Plant Analysis as a Guide to the Nutrition of Sugar Beets in California[1]

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Progress in the development of plant analysis as a guide to the fertilization of sugar beets rests primarily upon improvements in technique and upon the philosophy associated with the interpretation of the results. Without a satisfactory technique the analytical results are worthless, and even when the analytical values are estimated accurately, they have little meaning unless they can be interpreted in terms of the nutrient status of the crop. It is with these purposes in view that much of the research in plant analysis has been directed.

The early investigations in the use of plant analysis as a guide to the fertilization of sugar beets were based upon sampling procedures and analytical methods developed primarily for other crops (Chapman (2)[3], 1935, Emmert (4), 1934, Thornton (13), 1932, (14) 1933). These methods, with modifications were applied with success by Gardner and Robertson (6), 1935, in Colorado to sugar beet petioles collected from mature leaves of beets in a fertilizer experiment conducted in small plots designed to test the effectiveness of nitrogen, phosphorus and manure on beet growth. They concluded that the petiole test was sufficiently accurate to be applicable to determining the nitrate, phosphate and potassium needs of the soil. With this incentive as a background many experiments have been conducted in our laboratories to improve the methods of analysis, to ascertain the part of the beet leaf (petiole or blade) suitable for analysis, to establish the position on the plant from which to take the sample, to determine the time and frequency of collecting the leaf samples and finally to select the form of each element for analysis which reflects accurately the nutrient status of the beet plant. In other laboratories Brown (1), 1943, concurred with our findings regarding the type of petiole suitable for sampling, while the number of petioles recommended by him for a sample was considerably higher than used in our investigations.

While progress in the experimental technique for applying plant analysis to the solution of nutritional problems with sugar beets has been considerable, developments in the interpretation of the results are not easy to evaluate. A number of workers studying primarily crops other than sugar beets, have presented several interesting viewpoints. Some of these ideas have been mentioned briefly in a review that has appeared recently (Goodall and Gregory (7), 1947, while contrasting theories have been given in

[1]The experiments of the nitrogen series reported in this paper are part of a study being conducted in cooperation with The Spreckels Sugar Company and the International Minerals and Chemical Corporation. Grants-in-aid were received from The International Minerals and Chemical Corporation for the chemical analyses of the petioles from the nitrogen experiments.

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[3]Numbers in parentheses refer to literature cited.

articles by Thomas (12), 1937, Macy (9), 1936, Lundegardh (8), 1941, Clements and Kubota (3), 1943, Ulrich (15), 1943, and in press 1948) and Shear, Crane and Myers (10), 1946.

Of the many concepts of plant analysis which have appeared from time to time, the one centering about the ideas associated with "limiting factors" appears from many aspects to be the most fruitful. This concept in the main, states that increases in yield or growth are obtained from the addition of the factor that is limiting growth. Strict adherence to this theory is not possible because we know that the severity of some of the deficiencies may be modified by accompanying factors. Thus the addition of sodium to a nutrient medium deficient in potassium will enhance the growth of beets initially devoid of sodium. However, sodium in itself will on the average substitute for only a part of the potassium, and thereafter, potassium additions are necessary for more growth. Similar modifications of growth most likely occur for other nutrients, but essentially, the major increases in growth take place only after the addition of the factor that is deficient. This modified theory of "limiting factors" also applies when two or more deficiencies occur at the same time. When this happens major increases in growth take place only by correcting both deficiencies simultaneously, and thereafter, further additions of the factor or factors have no large effect upon the growth of the crop.

Theoretical Considerations

Plant Nutrient Equation.—The nutrient concentration found within the plant or in any one of its parts is an integrated value of all the factors that have influenced the nutrient concentration of the plant up to the time of taking the sample. These factors may be listed as follows: soil (S), climate (CL), time (T), plant (P), management (M) and possibly others. Their relationship to the nutrient concentration (X) of the plant may be readily visualized in the following generalized equation:

