when sugar beets that have been grown in fertile soil with an abundance of nitrogen for a comparatively long time are subsequently grown under a low light intensity, and that the toxic substances involved are probably normal nitrogenous constituents of the plant temporarily in excessive concentrations. If the light intensity is too low to supply sufficient energy for rapid nitrate uptake, its reduction, and its subsequent combination with carbohydrates to form non-toxic amino acids, the reduced nitrogen compounds are toxic. Stout and Tolman (23) found that low concentrations of ammonia, if the concentration was maintained by constant flushing, were toxic to germinating sugar beet seeds and two-month-old plants.

High nitrate uptake causes a high rate of uptake of positively charged ions such as sodium and potassium in order to maintain electrical balance of cations and anions in the roots (16, 31). The data in Table 1 show that sugar beets heavily fertilized with nitrogen late in the season were much lower in sugar percentage and purity. They were also much higher in sodium, potassium, and amino nitrogen than normally fertilized sugar beets.

Table 1.—Effect of late, heavy application of nitrogen[1] on sugar beets, Gallinat plot, Salt Lake City, Utah, 1954.

Treatment	Average root wt.	Percent sucrose	Purity	Amino N	Sodium	Potassium
	Pounds		Percent	Percent	ppm	ppm
Heavy nitrogen	3.15	14.98	84.6	0.56	427	3318
Check	3.21	17.72	89.8	0.23	197	2569

[1] Nitrogen applied August 27, 1954, 300 pounds per acre of ammonium sulphate and September 10, 1954, 300 pounds of ammonium nitrate.

Variety SL 342,400. Above figures are average values of 20 individual beets of each nitrogen treatment.

Rounds, et al. (22) studied the effect of nitrogen nutrition and variety on processing losses. They found that high nitrogen nutrition caused increased impurities that reduced quality and extraction. Nitrogen compounds were highly correlated with non-sugars and ash, although different varieties responded somewhat differently to fertility levels.

Ulrich (28, 29) found that the sugar percentage of sugar beets when grown in full nutrient culture could be increased from about 7 to 12 percent by the best combination of day and night temperatures available at the Earhart Laboratory in Pasadena, California. Sugar values above 18 percent were observed when nitrate was eliminated from the otherwise full nutrient medium for a time before harvest.

The roots of sugar beet plants are slow to enlarge until a fairly large canopy of leaves develops so that the leaves can capture enough sunlight and carbon dioxide to make more sugar than is required for new leaf growth and other metabolic processes. Only after this stage of development are the beets able to store an appreciable amount of sugar in their roots. Since an abundance of nitrogen stimulates the growth of new leaves, the plants apparently need a large amount of nitrogen early in the season to produce a rapid growth of foliar photosynthetic "equipment." For a period before harvest the nitrate supply should be greatly reduced to prevent the reinvestment of stored sugar in the production of surplus foliage. This regime of high nitrate uptake early in the season followed by a low rate of uptake before harvest should result in the maximum proportion of energy being used for photosynthesis and sugar storage and a minimum lost in excessive respiration, nitrate uptake, reduction and metabolism, and the production of excessive leaf growth.

The formation of an overabundance of leaves is not conducive to sugar accumulation in the root. Leaves are very porous to gases (5) and have a very high rate of respiration and transpiration in comparison with storage tissues. When leaves are exposed to light they normaly make more sugar than they consume. In the dark, especially at high temperatures, they burn up much of the sugar that is photosynthesized during the day. A surplus of leaves producing severe shading for some of them can cause the too densely shaded leaves to be a liability, rather than an asset.

In summarizing the best sequence of nutrients and environment for sugar beets, Went (33) stated that it should involve early nitrogen feeding at warm summer temperatures for maximum growth followed by low nitrate nutrition in sunny autum weather with night temperatures near freezing. The thermal requirements are fairly adequate in many of the sugar-beet-growing areas. Neither temperature nor light factors can be easily modified economically, therefore, the nitrate-nutritional regime is probably the most important factor subject to some measure of control.

The Possibility of Some Measure of Control of Nitrogen Uptake

Withholding nitrate from a culture solution is easy, but taking it out of the soil at the right time is more difficult. The method generally used is to estimate the optimum amount to apply earlier in the season so that the nitrate will be depleted to the proper extent in the root zone at the right time. One problem frequently encountered in estimating nitrate requirements for sugar beets is the effect of incorporation of organic residues into the soil before planting the sugar beet crop. Tolman (25, 26) pointed out that the greatly increased number of micro-organisms that develop to decompose the organic material compete with the beets for available nitrate when the beets need it most. Late in the summer the micro-organisms begin to die and release nitrate when the supply to the beets should be greatly reduced.

Leaching nitrate from the root zone by heavy irrigation late in the summer would be wasteful of water and nitrate and, to be effective, would probably reduce aeration of the roots to the point where growth would be reduced and root rots would develop. Soil-profile nitrate studies (19) and preliminary studies by the writer of the nitrate content of irrigation and drainage waters have indicated that under normal irrigation practices leaching of nitrate from soils has been overestimated. Another, and not such an obvious approach to the reduction of nitrate uptake late in the season, is to help nature put the nitrate where the plants cannot get it—and save it for succeeding crops. This method has been in use since the beginning of agriculture especially in irrigated, arid climates such as those of western United States. Scientists have studied and given much concern to the movement of soluble salts in our soils (3, 18, 32) because these salts sometimes build up to such high concentrations as to threaten crop production in certain areas. The relationship between precipitation and evaporation is largely responsible for our saline soils and streams, but these same factors also affect the availability of plant nutrients. Nitrate is probably the most soluble anion in our soils and it is also the principal source of nitrogen taken up by plant roots.

In arid climates where there is little prospect of late-summer and fall rains, practices conducive to the redistribution of nitrate in the soil profile may be used to make some of the excess nitrate unavailable to the plants. In such areas the two nitrate-depleting factors, uptake by the roots and redistribution into dry surface soil, would complement each other. The extent of the evaporative redistribution of nitrate in the soil profile as a means of control of nitrate nutrition has not been fully recognized or utilized.

The tremendous amount of moisture that is evaporated from the surface of the soil is often ignored. Evaporation accounts for a large proportion of the total moisture applied to the soil by rain or irrigation. Studies (17) at Rothamsted, England, with a 60-inch drain gauge over a number of years showed that over 53 percent of the average annual rainfall of 28.73 inches was evaporated from the soil surface (1871-1912). Hilgard (15) reported variations in annual evaporation values from a free water surface at ground level from 17.8 inches at Rothamsted, England, up to 108 inches at Calexico, California. The evaporation in the Salt Lake Valley, July, 1959, amounted to 14.2 inches. The same station recorded a total evaporation of 69.09 inches from April 1 to October 31, 1959.

No information on the moisture loss from a field of sugar beets is available, but Campbell, et al. (7) reported evapotranspiration values from sugar cane in Hawaii. They reported values of 0.37 tot 0.86 cm per day. The ratio of lysimiter evapotranspiration values to pan evaporation rate at cane-top height increased with the growth of the cane from initial values of about 0.4 to values averaging 1.1 for cane with well-developed canopies. The upward movement of moisture carries with it the soluble salts in the soil solution. The mobility of the salts or ions involved depends upon their concentration, solubility, and ability for ion exchange with other ions of relatively insoluble minerals in the soil. The high water-solubility of nitrate salts would probably preclude appreciable retention on the mineral constituents of the soil, but nitrates may be tied up rapidly by an increase in the number of microorganisms decomposing organic matter. In this case the nitrate is changed into organic-nitrogen compounds as well as rendered relatively immobile until the organisms die and the compounds are re-oxidized to nitrate.

Soil-profile nitrate and petiole-nitrate studies of growing plants can do much to evaluate the areas of nitrate concentration in the soil (18, 19) and the nutritional status of the plants (10, 11, 27). However, such studies can only evaluate, not modify the condition. As guides they can be used to develop modifications of cultural and irrigation methods to give some measure of control during the growing season. Late-summer or fall rains on beet fields frequently result in responses similar to those following an application of nitrate fertilizer. Haddock (12) found that sprinkler irrigation resulted in lower quality beets than applications of the same amount of water by furrow irrigation. Under sprinkler irrigation the petiole-nitrate values at harvest were more than four times as high as under furrow irrigation.

Many soils and petioles of beets have been tested for nitrate by means of diphenylamine reagent (27). Shortly before harvest the petioles frequently show little or no coloration with the reagent, but the dry soil in the ridges between beets is often very high in nitrate. This sample qualitative test can give very useful and convincing information concerning nitrate nutrition and distribution. If the season has been dry the nitrate-redistribution pattern is evidently developed to the point where nitrate uptake by the plants is low. Obviously if the furrows are shallow a heavy rain or flood irrigation would upset this distribution pattern and result in high nitrate uptake, increased growth of leaves, and reduced sugar percentage and purity (6).

A quantitative laboratory study of nitrate redistribution was made by filling a 4-foot glass tube with well-mixed soil. Distilled water was supplied to the bottom of the tube and after the soil was moistened to the top, a 75-watt light bulb was placed 1 inch above the soil. Twenty days later the soil was removed in sections, dried, and analyzed. The total nitrogen concentration of the top inch of soil was ten times as high as that of the lower layers.

Soil samples were taken in a farmer's field of sugar beets near enough to a source of tap water so that a rain could be simulated by sprinkling if necessary. Even though the soil sampled in the ridge between furrows had been flooded at each irrigation, the data in Figure 1 (solid line) show a rapid decrease in total nitrogen content from the surface to lower layers. During the night following the first sampling and the next day, 0.46 inch of rainfall was recorded. Samples taken immediately after the rain, adjacent to and at the same elevation as the previous samples, showed a marked shift in the nitrogen content of the soil (broken line, Figure 1). Even less than 0.5 inch of rain had evidently shifted the maximum concentration from the surface to a depth of 4 or 5 inches.

