Nitrogen Fertilization of Sugar Beets In the Woodland Area of California[1]

II. Effects upon the nitrate-nitrogen of petioles and its relationship to sugar production

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The importance of nitrogen in the fertilizer program for the production of sugar beets in the Woodland area has been indicated by several plant nutrient surveys (3)[3]. Trials with nitrogen in this area have given both positive and negative results. Failure to obtain increases in yield from the application of nitrogen on deficient fields were believed to be related to the use of insufficient amounts of nitrogen, to an incorrect placement of the materials or to faulty timing of the fertilizations; whereas in fertile fields the supply of nitrogen was already adequate for the needs of the crop. A unique opportunity for testing these ideas arose in a series of field experiments conducted in 1947 (7). These experiments were designed to study the effect of nitrogen and phosphorus fertilization on the growth and development of sugar beet plants in 7 different fields varying in crop-producing power and, as will be shown later, in nitrogen nutrition. Through the use of petiole analyses, it was possible to follow the changes taking place in the nitrogen status of the beets and to relate these observations to sugar concentrations, to beet yields, to sugar production and to efficient nitrogen fertilizations. It is the purpose of this paper to report these findings.

Reference in this paper will be made from time to time to the critical nutrient concentration of sugar beets. The theoretical basis for this concept and its relationship to beet growth has been reported elsewhere (4, 6). Briefly, the critical concentration is that narrow range of concentrations for a given nutrient at which growth is first retarded in comparison to plants with higher concentrations of the same nutrient.

Procedure

The procedures employed in the present experiments, except for the petiole analyses, have been given in the previous paper of this series (7). The plant samples in all fields except Y consisted of 20 petioles which were collected from each plot at 2-week intervals from the time the beets were fertilized until they were harvested. The first petiole for the sample, blade

[1] During the course of these experiments assistance was received from the personnel of the International Minerals and Chemical Corporation, the California Packing Corporation and the Spreckels Sugar Company. In addition to this aid, the International Minerals and Chemical Corporation furnished the fertilizers for the experiments and supplied funds for the analysis of the petioles for nitrate and the beets for sugar. The cooperation received from these sources is gratefully acknowledged.

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[3] Numbers in parentheses refer to literature cited.

discarded, was taken from a recently "matured" leaf (4) from **a** beet in the 2 center rows of the plot 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. In field Y (6) the petiole samples were collected by walking 30 feet into the plot and taking 4 petioles from the center 4 rows. