Nutrient Balance and Concentration in Sugar Beet Production[1]

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Eighty percent of all commercial fertilizer used on the sugar beet producing land in Western United States is applied without the guidance of soil or plant tissue analysis. Many students (1,4,6,7,9,10,11,12,15)[3] of plant production requirements indicate that mineral nutrient content and balance in plant tissue strongly affect yield and quality.

Ulrich *et al.* (13) have proposed and successfully used the theory of "critical concentrations" of nitrogen, phosphorus, and potassium in sugar beet petioles as a guide to crop fertilization. Ulrich (14) has defined the critical nutrient level as that range of concentrations within which the growth of the plant is restricted in comparison to plants maintained at higher nutrient levels. He proposes 1,000 ppm of nitrate-nitrogen, 750 ppm phosphorus, and 10,000 ppm potassium as constituting "critical levels" in sugar beet petioles. These criteria however, give little consideration to total nutrient concentration or balance. Furthermore, the authors (2) have presented data which indicate the superiority of quantity-quality factor over critical levels as a basis for identifying nutritional disturbances in sugar beet plants. Sugar beet plants are exposed to a wide range of nutrient ratios and concentrations in commercial sugar beet fields. Little information is now available on the influence of these factors on sugar beet production. It appeared desirable to extend the former study and comparison to include a wide range of nutrient ratios and total nutrient concentrations in the nutrient medium and in plant tissue.

A survey of the literature indicates that serious consideration has not been given to the statement of Shear and Crane (8) that each essential element must occur in the leaf in proportion to every other essential element, nor to that of Lucas *et al.* (5) that a balanced nutrition does not imply an adequate nutrition but an adequate nutrition does imply a balanced nutrition.

Yield, quality, and chemical composition data derived from analyzing sugar beets grown in seven nutrient culture treatments

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[3] Numbers in parentheses refer to literature cited.

are presented below. The experiment had been designed to test the hypotheses that:

1. "Critical levels" do not constitute a sensitive measure of nutrient conditions in the sugar beet.

2. The relative concentrations of the components of a nutrient medium may by important factors in yield and quality of sugar beets.

3. The balance of nutrients attained in the plant tissues exerts an important influence on yield and quality of sugar beets.

Experimental Methods and Procedure

Ten-gallon cans (each with a 14-inch diameter and a 15-inch depth) painted inside with asphaltic interior water tank coating and with five holes punched in the bottom for free drainage were filled with No. 2 vermiculite. They were buried in moist soil to within 1 inch of the top rim in order to maintain plant roots at normal soil temperatures. The cans were spaced on 40-inch centers with two sugar beet plants growing in each can.

The compositions of the nutrient solutions used are shown in Table 1. Nutrient concentrations were unchanged throughout the experiment. Each treatment was replicated 12 times. One gallon of each nutrient solution was applied to its respective can daily except during hot weather in mid-July and August when a total of one and one-half gallons were used in two applications.

Table 1.—Nutrient concentration in various nutrient solutions, 1962.

No.	Nutrient Solutions	Various nutrients * in solution ppm						pH	Salinity E. C. X 10^3 @ 25° C.
		NO_3N	P	K	Ca	Mg	Na		
1	Check	100	16	100	150	40	12	7.4	1.60
2	2 X Check	200	32	200	250	60	24	7.4	2.60
3	Field**	60	16	20	80	50	40	7.6	1.00
4	2 X Field	120	32	20	160	100	80	7.5	1.53
5	½ Field	30	8	20	70	25	20	7.5	0.70
6	¼ Field	15	4	20	60	15	15	7.5	0.55
7	Field + K	60	16	40	100	50	50	7.6	1.10

*Minor elements added to all nutrient solutions: B = 0.25, Mn = 0.25, Zn = .028, Cu = .01, Mo = .004, and Fe = 4.5 ppm.

**Field solution modified from check so as to produce beets chemically typical of those found in commercial fields.

Leaf petiole samples were taken from the most recently matured leaves on each test plant. A sample was taken from each plant June 25, July 16, August 6, September 20, and October 15. These tissues were rinsed in deionized water, dried rapidly at 70° C, ground to pass a 40-mesh screen, and examined by standard chemical procedures to determine acetic-acid-soluble nutrients.

Hoagland's (3) nutrient solution No. 1 was used at one-half strength as a check solution. Modifications of the check solution as shown in Table 1 constituted the other six treatments referred to in this study. The solution designated Field (F)[4] was devised to produce sugar beet plants typical of those found in commercial fields.