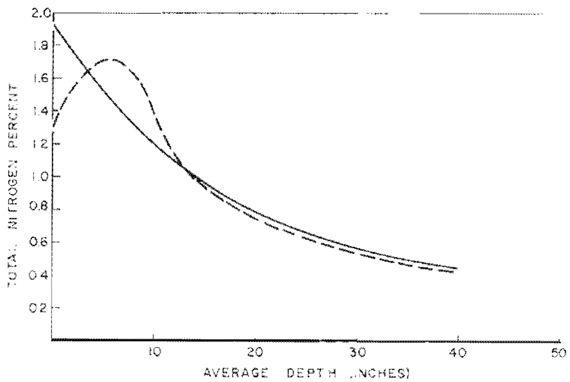

Figure 1.—Soil-profile nitrogen values before (solid line) and after a rain of 0.46 inches. Swensen Farm, Salt Lake Valley, October, 1957.

Data reported by Rost and Alway (21) showed that the surface 6-inch layers of three Minnesota soils contained 6 to 11 times as high concentration of nitrogen as the 25- to 36-inch layers.

McGeorge and Wharton (18) studied salt-concentration gradients in lettuce beds. The data showed that most soluble salts moved laterally toward the centers of the beds as a result of irrigation and upward with the evaporation of moisture from the surface. Nitrate moved more rapidly than other salts. Bernstein (3) also reported cross-sectional points of concentration of salts in various types of beds and explained why certain types are preferable for growing crops on saline soils under furrow irrigation.

The very high solubility of nitrates in comparison with that of other ions in the soil indicates that extreme redistribution of nitrate in the soil-profile might occur under arid conditions. Unpublished studies by the writer and also by R. A. Nielson of soils in sugar beet fields showed that nitrate concentrations in the top 0.5 inch of soil may be 500 or more times as high as at lower levels of the soil. This high concentration gradient was found in the dry surface soil between beets in the ridges of soil between furrows. Depletion of nitrate in the moist soil by the sugar beets as well as protection from rainfall by the foliage evidently contributed to the extremely high concentration gradients. Unprotected bare soil did not show this extreme concentration gradient after a rainfall. Immediately following a rain the nitrate concentration may be much higher in lower levels than in the surface of unprotected soils.

The extreme solubility and mobility of nitrate in soils with respect to moisture movement can be utilized in developing agronomic and irrigation methods to modify nitrate-uptake by sugar beets in relation to the growing and harvest seasons. Many instances of high yields and high sugar percentage and quality have been reported. The influence of nitrate nutrition in relation to the seasonal needs of the sugar beet in order to produce maximum yields and quality is very important in sugar beet culture. Under different climatic conditions, other methods may be superior but the basic effect of these climatic factors on nitrate movement in the soil should be understood in order to develop better modifications of cultural practices. High ridges of soil in the rows of beets and foliar protection of the soil from rain may serve as an additional means of depleting the available nitrate late in the season in arid climates. With good foliar protection the nitrate in the surface may remain relatively unavailable following light rains. If, however, fall rains are heavy and frequent, the nitrate may become available to the plants at the least desirable period (6).

The principal purpose of the present report is to bring together some well-established basic facts concerning nitrogen metabolism and to point out that these facts have an important practical bearing on both the yield and quality of sugar beets. Proper timing of the relative rates of these basic processes is probably the key to a sound, economic solution. The effects of certain climatic conditions that modify the distribution of nitrate in the soil profile also affect nitrate uptake. This redistribution of salt concentrations in the soil profile has been studied extensively in relation to salinity problems. Concentration patterns shown by these studies have attractive possibilities for use in modifying the seasonal nutrition of the sugar beet. Figure 2 is a diagrammatic summary of some of these basic facts.

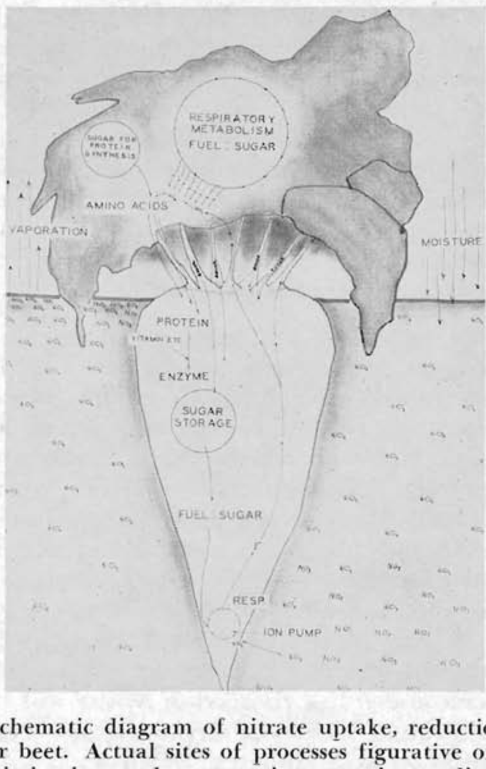

Figure 2.—Schematic diagram of nitrate uptake, reduction and metabolism in the sugar beet. Actual sites of processes figurative only. The effects of rainfall or irrigation and evaporation on nitrate distribution in the soil profile are indicated.

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