# Critical Levels Versus Quantity - Quality Factors for Assessing Nutritional Status of Sugar Beet Plants[1]

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*Received for publication September 30, 1963*

The ideal plant nutrient concentration and balance for sugar beet plant tissue has not been proposed. Many plant physiologists and agronomists, doubt the possibility of establishing stable reference values for plant nutrient concentration in specific plant tissue that will hold even in a restricted climate.

Much effort has been directed to find the kind and quantity of plant nutrients that must be added to soils to obtain high yields of high quality sugar beets. During the past forty years, sugar beet yields in most areas have shown a gradual increase. Unfortunately, during this same period there has been a persistent decline in quality. Even with the marked improvement in yield of roots per acre, many students of production problems feel that yield can be doubled and quality improved.

Before important additional progress can be made towards increasing yield and quality of commercial sugar beets by fertilization, it will be necessary to establish standards of reference that will sharply distinguish between well-nourished and inadequately nourished beet plants.

Goodall and Gregory (3)[3] discussed the relation of yield to nutrient supply and uptake and proposed the use of the term *intensity level.* They stated "For each factor in turn there is an *optimum level.* Growth is increased if intensity is brought to this level and decreased if raised further." Macy (8) proposed the concept of the "poverty adjustment zone" as a mechanism which may explain why nutrient composition of plant tissue may vary and growth be compensated for, by the relatively favorable effects of other factors. He further suggested the use of *critical* and *minimum* percentages as precise values of nutrient composition which set the upper and lower limits respectively of "poverty adjustment zone." He did not hold that the critical and minimum percentages of nutrients in plant tissue are invariable. Shear and Crane (11) observed that *"optimum nutritional status* as reflected by leaf analysis is different for each crop and standards of comparison must be set up for different tissues and for each crop." They (1943-47) further stated "The first and only infallible symptom of the deficiency of any element is evidenced by a reduced rate of growth."

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[1] Contribution from the Southwest Branch, Soil and Water Conservation Research Division, Agricultural Research Service, USDA, in cooperation with the Utah Agricultural Experiment Station, Logan, Utah. Utah Experiment Station Journal Paper No. 231.

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[3] Numbers in parentheses refer to literature cited.

Thomas (13) summarized his conclusions on the application of foliar diagnosis as a tool for diagnosing mineral requirement of plants by the statement "Soil and plant testing methods are necessarily valid only when each is used in a comparative manner and are usable only with a key or reference to some standard." Thomas (14) concluded that the use of limiting values of each nutrient is inadequate as a basis of ascertaining relationships of composition to yield. The most effective procedure is one that will give not only a quantitative measure of these nutrients present in the leaf at the moment of sampling, but in addition, an index of the qualitative relations resulting from their interactions. Thomas was of the opinion that there was no fundamental physiological experimental basis to support the use of tissues other than whole active leaves.

Ulrich (17) combined Macy's minimum percentage and critical percentage into one value which he identified as *critical level*. He identified this concentration of plant nutrients by saying "When the nutrient concentrations of the plants are above the critical level and remain there throughout the entire growth period, there is very little chance of a response in growth from addition of more nutrients." Ulrich, et al. (18) proposed the following critical levels for sugar beet petioles from recently matured leaves: nitrate-nitrogen 1,000 ppm, phosphorus 750 ppm and potassium 10,000 ppm. These values were proposed for a 2 percent acetic acid extract of oven-dry, finely-ground leaf petioles.

Many students of sugar beet production problems believe that the most immediate and significant advance in yield and quality of sugar beets can be obtained by improving the nutritional conditions in commercial fields. The authors approached a study of this problem with the following assumptions which they obtained from a review of available literature on methods of appraising nutritional status of plant:

1. There is an established casual relationship between internal nutrient concentration and plant growth.

2. The pot culture method in which root temperatures are maintained in a manner similar to that found in commercial sugar beet fields, provides the most rapid and convenient approach to the identification of the optimum mineral nutrition of sugar beets.

3. Those sugar beet plants which make the best growth must be the best nourished. An adequate nutrition must be the best balanced nutrition.

4. If there is a well-defined minimum percentage of mineral element in plant tissue there must also be an optimum percentage.

A study of the available literature led the authors to select the Ulrich (17) technique and a modification of the Thomas (13) procedure as the most fruitful methods for diagnosing nutritional status of sugar beet plants.

The data presented in this paper are the result of an attempt to determine which of the two methods under observation was more suitable as a basis for diagnosing significant nutritional disturbances in sugar beets. A second closely related objective was to observe the optimum nutrient concentration and balance of the three primary plant nutrients, nitrogen, phosphorus, and potassium, in sugar beet petioles conducive to high yields of roots and sugar.