The concentrations of the nutrient components of each solution per se were not the primary concern in these experiments. Rather, the nutrient concentrations in the tissues of sugar beet plants growing in these solutions were the major interest. The objective of these studies was to relate plant tissue composition to productivity.

Experimental Results

Gross sugar yields are shown in Figure 1. The electrical conductivity of each nutrient solution indicates both the total concentration of soluble salts and the intensity of nutrition.

The differential responses of roots and tops to a range of nitrogen and phosphorus concentrations are shown in Figure 2.

Critical levels are not shown here for phosphorus and potassium. In no instance, however, did the phosphorus concentration fall below 1500 ppm nor the potassium below 30,000 ppm in the petiole tissues examined. The seasonal levels for nitrate-nitrogen are shown in Figure 3. None of the plants contained nitrogen below the critical level.

The senior author has previously used quality factors as a means of characterizing nutritional status of sugar beets (2). This technique is used in presenting the data in Figures 4 and 5. Data in Figure 3, used here to characterize the nitrogen nutritional status of sugar beet plants by the "critical level" technique, can be compared with the data on quality of nitrogen presented in Figure 4.

Discussion

Yields of sugar, from treatments involving solutions 3, 4, 5, and 6 (left half of Figure 1), indicate that the concentrations of nitrogen and phosphorus in the root medium significantly affect yield. When the ratio of nitrogen to phosphorus was held constant, concentrations higher or lower than those in solution F depressed yields significantly. This situation prevailed only rela-

[4] Field survey in 1961 of 48 high-producing commercial fields indicated plant tissue high in N, high in Na, and low in K relative to composition of ideal nutrient-cultured beets.

tive to the four nutrient solutions ¼-F to 2-F. Sugar yield was not necessarily depressed as a result of increasing the total concentration of nutrients in the root medium. The Ck solution contained higher concentrations of nitrogen and potassium than did solution F. The Ck solution also had a high electrical conductivity, yet it did not depress yields. However, when the Ck solution ratio among nitrogen, phosphorus, and potassium was maintained but the total concentration of salts was increased (as in 2-Ck), sugar yield was depressed significantly relative to Ck treatment.

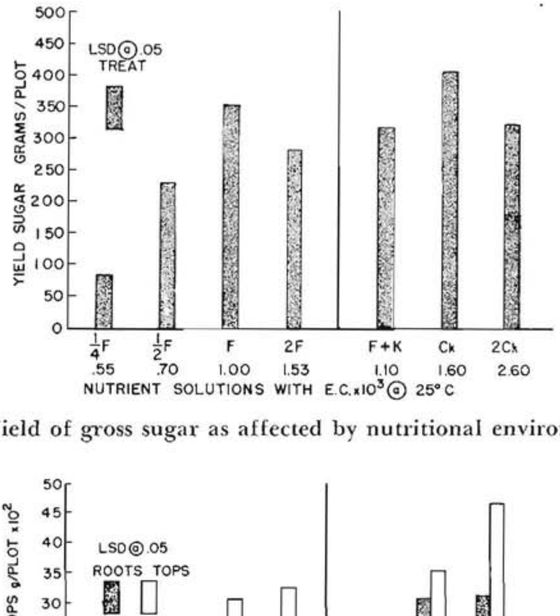

Figure 1.—Yield of gross sugar as affected by nutritional environment, 1962.

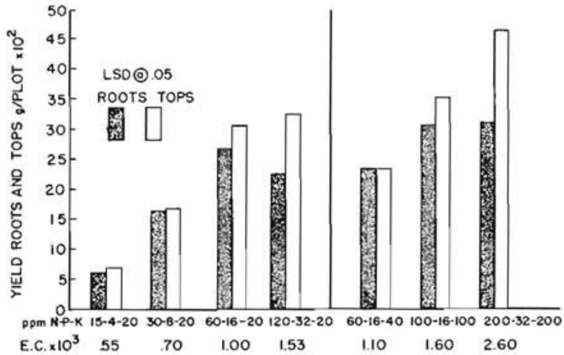

Figure 2.—Yield of sugar beet roots and tops as related to nitrogen, phosphorus and potassium concentration in nutrient solutions, 1962.

These observations suggest that the concentration of nutrients in the root medium plays a significant role in sugar beet production. The balance or ratio among the three primary nutrients appears to be important in the growth of sugar beets in the range of concentrations studied. Undoubtedly, nutrient elements other than nitrogen, phosphorus, and potassium exert their individual and combined influence on growth. It is impossible to avoid completely a confounding of some cause and effect relationships when one is working with such complex mediums.

It has often been said that one cannot grow a crop of beets without a good yield of tops, but top growth is not a good indicator of root yields. While growth response of both roots and tops is similar over the lower portion of the nutrient concentration range, data in Figure 2 indicate that root growth is less sensitive to continued increases in nutrient concentration than is top growth. This is because top growth continues to respond favorably to higher intensities of nutrition and higher concentrations of nitrogen which have no additive effect on root growth (Figure 2).

The ranges in yields of roots, tops, and sugar shown in Figures 1 and 2 would seem to indicate the existence of significant differences in chemical composition among plants grown in these nutrient cultures. None of the plants studied, however, were deficient in nitrogen, phosphorus, or potassium on the basis of critical levels. The nearest approach to a critical level was associated with the July 16 sampling for the ¼-F treatment (Figure 3). One must assume from these observations either that nitrogen, phosphorus, and potassium are not related to the yield variations shown in Figures 1 and 2, or that proposed "critical levels" are inadequate as a measurement of nutritional status.

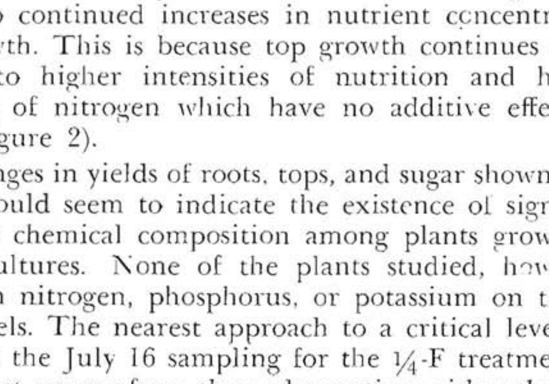

Figure 3.—Seasonal nitrate-nitrogen content of sugar beet petioles as influenced by nutritional environment, 1962.

Data on the chemical composition of the sugar beet petiole samples were calculated to obtain quality factors for nitrogen, and are represented graphically (Figure 4). The most productive plant is assumed to be the best nourished. Seasonal ranges in the nitrogen quality factor for an adequately nourished plant are selected as tolerance limits, within which such a plant can be identified. These arbitrary limits are shown by horizontal solid lines in Figure 4. The extent of departure from these tolerance limits is assumed to indicate the nature and extent of nutritional disturbance resulting in unsatisfactory growth performance. The 2-F and 2-Ck treatments produced plant tissue high in nitrogen quality (Figure 4). Four of the treatments resulted in plant tissue too low in nitrogen quality for optimum growth.

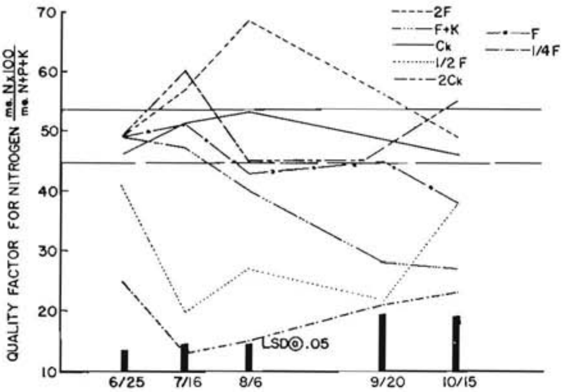

Figure 4.—Seasonal quality factor for nitrogen in sugar beet petioles as influenced by nutritional environment, 1962.

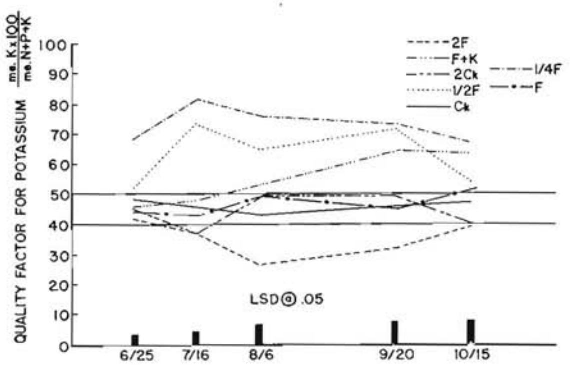

Figure 5.—Seasonal quality factor for potassium in sugar beet petioles as influenced by nutritional environment, 1962.