$$X = f(S, P, CL, T, M \ldots\ldots\ldots\ldots)$$

From an inspection of the equation one can readily see that the nutrient concentration of the soil is just one of the many factors that influences the nutrient concentration of the plant. Not only must the concentration of nutrients in the soil be evaluated carefully before an estimate of its supplying power for nutrients can be made correctly, but other soil factors such as its depth, texture, organic matter, pH, aeration, drainage, etc , should be considered in terms of fertility at the same time. In this evaluation of the nutrient concentration of the soil it is obvious that shallow soils must have higher nutrient concentrations than deep soils in order to support plants of comparable yields. An important factor, too, is the plant itself, particularly the quality and extent of the root system. Plants with roots of high foraging capacity will obtain more nutrients from a given soil than from one with a restricted root system of low activity. Likewise plants which are in a favorable climate will require more nutrients than one growing in an unfavorable environment. Soils with low nutrient concentrations would supply an adequate quantity of nutrients when the demand for nutrients was low during poor growing conditions, but would fail to do so under conditions of good growth. Complicated as these relationships are, they become still more so when the grower introduces his cultural practices on the field when plowing, cultivating, irrigating, liming, cover cropping and fertilizing. Thus, it is no wonder that a simple estimation of the nutrient concentration of the soil often fails to evaluate the fertilizer requirements of a soil correctly. In contrast to *soil analysis,* the analysis of *plants* gives an integrated value of the effects all factors have had upon the nutrient concentration of the plant up to the time of taking the samples. All that remains to be done from the practical point of view is to find a way to interpret the results of the plant analyses so that the necessary changes in the nutritional program for the crop can be introduced effectively during the current growing season or for subsequent crops on the same field.

Essential Elements.—Before attempting to interpret the results of plant analysis it is well to pause briefly to reflect upon the relationship of the nutrient elements to plant growth. Through numerous experiments plant physiologists over a period of years have established that certain elements are essential for growth. Without these elements growth decreases and finally fails completely during the vegetative or reproductive cycle of the plant. When an element has been found to be essential for growth, it must be contained within the plant itself, otherwise the element would not be essential. The exact concentration of the element required for growth will depend upon its function in the physical and chemical processes of the plant. Whether this concentration fluctuates within narrow or wide limits will again depend upon its function. Until the function of each element is clearly known, the practicality of plant analysis must be ascertained empirically through the comparison of nutrient concentrations of plants restricted in growth to those not so restricted in growth by a given nutrient. By such comparisons or correlation studies the "critical nutrient" levels for each element and for each crop can be established.

The Critical Nutrient Level.—For a given nutrient the critical nutrient level may be defined as that range of concentrations at which the growth of the plant is restricted in comparison to those plants at a higher nutrient level. Whether the critical level is a relatively narrow range of values or fluctuates widely is still a subject of investigation both under greenhouse and field conditions. Thus far, the evidence indicates that for sugar beets the critical levels for nitrogen, phosphorus and potassium fluctuate over a relatively narrow range of values in comparison to the nutrient concentrations that have been observed for beets above the critical level. While preliminary data obtained in the field support these observations, much more evidence is needed over a period of years before the critical nutrient levels for sugar beets grown in the field can be estimated correctly.

Probability of Response.—When plants are grown under field conditions the likelihood of getting a growth response from the addition of a nutrient to the soil will depend upon whether the nutrient concentrations of the plants are above or below the critical level. When the nutrient concentrations of the plants are above the critical level and remain there throughout the entire growth period of the plant, then there is very little chance of getting a response in growth by adding more nutrients. Conversely, when the nutrient concentrations of the plants fall below the critical level, then the chance of getting a growth response under field conditions increases rapidly as the nutrient concentrations in the plants decrease. The magnitude of the response will depend upon the relative abundance of the other growth factors and upon the time and duration of the deficiency. When the relative abundance of the other growth factors is great, then the addition of the deficient nutrient will result in a relatively large increase in yield. However, when another factor or set of factors soon become limiting, then upon the addition of the required nutrient, the yield increases will be relatively small. This small increase in yield will not be detected unless the error of the experiment is very low. Similarly, the chance of getting a measurable growth response in the field will decrease as the duration of the deficiency decreases and the later in the growing season the deficiency first appears.

Estimation of the Critical Nutrient Level

Through Pot Experiments.—A preliminary estimate of the critical nutrient level for a given element and crop may often be obtained by growing plants in pots of soil known to be deficient in a given nutrient. Such an experiment was started on April 29, 1947, with sugar beets of the U. S. No. 15 variety on a soil known to be deficient in phosphorus.[4] When these beets were harvested on September 2, 1947, the recently "matured" leaves were taken from the tops (figure 1), separated into petioles and blades and then dried in a forced-draft oven maintained at 70 degrees C. The dried plant material was ground in a Wiley mill to pass a 40-mesh sieve and analysed for phosphate soluble in 2 percent acetic acid, for potassium (Ulrich (16), 1945) and for nitrate-nitrogen (unpublished procedure). The analytical values are expressed on the dry basis for phosphate in parts per million of phosphorus, nitrate in parts per million of nitrogen and potassium in percentage. The beet yields are for beets topped at the first leaf scar and are given on the fresh basis throughout.

[4]For the experiment 30.0 pounds of uniform soil were placed into 5-gallon pots provided with pans for the return of the drainage water. The soil for the pots was obtained from the vicinity of Paradise, California, and is classified as Aiken clay. This soil is extremely deficient in phosphorus and in order to get beets to grow on it beyond the early two-leaf stage it was necessary to add a small amount of phosphorus to the soil. The amount of treble super-phosphate used in this treatment as well as in the other treatments are given in table 1. On May 24, 1947, when the plants were still in the early two-leaf stage the phosphorus required for each pot was applied between the plants to the bottom of trenches from 1 to 2 inches deep. Nitrogen from ammonium nitrate was applied at the rate of 2.8 grams of N per pot (280 pounds N per acre of surface) on June 3, 1947, and again on July 25, 1947, at the rate of 3.5 grams per pot (350 pounds per acre). When the plants were in the late two-leaf stage they were thinned to four plants to a pot. These plants grew well and continued to do so until those with the low phosphorus applications showed definite signs of reduced growth accompanied by a deep greening of the leaf blades. These were the main signs of stress shown by the plants except during the cotyledon stage when phosphorus-deficient plants had a reddish caste and when in the later stages of growth an occasional leaf blade showed some purpling or reddening between the veins or a darkening of the veins. At the time of harvest on September 2, 1947, a few of the plants in about half of the pots with the three highest phosphorus treatments had developed leaf symptoms similar to potassium deficiency, which in a few instances was confirmed by leaf analysis.

Figure 1.—Selection of sugar beet leaves for analysis. A leaf stalk from any one of the recently "matured" fully expanded leaves marked "A" in the photograph may be included in the plant sample. Avoid the small leaves in the center or the old leaves of the outer whorls of the plant.

Of major interest from the standpoint of plant analysis are the results illustrated graphically in figures 2 and 3. In figure 2 in which the soluble phosphate-phosphorus values of the leaf petioles are plotted against the corresponding yields, the beet yields increase sharply with the additions of phosphorus to the soil, while at the same time the phosphorus concentrations in the petioles fail to increase. In this portion of the curve the yields increase directly in relation to the quantity of phosphorus the plants can obtain from the soil. Then as more phosphorus is added to the soil the yields and phosphorus concentrations within the petioles increase simultaneously until the critical level of 600-800 parts per million is attained. Thereafter the soluble phosphate-phosphorus concentrations increase in the petioles of the beets without a corresponding increase in yield. In figure 3, in which the soluble phosphate-phosphorus concentrations of the leaf blades are compared with the yields, the results are much the same as in figure 2, except that here the zone in which the yields and phosphorus concentrations increase simultaneously is much broader than when the petioles are analysed (figure 2). Accordingly, from the diagnostic point of view the petioles would serve

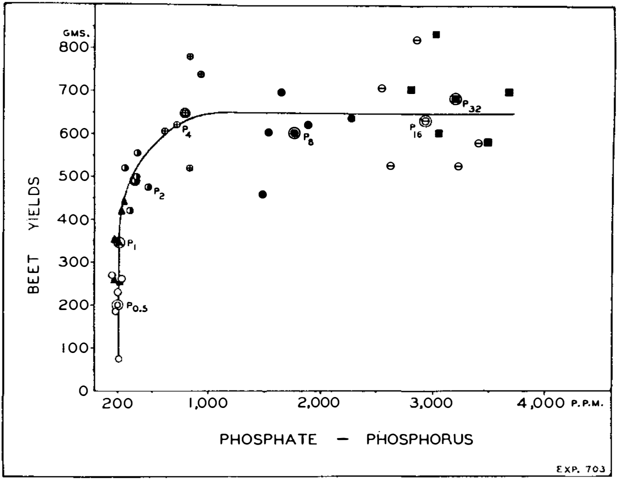

Figure 2.—Relationship of beet root yields (fresh basis) to the concentration of phosphate phosphorus (dry basis) in *petioles* of recently "matured" leaves. $P_1 = 1.00$ grams P_2O_5 (2.27 grams treble superphosphate) per pot or 100 pounds P_2O_5 per acre. The points which are circled represent average values for a treatment.