## Methods and Procedure

While ten nutrient solutions were used in this study, only six of these are referred to in this paper in order to simplify presentation of data (Table 1). All of these were modifications of Hoagland's (6) nutrient solution No. 1. The nutrient solutions were made with tap water which contained 0, 2, 16, 44 ppm of K, Na, Mg and Ca, respectively, and further modified by the vermiculite substratum which at equilibrum with the water provided 18, 5, 19, and 46 ppm of K, Na, Mg and Ca, respectively. These concentrations were constantly being modified by nutrient solution additions, unequal water and plant nutrient withdrawal, and chemical precipitation. Ten-gallon cans filled with No. 2 vermiculite were buried in soil to within 1 inch of the top rim in order to maintain root temperatures comparable to normal soil temperatures. Five holes were punched in the bottom of each can to provide adequate drainage. Twenty sugar beet seeds of a commercial monogerm variety, SLC 126, were planted April 15, 1960. These were thinned June 29, to leave a final stand of three plants per can. There were ten cans in each treatment which were randomized in each row. The cans were spaced on 40-inch centers so that each pot had 11 sq ft of surface. The nutrient solutions were prepared similarly all season except for treatment Check-N which was reduced in nitrogen to one-half normal concentration on September 1 and to zero nitrogen October 1. One gallon of each nutrient solution was applied to its respective can daily, except during hot weather in mid-July and mid-August when one and one-half gallons were used.

Thomas (14) believed it incongruous to use plant tissue other than whole leaf tissue as a basis for characterizing nutritional status of plants. Nevertheless, in order to extend the comparison of the Ulrich and Thomas techniques the authors modified the Thomas procedure to include soluble extract of beet leaf petioles as well as total composition of leaf blades.

Quantity and quality factors are expressed in this paper in terms of milliequivalents per 100 grams of oven-dry plant tissue. To express the intensity of nutrition on a quantitative basis, the milliequivalents per 100 grams of N + P + K are summed. The quality nitrogen value is expressed as a percentage of the total, e.g. $\frac{\text{N in meq / 100 g} \times 100}{\text{N + P + K in meq / 100g}}$ = N quality. When leaf blades were used, these plant nutrient values were expressed on the basis of total composition. When sugar beet petioles were used, the quantity and quality factors were calculated from the concentration of soluble nitrogen ($NO_3$ — N + organic — N + $NH_4$ — N) phosphorus and potassuim in acid extract (1 gram petiole tissue oven dried at 70° C, ground to pass 40 mesh sieve and extracted with 100 ml solution.) The general outline of the Ulrich (17) technique was used.

Leaf blades and petiole samples from the most recently matured leaves were obtained from each plant every two weeks beginning July 1. These tissues were dried rapidly at 70° C, ground to pass a 40-mesh screen, and examined chemically to determine the concentration of acetic acid soluble nutrients in petioles.

The 2 percent acetic acid extract (1 gram of plant tissue per 100 ml of solution) from petioles was analyzed for nitrate-nitrogen using the dephenylamine spot plate method. Soluble ammonia and organic-nitrogen were obtained by the Hillebrand, et al. (6) procedure. Total nitrogen was determined in leaf blades by Perrin's (9) method. Phosphorus was determined in both leaf blades and petioles by Barton's (2) procedure. The flame photometer, direct intensity method, was used for potassium determinations. Sucrose and purity were determined on the sugar beet pulp, obtained with the Keil rasp, by the cold water digestion Sachs-Le Docte method.

## Experimental Results

### *Yield and Quality of Sugar Beets as Affected by Nutritional Environment*

The data on the yield of sugar beet roots are presented in Figure 1[4]. Treatments $NH_4$, 1/4 N and Low K, gave root yields significantly lower than Check-N treatment, and the 1/2 N and 1/2 K treatments showed a strong tendency for reduced growth.

[4] Duncan's multiple range test for a comparison of six means at the .05 level of significance is used throughout this paper.

The nutritional environments used in this study exerted as much or greater influence on the yield of tops as on roots as shown in Figure 2. When yield of roots and tops are graphed in ascending arrangements as in Figures 1 and 2, it will be noted that the relative growth rates of roots and tops are affected differently by different nutrient solutions. However, four treatments giving the lowest root growth also gave the lowest top growth. The top growth from treatment 1/2 K was significantly greater than from 1/2 N, $NH_4$, Low K, and 1/4 N.

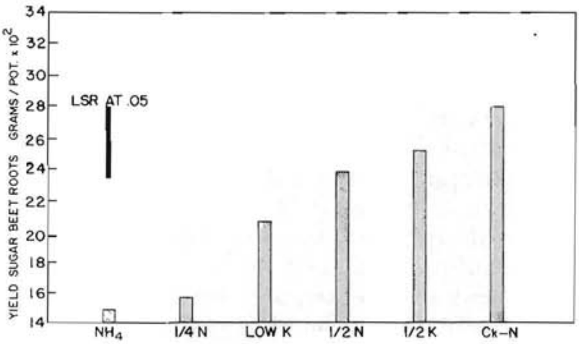


**Figure 1.—Yield of sugar beet roots as affected by nutritional environment 1960.**

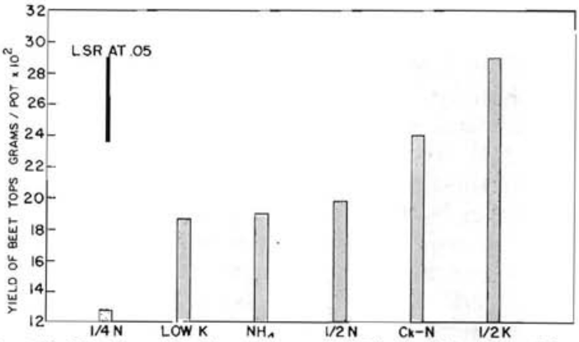


**Figure 2.—Yield of sugar beet tops as affected by nutritional environment 1960. (Fresh weight.)**

The yield of gross sugar may be of greater significance than either yield of roots or tops as an indication of the influence of nutritional environment on total growth rate. These data are shown in Figure 3. Again, four of the five nutritional treatments adversely influencing yields of roots were responsible for depressed yields of sucrose when compared to Check-N treatment. The 1/2 N treatment did not depress yield of gross sugar significantly below Check-N, however, the trend for this treatment was strongly in the direction of depression.

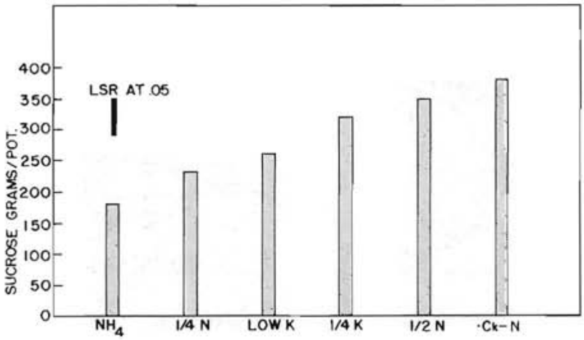


Figure 3.—Yield of sugar as affected by nutritional environment 1960.

### *Yield and Quality Related to Critical Nutrient Level*

The concentrations of the three primary plant nutrients, in recently matured leaf petioles, are shown in Figures 4, 5, and 6. It is obvious from the graphical data in Figure 4, that the nitrate-nitrogen concentration in sugar beet petioles was above the critical level for all treatments. The ¼ N treatment reached the critical level at two sampling periods but was not below it at any time.

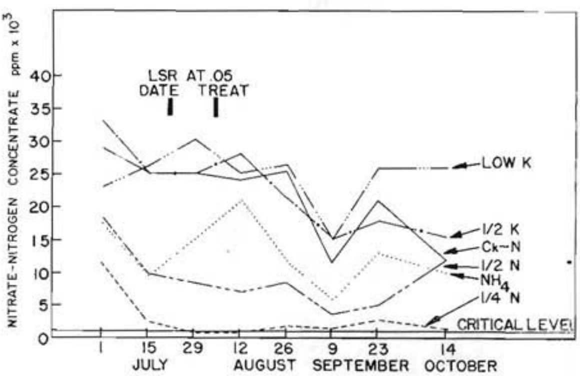


Figure 4.—Seasonal concentration of nitrate nitrogen in sugar beet petioles as influenced by nutrient environment 1960.

The graphical representation of the phosphorus concentration in sugar beet petioles as given in Figure 5 shows adequate nutrition with respect to this nutrient for the six nutrient-cultured plants.

The seasonal potassium concentration in sugar beet petioles shown in Figure 6 suggests that all plants were well supplied with this nutrient.