Since the quality technique involves a calculation of the ratio N : P : K, it follows that when nitrogen quality is low, potassium quality tends to be high. This is illustrated by the data in Figure 5. When this analysis was extended to phosphorus, it was evident that none of the plants was deficient in phosphorus.

The influence of the three primary, as well as other plant nutrients, has been poorly defined with respect to their potential excess and deficiency relative to sugar beet production. These interrelations need clarification and more precise definition.

Summary and Conclusions

The yield of sugar from sugar beets was influenced significantly by various concentrations of nitrogen and phosphorus in nutrient cultures that did not approach critical levels.

Under the conditions of nutrient culture used in this study, as total nutrient concentration increased, nutrient balance became a more important factor influencing the yield of sugar.

The maximum peak in the growth curve for sugar beet tops, appears to occur at a higher concentration of nitrogen in the growth medium than does the comparable peak in root growth. Both curves are markedly and differentially affected by nutrient balance in the growing medium.

Nutrient culture studies using the buried pot, out-of-doors technique have shown that intensity of sugar beet nutrition and the balance among nutrients are important factors in obtaining high yields of sugar beets.

While critical levels have been widely used to identify nutrient deficiencies in commercial sugar beet fields, they appear to be an inadequate measure of good nutritional status of the sugar beet plant. Some modification of definition or levels should be made to increase the value of this technique.

The use of quality factors for nitrogen, phosphorus, and potassium in sugar beet petioles appears to provide a good means of appraising the quality of nutrition. This and techniques other than "critical levels" need further study and more precise definition for commercial field application.

Literature Cited

(1) GREGORY, F. G. 1937. Mineral nutrition of plants. Ann. Review Biochem. 6: 557-578.

(2) HADDOCK, JAY L. and DARREL M. STUART. 1964. Critical levels versus quantity-quality factors for assessing nutritional status of sugar beet plants. J. Am. Soc. Sugar Beet Technol. 13 (1): 42-58.

(3) HOAGLAND, D. R. and D. I. ARNON. 1938. The water-culture method for growing plants without soil. California Agric. Expt. Sta. Circ. 347.

(4) LUNDEGARDH, H. 1951. Leaf analysis, p. 46. Hilger and Watts Ltd. London, England.

(5) LUCAS, R. E., G. D. SCARSETH and D. H. SIELING. 1942. Soil fertility level as it influences plant nutrient composition and consumption. Purdue Univ. Agr. Exp. Sta. Bul. 468.

(6) MACY, PAUL. 1936. The quantitative mineral nutrient requirements of plants. Plant Phys. 11: 741-764.

(7) SCARSETH, G. D. and R. E. LUCAS. 1947. Potassium calcium and magnesium balance and reciprocal relationship in plants. Agron. J. 39: 887-896.

(8) SHEAR, C. B. and H. L. CRANE. 1946. Nutrient-element balance. A fundamental concept in plant nutrition. Proc. Am. Soc. Hort. Sci. 51: 319-326.

(9) SHEAR, C. B. and H. L. CRANE. 1943-1947. Nutrient-element balance. Yearbook of Agriculture pp. 592-601.

(10) SHIVE, J. W. and W. R. ROBBINS. 1939. Mineral nutrition of plants. Ann. Rev. Biochem. 8: 503-520.

(11) STEWARD, F. C. 1935. Mineral nutrition of plants. Ann. Review Biochem. 4: 510-544.

(12) TYNER, E. H. and J. R. WEBB. 1946. The relation of corn yields to nutrition balance as revealed by leaf analysis. J. Am. Soc. Agron. 38: 173-185.

(13) ULRICH, ALBERT, DAVID RIRIE, F. J. HILLS, ALAN G. GEORGE and MORTON D. MORSE. 1959. Plant analysis, a guide for sugar beet fertilization. Calif. Agr. Exp. Sta. Bul. 766.

(14) ULRICH, A. 1948. Plant analysis methods and interpretation of results. Diagnostic Techniques for Soils and Crops. Chap. IV American Potash Institute, Washington, D. C.

(15) ZHURBITSKII, Z. I. and WEN-HANG HUANS. 1962. Influence of nutrient solution concentration on absorption of mineral elements by plants. (Toane) Am. Institute of Biolog. Sci. 8: 468-474.