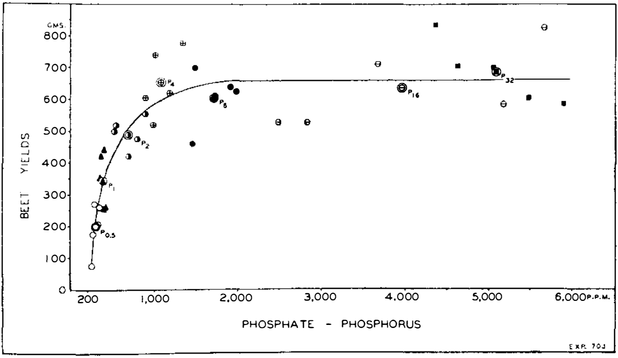

Figure 3.—Relationship of beet root yields (fresh basis) to the concentration of phosphate phosphorus (dry basis) in *blades* of recently "matured" leaves. $P_1 = 1.00$ grams P_2O_5 (2.27 grams treble superphosphate) per pot of 100 pounds P_2O_5 per acre. The points which are circled represent average values for a treatment.

better than the corresponding blades as a means of estimating the phosphorus status of sugar beets.

A review of the yields, sugar percentages and chemical analyses of the leaves presented in table 1 discloses several points of interest. When phosphorus was added to the soil in increasing amounts the yields of tops and of beets increased rapidly at first and then more slowly with further additions of phosphorus until the increases in yield were not significant statistically. In the meantime the soluble phosphate-phosphorus concentrations of the petioles and blades, as mentioned earlier, increased very slowly at first and then very rapidly. Of the two plant parts analysed for phosphorus the blades attained higher soluble phosphate-phosphorus concentrations than the petioles. The potassium concentrations of the petioles and blades, in contrast to the phosphorus concentrations, were the highest in the low phosphate plants and then gradually decreased as phosphorus was applied to the soil. Of the plant parts studied, the potassium concentrations of the petioles were higher than the blades for the lowest phosphorus treatment, and then thereafter, the potassium concentrations in the petioles decreased more rapidly than the blades as phosphorus was applied to the soil. That these low potassium values were on the verge of becoming critical was suggested by the fact that a few plants of the three highest phosphorus treatments had a few leaves which showed leaf scorch similar to the symptoms of potassium deficiency. These leaves upon analysis were found to have potassium concentrations comparable to those of plants known to be deficient in potassium. Thus, in future pot experiments with sugar beets on this soil, potassium as well as nitrogen, should be included as a basic treatment. The nitrate-nitrogen concentrations in the petioles decreased only with the high phosphorus applications, but even here the nitrogen supply was ample for growth at harvest time. Another point of considerable interest is the fact that the sugar concentrations of the beets failed to change significantly even though large changes took place in the beet yields and in the phosphorus and potassium concentrations of the leaves of the plants.

Table 1. Summary of results for sugar beets grown in pots of Aiken clay fertilized with increasing amounts of phosphorus.

Treatments[3]	Weight of tops		Sugar[1] (Roots)	Weight of beets[1]	Soluble phosphate phosphorus[2]		Potassium[2]		Nitrate-nitrogen[2]
	Fresh	Dry			Petioles	Blades	Petioles	Blades	Petioles
	gms.	gms.	%	gms.	ppm.	ppm.	%	%	ppm.
$P_{.5}$	256	60	13.1	202	201	289	3.42	3.17	3540
P_1	454	89	13.0	346	210	378	2.35	3.22	3890
P_2	765	124	13.6	493	355	680	1.31	2.43	4680
P_4	892	136	13.3	653	786	1070	1.25	2.19	3160
P_8	953	148	14.0	607	1768	1700	1.09	1.98	1750
P_{16}	1026	154	14.0	637	2932	3956	1.08	1.98	1940
P_{32}	1011	154	13.5	686	3214	5078	1.15	1.85	2120
Significant difference[4]	145	17	N.S.	115	275	790	0.39	0.46	1280
F-value[5]	36.3	40.7	1.68	21.5	190	48.4	43.7	13.7	6.43

[1] Fresh basis.