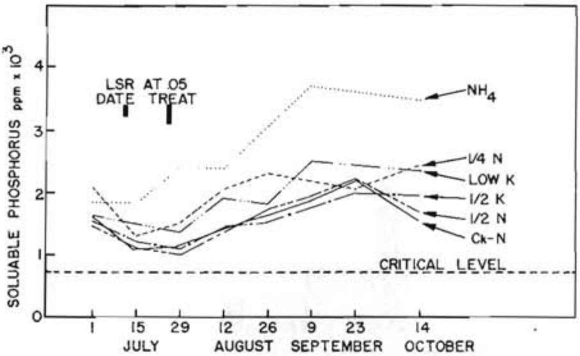


Figure 5.—Seasoal soluble phosphorus concentration in sugar beet petioles as influenced by nutritional environment 1960.

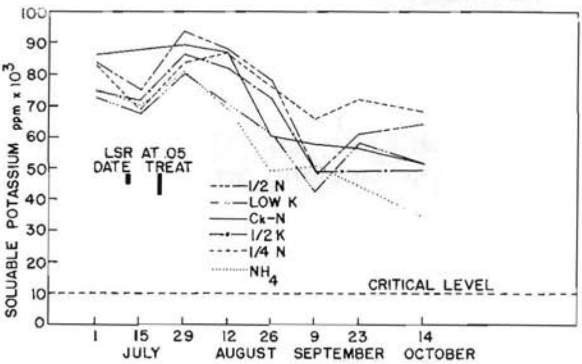


Figure 6.—Seasonal soluble potassium concentration in sugar beet petioles as influenced by nutritional environment 1960.

*Quantity factor of nutrition in beet petioles*—The data in Figure 7 for quantity factor for soluble constituents in sugar beet petioles are plotted by line graphs and cover the period from July 1 to harvest. The solid horizontal lines represent the extremes in seasonal variation for intensity of nutrition for well-nourished sugar beet plants. These arbitrary boundaries appear to serve the useful purpose of separating well-nourished from inadequately-nourished plants. The seasonal range is established on the basis of the composition of sugar beet plants growing in the Check-N treatment (Hoagland's ½ strength solution depleted in nitrogen to 50 ppm of nitrate-nitrogen from September 1 to October 1 and devoid of nitrogen after October 1). Three treatments (½ N, $NH_4$, and ¼ N) produced plants with quantity below desirable limits.

*Quality factor for nitrogen in beet petioles*—The graphical data in Figure 8 represent the quality factor for nitrogen. It is

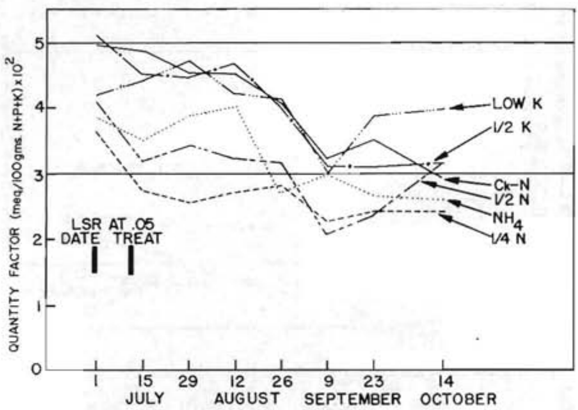


**Figure 7.—Seasonal quantity factor of sugar beet petioles as affected by nutritional environment 1960.**

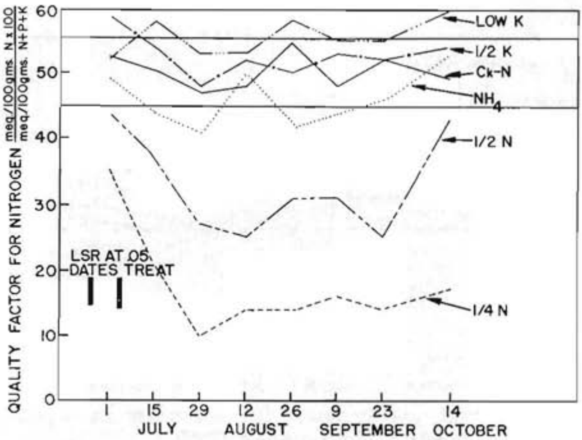


**Figure 8.—Seasonal quality factor for nitrogen in sugar beet petioles as influenced by nutritional environment 1960.**

noted that two treatments (¼ N and ½ N) are well below the boundary limits. Only the Low K treatment produced plants frequently above desirable limits. The ideal for nitrogen quality appears to be about 50. However, a seasonal range between 45 and 55 is characteristic of well-nourished plants.

*Quality factor for phosphorus nutrition in beet petioles*—The data in Figure 9 show the phosphorus quality factor in petioles from the Check-N treatment to vary from 2.5 to 6 throughout the season. The composition of petioles from the ½ K treatment is close to these same values. If these are ideal values, it is evident

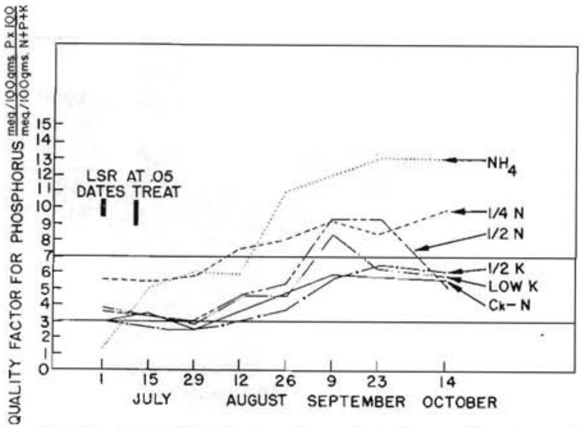


Figure 9.—Seasonal quality factor for phosphorus in sugar beet petioles as influenced by nutritional environment 1960.

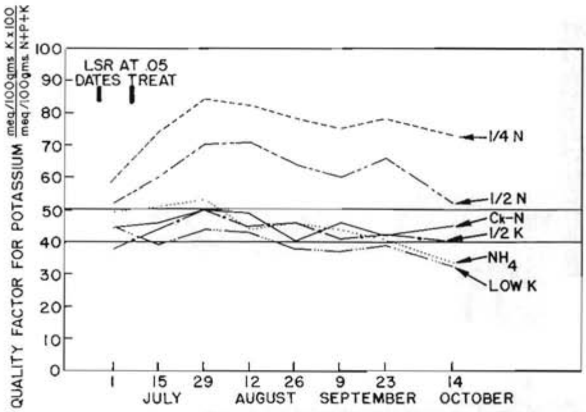


Figure 10.—Seasonal quality factor for potassium in sugar beet petioles as influenced by nutritional environment 1960.

that leaf petioles from treatment ½ N, ¼ N and $NH_4$ and to some extent Low K had excessive concentrations of phosphorus.

*Quality factor for potassium nutrition in beet petioles*—The data in Figure 10 show the ideal seasonal range in quality factor for soluble potassium in beet petioles of well-nourished plants to be between 40 and 50.

*Quantity factor of nutrition in beet leaf blades*—Data showing the seasonal quantity factor for sugar beet leaf blades are given in Figure 11. While there were differences between treatments, none varied widely from the Check-N treatment. The ideal quantity factor for leaf blades appears to have a seasonal variation between 400 and 500 meq per 100 grams in dry leaf blade tissue.

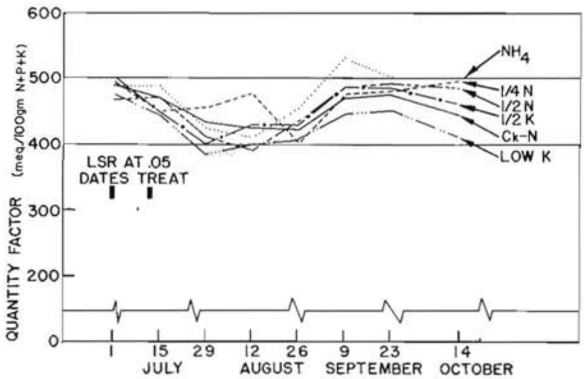


Figure 11.—Seasonal quantity factor of sugar beet leaf-blades as affected by nutritional environment 1960.

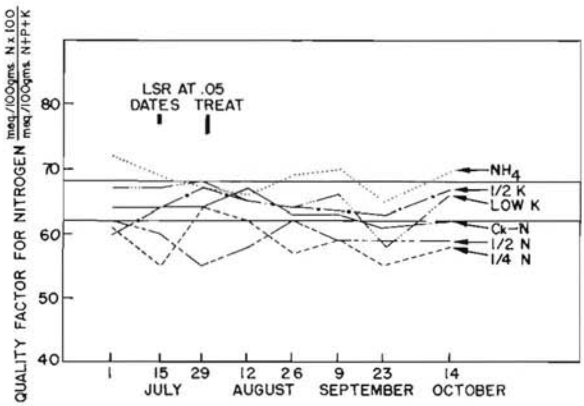


Figure 12.—Seasonal quality factor for nitrogen in sugar beet leaf-blades as affected by nutritional environment 1960.

*Quality factor for nitrogen in sugar beet leaf blades*—The data for nitrogen quality in Figure 12 clearly show that treatments ¼ N, and ½ N were low in nitrogen. None of the other treatments can be identified as being out of nitrogen balance.

*Quality factor for phosphorus in sugar beet leaf blades*—The graphical data in Figure 13 indicate that two treatments, $NH_4$ and Low K, produced plants which contained relatively high concentrations of leaf phosphorus.

*Quality factor for potassium in sugar beet leaf blades*—The graphical data in Figure 14 clearly segregate plants from treatments $NH_4$, Low K, ¼ N and ½ N as being too high or too low in potassium for ideal growth, relative to treatment Check-N.

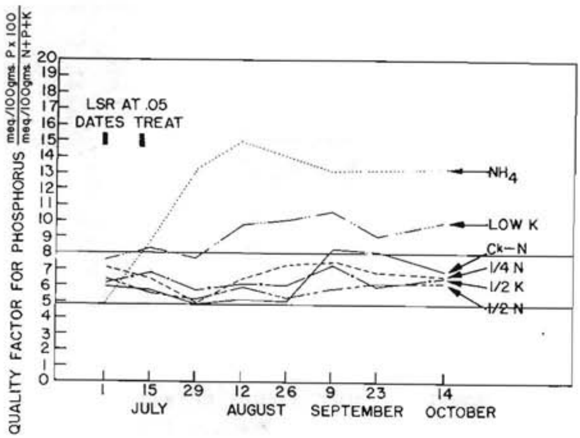


Figure 13.—Seasonal quality factor for phosphorus in sugar beet leaf-blades as affected by nutritional environment 1960.

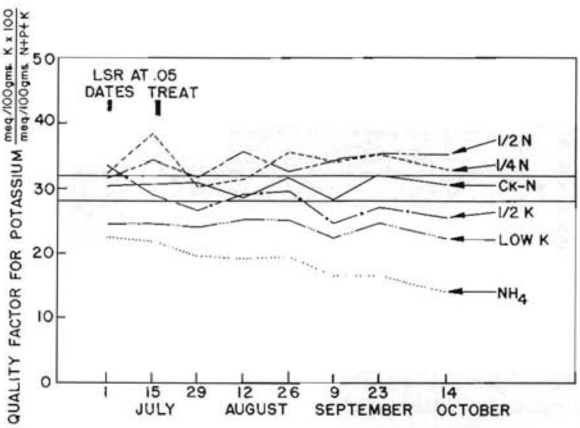


Figure 14.—Seasonal quality factor for potassium in sugar beet leaf-blades as affected by nutritional environment 1960.

*Nitrogen : Potassium ratio in beet leaf blades*—The data in Figure 15 showing the seasonal nitrogen : potassium ratio in sugar beet leaf blades indicate that this factor is remarkably sensitive to nutritional disturbances in the sugar beet plant. It is a simple matter to identify plants with nutritional disturbances by this method, if one can safely assume that the treatment Check-N is an ideal nutrient culture for the sugar beet plant.

*Nutrient Quantity and Quality Values*—The data in Table 2 represent a summary of tentative quantity and quality values which appear best suited for maximum growth of sugar beet roots and yield of sugar. Further study may result in confirmation or

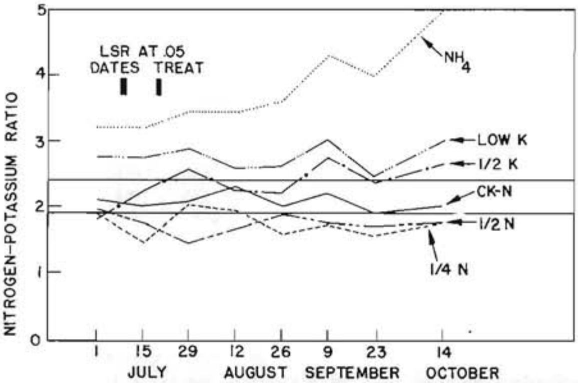


**Figure 15.—Seasonal nitrogen:potassium ratio in sugar beet leaf-blades as affected by nutritional environment 1960.**

modification of these tentative references. It is possible that a study of other sugar beet varieties or significant climatic changes from those involved in this study might dictate small modifications of these suggested values.

## Discussion

The authors have used the Ulrich (17) procedure for a number of years as a means of identifying the nutrient status of sugar beet plants grown under field experimental conditions. It has served a very good purpose under conditions where nutrient compositions among plants varied widely.

Yield data in Figures 1, 2 and 3 show that relatively minor variations in available nutrients, nitrogen and potassium, may result in significant yield differences. While phosphorus was applied to the six treatments in equal concentrations, the presence of variable concentrations of nutrients other than phosphorus, physiological changes in the substrate modifying the pH, and variable root and top productions resulted in a significant range in phosphorus concentration in plant petioles (see Figure 5).

Commercial sugar beets generally will show a wider seasonal fluctuation in nutrient composition than did these six nutrient-cultured beets. Nevertheless, since factors other than available nutrients were kept uniform and since significant yield differences were obtained among treatments, plant material from this study appeared to be suitable for a comparison of *critical level* and *quantity-quality factor* methods.

It is obvious that the critical level for nitrate-nitrogen shown in Figure 4 would have to be raised above 1,000 and probably up to 5,000 ppm in order to properly identify plants with the minimum of nitrogen nutritional disturbance which could be

Table 1.—Nutrient concentration in various nutrient solutions, 1960.

| No. | Description | Parts per million of various nutrients[1] | | | | | | | pH |
|---|---|---|---|---|---|---|---|---|---|
| | | $NO_3$-N | $NH_4$-N | P | K | Ca | Mg | Na | |
| 1 | Check-N<br>½ N Sept. 1 to Oct. 1<br>No N Oct. 1 to Oct. 15 | 105 | ---- | 15 | 110 | 145 | 50 | 18 | 7.6-8.0 |
| 2 | ½ K | 105 | ---- | 15 | 55 | 165 | 50 | 18 | 7.7-8.0 |
| 3 | Low K | 105 | ---- | 15 | 15 | 205 | 50 | 18 | 7.6-8.1 |
| 4 | ½ N | 70 | ---- | 15 | 110 | 145 | 50 | 18 | 7.8-8.1 |
| 5 | ¼ N | 30 | ---- | 15 | 110 | 145 | 50 | 18 | 7.7-8.0 |
| 6 | $NH_4$ | ---- | 75 | 15 | 110 | 145 | 50 | 18 | 7.4-6.0 |

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

Table 2.—Nutrient quantity and quality values for sugar beet leaf blades and leaf-petioles which resulted in maximum sugar yields.

| Factors | Leaf blades | | Leaf petioles | |
|---|---|---|---|---|
| | Range | Ideal | Range | Ideal |
| Quantity Factor med/100g | 400-500 | 450 | 300-500 | 410 |
| Quality Factors | | | | |
| Nitrogen | 62-68 | 65 | 45-55 | 50 |
| Phosphorus | 4.8-8.0 | 6.4 | 3-7 | 5 |
| Potassium | 28-32 | 30 | 40-56 | 45 |
| N:K ratio | 1.9-2.4 | 2.15 | 0.9-1.4 | 1.1 |

identified as affecting root yield. The low yield performance of plants grown in treatment ¼N as shown in Figures 1, 2, and 3 is closely associated with, if not a result of, low nitrogen content of leaf petioles. Present standards of critical levels (18) do not clearly identify these plants as nitrogen deficient.

Critical levels are not helpful in identifying nutritional disturbances related to phosphorus in this study.

It does not appear possible to identify any of the petiole tissue in Figure 6 as manifesting chemical composition symptoms of potassium nutritional disturbance. A review of the data in Table 1 and Figures 1, 2 and 3 would impress one that the reason for poor performance of plants in Low K treatment must be related to inadequate potassium, but deficiency of potassium is not evident in the data in Figure 6.

The data on quantity factor, shown in Figure 7, throw some doubt on the nutritional adequacy of petiole tissue from three treatments, viz. ¼ N, $NH_4$ and ½ N if the arbitrary bracket lines are accepted as including optimum intensity of nutrition.

The graphical data in Figure 8 lend support to the statement by Thomas, et al., (16) "Foliar diagnosis can be a more accurate index of the effect of a fertilizer than are yields." While the yield of sugar from treatment ½ N was not significantly different from that of Check-N, the quality factor for nitrogen suggests the possibility of slight inadequacy in nitrogen all season.

The authors do not have clear-cut evidence that a relatively high concentration of phosphorus is detrimental to growth of sugar beets. It is evident, however, that high quality factor for phosphorus is associated with low production performance in the case of $NH_4$ and ¼ N treatments in Figure 9. Goodall and Gregory (3) in discussing the relation of yield to nutrient uptake state, "For each factor in turn there is an optimum level. Growth is increased if intensity is brought to this level and decreased if raised further."

The data in Figure 10 direct one's attention to the high rather than low relative concentration of potassium with particular reference to treatments ¼ N and ½ N. Thomas (15) observed in his studies ". . . when out of physiological balance luxury consumption will occur. Luxury consumption results in disturbances of normal metabolism sufficient to affect growth and reproduction."

In a discussion of the functional aspects of mineral nutrition of green plants Pirson (10) states "It has not yet been clarified whether excess of an element causes disturbances which represent direct and specific consequences of this particular excess within the cell or whether they are dependent upon the exclusion of another element in the simplest case according to the pattern of competitive inhibition."

The authors do not know whether the relatively high nitrogen found in petioles from Low K treatment (Figure 8), and high phosphorus in petioles from treatments $NH_4$, ¼ N and ½ N (Figure 9) were the result or cause of yield disturbances. Some students of plant nutrition (1,4,5,7) believe an excess of specific nutrients may be as harmful to growth processes as is a deficiency. If this be true, the use of the *quality factor* concept may be a valuable tool in diagnosing nutritional disturbances.

The graphical data shown in Figures 11 to 14 were obtained according to Thomas' (13) proposals with the following modifications: (A) phosphorus and potassium were considered on the elemental rather than oxide basis throughout and (B) the quantity factor was calculated on the basis of milliequivalents of each nutrient per 100 grams of dry plant tissue rather than percentage of N, $P_2O_5$ and $K_2O$ in dry plant tissue.

The data in Figure 11 do not clearly indicate intensity of nutrition as a serious problem in any of the nutrient solutions under observation in this study. This criterion of nutritional intensity disturbance may be more useful in identifying difficulties among commercially grown beets than among experimentally grown plants with a limited range in nutritional intensity.

The quality factors for nitrogen in leaf blades shown in Figure 12 emphasize that plant tissues from treatments ¼ N and ½ N are inadequately supplied with nitrogen most of the season. Conclusions reached from a study of these data are similar to those drawn from a study of the petiole data in Figure 8.

Quality factor data for phosphorus presented in Figure 13 indicate that tissues from the two treatments $NH_4$ and Low K may have luxury-consumed phosphorus. This is concluded from the fact that these treatments gave low production performance and therefore that phosphorus at levels found in tissue from these treatments was not required for rapid plant growth.

Graphical data on quality for potassium are shown in Figure 14. It is obvious that treatments $NH_4$ and Low K produced leaf blades low in potassium and treatments ¼ N and ½ N produced tissue high in potassium relative to that found in leaf blades from Check-N treatment. It may be of passing interest to note that high seasonal potassium values for treatments ¼ N and ½ N were clearly segregated in petiole tissue (Figure 10) while low potassium values for $NH_4$ and Low K treatments were distinctly separated in leaf blades (Figure 14). There are some discrepancies between the conclusion and interpretations one would make from the chemical compositions of petiole and blade tissues. In most cases these differences in interpretation appear to be in the realm of degree of deficiency or excess rather than adequate or inadequate balance. However, the graphical data showing quality factor for phosphorus indicate that it is too high in leaf blades (Figure 13) and about right in leaf petioles (Figure 9). The authors have no satisfactory explanation for this particular discrepancy.

While Thomas (13) did not propose the use of nitrogen : potassium ratios as an essential feature of his *foliar diagnosis*, the authors have included Figure 15 as a supplement to the Thomas method. The graphical data in Figure 15 are calculated from data already available in the development of this method. Arbitarary boundary lines are used in Figure 15 to include the eight seasonal values for nitrogen : potassium ratio of leaf blades from treatment Check-N. This graphical analysis indicates that leaf blade tissue from treatments $NH_4$ and Low K is too high and from treatments ½ N and ¼ N too low in N:K ratio. It throws some doubt on treatments ½ K. Thus it may be possible to identify a wide range of variation in the nutritional disturbance of sugar beets in one graph, when it is certain that only the two nutrients, nitrogen and potassium, are involved.

## Conclusions

The critical level procedure as proposed by Ulrich (17) for diagnosing nutritional disturbances in the sugar beet has been demonstrated to be a useful tool in commercial fields. In its present form and for nutrient culture studies this technique appears to lack sensitivity. Pot culture studies revealed that concentrations of plant nutrients in plant tissue may be considerably above proposed critical levels and yet not high enough to support maximum yield of roots and sugar.

A modification of the Thomas (13) method appears to be well suited to the diagnosis of nutritional disturbances which adversely influence yield of sugar beet roots and sugar. Not only is the quantity-quality technique sensitive as a measure of minimum concentrations which limit plant performance, but it appears to be suitable as a device for the recognition of luxury consumption of plant nutrients.

It appears from this limited study that the essential nutrient concentrations in plant tissue responsible for optimum production of plant material may be relatively narrow.

Additional study is needed to determine more precisely the influence of season and a wide range in nutrient availability on plant performance and composition.

## Acknowledgements

The authors are indebted to California Chemical Company for financial assistance in conducting this study.

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