[2] Dry basis.

[3] P_1=1.00 grams P_2O_5 (2.27 grams treble superphosphate) per pot or 100 pounds P_2O_5 per acre. Each treatment was replicated five times.

[4] Significant differences are for the 5 percent level. N.S.—not significant.

[5] The F-values required for significance at the .5 percent and 1 percent levels are 2.51 and 3.67, respectively (Snedecor (11), 1946).

Under Field Conditions.—The estimation of the critical nutrient level for sugar beets under field conditions is considerably more difficult than when plants are grown in pots of soil. In the field it is frequently impossible to control the conditions of the experiment as rigidly as desired, and it is often impossible to locate the experiments on soils with fertility levels as low as those which can be induced in pot experiments. But in spite of these difficulties data often can be obtained which will assist in getting an estimate of the critical nutrient level for sugar beets growing in the field. This estimate of the critical nutrient level may be established in the field in much the same manner as in the pot experiments just reviewed for phosphorus. Success by this procedure, just as in the pot experiments, will depend upon getting large differences in beet growth and in harvesting the beets before the nutrient supplies have been depleted within the leaves to the same low level for all rates of the fertilizer application. Often this will require harvesting the beets in mid-season in order to get large differences in yield that can be compared to large differences in nutrient concentration of the beet leaves. By following this procedure it is believed that the critical nutrient level for beets can be established rather efficiently under field conditions.

Another approach to estimating the nutrient level at which the growth of a crop is reduced, is through the collection of leaf samples at frequent intervals during its growing season. When the nutrient under study becomes deficient in the untreated plants and decreases within the plant to a relatively constant level, this may be taken as being at or below the critical level for that nutrient. Through many experiments of this nature, conclusions may be drawn as to the probable nutrient level at which the growth of the crop is reduced significantly below those at higher nutrient levels.

An example of the latter procedure was made available through a cooperative field experiment conducted with the International Minerals and Chemical Corporation and The Spreckels Sugar Company. In this experiment the effect of nitrogen on the growth of the beets was primarily under investigation while phosphorus was applied only in combination with the highest nitrogen application. Leaf samples were collected at about 14-day intervals starting at the time of applying the fertilizer on April 26 (first irrigated thereafter on May 1) and ending with the harvest of the beets on August 21, 1947. Other details of the experiment may be stated briefly as follows:

Sugar beet seed of the variety U. S. 15G was planted on January 26, 1947, in rows spaced 16 inches on a ridge and 24 inches between ridges. The beets were thinned on March 22 and then fertilized on April 25 by means of a Fairbank (5), 1940, two-row fertilizer applicator. The fertilizer was applied at the side of the beets in the wide spacing (irrigation furrow) at a depth of 4½ inches and a distance of 4 inches from the beets. Each plot was 6 rows wide and 100 feet long, and only the center 80 feet of the 2 center rows were harvested for yields and sugar determinations. The treatments applied were untreated, 80N, 160N, 240N and 240N+200 P_2O_5, where N equals "pounds of nitrogen per acre from ammonium nitrate" and P_2O_5 equals "pounds of P_2O_5 per acre from treble superphosphate." The five treatments were replicated eight times according to the randomized block technique (Snedecor (11), 1946). Plant samples consisting of 20 petioles each were collected from each plot at 2-week intervals from the time the beets were fertilized until they were harvested on August 21, 1947. The first petiole for the sample was taken from a recently "matured" leaf from a beet in the 2 center rows after walking into the plot 2.5 feet. Thereafter a petiole was taken every 5 feet alternating from row to row until 20 petioles had been collected. The samples were received at Berkeley, California, within 24 to 48 hours after their collection and upon their arrival were cut into sections from 2 to 5 millimeters in length. A 50 or 100-gram sample of each was dried in an oven at 70 degrees C., ground in a Wiley mill to pass a 40-mesh sieve and then analysed for nitrate-nitrogen (unpublished procedure), phosphate-phosphorus and potassium (Ulrich (17), 1945).

The results for the nitrate-nitrogen analyses are presented in figure 4 and in table 2. An inspection of the curves in figure 4 show that there was no significant difference in nitrate concentration of the beets prior to their fertilization. Thereafter the addition of nitrogen to the plots increased the nitrate concentrations of the beets in agreement with the rate of nitrogen applied. The lowest nitrate-nitrogen values were observed for the untreated beets throughout the experiment. These on May 13 had decreased markedly over those for April 25. Another decrease took place by May 26 and thereafter the nitrate values for the untreated beets were more or less constant even through to the time of beet harvest. Accompanying these low nitrate values for the untreated beets there was observed during June a distinct decrease in top growth of the beets in comparison to those beets fertilized with 80 pounds or more of nitrogen. At that time the treatments with more than 80 pounds of nitrogen had no further visible effect on the growth of the beets. Combining these observations, namely the low nitrate values with the poor growth of the untreated beets, along with the fact that only the untreated beets gave lower yields at harvest time than for any of the other treatments (table 2), the critical nitrogen value for beet petioles appears from this experiment to be approximately 400 parts per million of nitrate-nitrogen. How much more or less than 400 parts per million must await the results of experiments now in progress or to further improvements in technique or to a more effective statistical analysis of the results now available.

Table 2.—Nitrate-nitrogen of sugar beet petioles as related to yields and percentages of sugar in beets grown in field plots near Woodland, California, on Yolo fine sandy loam.

Treatment[2]	Nitrate-nitrogen[1]									Beet yield	Sugar	Sugar yield
	April 25	May 13	May 26	June 9	June 23	July 8	July 21	Aug. 4	Aug. 18			
	ppm.	ppm.	ppm.	ppm.	ppm.	ppm.	ppm.	ppm.	ppm.	Tons/acre	%	Tons/acre
Untreated	9,600	2,360	920	233	310	412	397	380	407	25.09	17.47	4.38
80N	10,300	7,760	4,670	1,420	1,360	700	610	560	670	27.94	16.87	4.71
160N	10,800	10,600	9,360	3,050	2,690	1,280	880	740	830	28.05	16.09	4.52
240N	10,000	11,000	11,000	4,670	4,000	2,920	1,840	1,470	1,090	28.79	15.49	4.46
240N+200P_2O_5	10,400	11,700	11,100	4,630	4,230	3,390	2,110	1,390	1,240	27.75	15.42	4.28
Significant difference[3]	N.S.	1,950	2,140	820	790	1,160	880	490	470	2.09	0.54	N.S.
F-value[4]	0.99	32.5	36.7	48.0	37.5	11.2	11.4	8.68	4.11	3.85	89.9	2.27

[1]Values are expressed on the dry basis.

[2]Arranged in eight randomized blocks. N=pounds of nitrogen from ammonium nitrate. P_2O_5=pounds of P_2O_5 from treble superphosphate.

[3]Significant differences are for the 5 percent level. N.S.=not significant.

[4]The F-values required for significance at the 5 percent and 1 percent levels are 2.71 and 4.07, respectively (Snedecor (11), 1946).

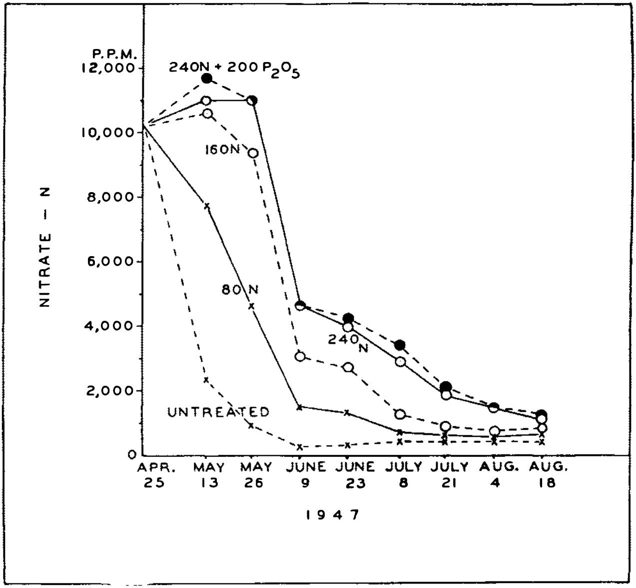

Figure 4.—Nitrate nitrogen (dry basis) of recently "matured" petioles as influenced by the amount of nitrogen applied and the date of leaf sampling. N=pounds per acre of nitrogen from ammonium nitrate and P_2O_5=pounds per acre of P_2O_5 from treble superphosphate.

Practical Applications of Plant Analysis

When once the critical nutrient level for an element has been established for a crop through many field experiments, plant analysis may have several interesting applications. Some of these applications include: (1) a determination of the kind of nutrient that might be deficient in the field; (2) estimation of the time of the application and the amount of fertilizer to apply; (3) aid in selecting the location of fertilizer experiments and (4) in the maintenance of soil fertility. Of these applications perhaps the most interesting from the practical standpoint is the use of plant analysis as an aid in the maintenance of soil fertility. Plants may be analysed in a systematic manner such as in the nitrogen experiment just reported (figure 4 and table 2). When the beets reach the critical level relatively early in the growing season as in the case of the untreated beets of the nitrogen experiment (figure 4) then emergency applications of nitrogen may be made to the field of beets. While emergency applications of nitrogen have effectively increased the yields of beets during the current growing season, nevertheless valuable growing time is often lost from the time the deficiency is detected to the time the nitrogen is absorbed by the plants. For this reason the use of plant analysis for emergency applications of fertilizers should not be stressed, but rather its use in the maintenance of soil fertility. This can be done rather conveniently when once it is recognized that certain fields from their fertilizer history are apt to become deficient in a given nutrient, as for example in the case of the field with the nitrogen experiment (figure 4 and table 2). In succeeding crops of beets on this field, nitrogen may be applied at a pre-determined time and rate before the beets are apt to become deficient in nitrogen. This time of application may be indicated by plant analysis. From figure 2 of the nitrogen experiment, the results for the untreated beets indicate that nitrogen should be applied so as to be available to the beets by the 1st of May. As to the amount of nitrogen to apply to succeeding beet crops, this cannot be estimated from the results of plant analysis for a single year on a given field unless this estimate is based on other data or upon the results of an experiment conducted concurrently using different rates of nitrogen as part of the treatments such as in the nitrogen experiment (figure 4 and table 2). The results of this experiment may be used as an illustration in estimating the amount of nitrogen to apply on subsequent crops of beets on this field. For this discussion let us assume that the critical nitrogen level for sugar beets has been established through many experiments to be approximately 1,000 parts per million of nitrate-nitrogen. Then in the case of the untreated plots, the beets were below the critical level from the latter part of May to the time of their harvest on August 21, 1947. During this 10-week period the results for the untreated beets indicate that they could have used more nitrogen for growth during the growing season, but what is not shown by the petiole analyses of the untreated beets is the degree of nitrogen deficiency. In some fields this deficiency may be extreme, while in others it may be relatively small. depending upon the rate of formation of available nitrogen. In the present experiment it may be surmised from the relatively good yield of 25.09 tons per acre from the untreated plots (table 2) that a considerable amount of nitrate was formed by the soil during the growing season of the beets. That the beets could actually use more nitrogen as indicated by the petiole analyses was shown by the 2.85-ton increase in beet yields obtained for the plots treated with 80 pounds of nitrogen per acre (table 2). Along with the increase in yield there was also an increase in the nitrate concentrations of the petioles (figure 4) so that the beets were below the critical nitrogen level for 7 weeks prior to harvesting them instead of the 10 weeks for the untreated beets. For the 160-pound per acre nitrogen treatment, the beets were below the critical nitrogen level for only 5 weeks before harvest, while for the 240-pound nitrogen application the beets were still *above* the critical nitrogen level when they were harvested. Of the increases in nitrate concentration in the leaf petioles with each increase in nitrogen added only the 80-pound nitrogen application was correlated with a significant increase in beet yield. The sugar percentages decreased significantly with each increment of nitrogen applied, and the net effect of this decrease in sugar concentration of the beets was a cancellation of the yield increase in the 80-pound nitrogen treatment. All these facts indicate that the beets were harvested prematurely, and what the final outcome would have been had they been left in the field longer should be a subject of considerable interest in future experiments. However, from the practical standpoint the 80-pound nitrogen treatment appears as a good basic nitrogen application for the next crop of beets on this field, providing all other conditions remain quite similar and that the beets could be left in the field longer to utilize completely the nitrogen applied. In any event the validity of the recommendations made with respect to time and to the rate of nitrogen applied should be confirmed through plant analysis for each crop grown on the field.

Aside from learning through plant analysis what fertilizer, and the approximate amount and time to apply it, one may also learn what materials are available to a crop in sufficient amounts for the time being. In the present experiment the phosphate and potassium concentrations[5] of the petioles, except for phosphorus on April 26, were well above what we now consider to be their critical concentrations, and accordingly their omission in fertilizer treatments for the next crop of beets would be well justified. The correctness of this assumption, however, should again be confirmed by analysing appropriate plant material from succeeding crops for their phosphate and potassium concentrations. Through observing the nutrient changes taking place in each crop, adjustments in the fertilizer program can be made over a period of years so that the crops for a given field will have an adequate supply of nutrients for growth.

Literature Cited

(1) BROWN, ROBT. J.
1943. Sampling sugar beet petioles for measurement of soil fertility. Soil Sci. 56:213-222.

(2) CHAPMAN, H. D.
1935. Inorganic phosphate in green plant tissue as a measure of phosphate availability. Soil Sci. 39:111-122.

(3) CLEMENTS, HARRY F. AND KUBOTA, T.
1943. The primary index, its meaning and application to crop management with special reference to sugar cane. Hawaiian Planters' Rec. 47:257-297.

(4) EMMERT, E. M.
1934. Tests for phosphate, nitrate and soluble nitrogen in conducting tissue of tomato and lettuce plants, as indicators of availability and yield. Ky. Agr. Exp. Sta. Cir. 43.

[5]The phosphate-phosphorus concentrations of the petioles from the beets of the 240N treatment were 970, 2210 and 2490 parts per million on April 26, June 9 and August 18, respectively, and the corresponding values for potassium were 5.87, 3.43 and 4.44 percent.

(5) FAIRBANK, J. P.
1940. Experimental machines for fertilizer placement. Proc. Nat'l. Joint Committee on Fertilizer Application 16:62-78.

(6) GARDNER, ROBERT AND ROBERTSON, D. W.
1935. The use of sugar beet petioles as indicators of soil fertility needs. Colo. Agr. Exp. Sta. Tech. Bul. 14.

(7) GOODALL, D. W. AND GREGORY, F. G.
1947. Chemical composition of plants as an index of their nutritional status. Imp. Bur. of Hort. and Plantation Crops. Tech. Comm. No. 17. East Malling, Kent, England. Pages 1-167.

(8) LUNDEGARDH, H. Die Tripelanalyse.
1941. Theoretische und praktische Grundlagen einer pflanzenphysiologischen Methode zur Bestimmung des Düngerbedürfnisses des Ackerbodens. Ann. kgl. landw. Hochschule Schwed. 9: 127-221.

(9) MACY, PAUL
1936. The quantitative mineral requirements of plants. Plant Physiol. 11:749-764.

(10) SHEAR, C. B., CRANE, H. L. AND MYERS, A. T.
1946. Nutrient-element balance: A fundamental concept in plant nutrition. Proc. Amer. Soc. Hortl. Sci. 47:239-248.

(11) SNEDECOR, G. W.
1946. Statistical methods applied to experiments in agriculture and biology. The Collegiate Press, Inc. Ames, Iowa.

(12) THOMAS, WALTER
1937. Foliar diagnosis: principles and practice. Plant Physiol. 12:571-599.

(13) THORNTON, S. F.
1932. A field and laboratory test on plant material for diagnosing phosphorus deficiencies. Purdue Univ. Agr. Exp. Sta. Bul. 355.

(14) THORNTON, S. F.
1933. A simple and rapid chemical test on plant material as an aid in determining potassium needs. Jour. Amer. Soc. Agron. 25:473-481.

(15) ULRICH, ALBERT
1943. Plant analysis as a diagnostic procedure. Soil Sci. 55:101-112.

(16) ULRICH, ALBERT
1945. Critical phosphorus and potassium levels in Ladino clover. Soil Sci. Soc. Amer. Proc. 10:150-161.

(17) ULRICH, ALBERT
1948. Diagnostic techniques for soils and crops. Chap. VI. Plant analysis: methods and interpretation of results. Pages 157-198 American Potash Institute, Washington 6, D. C.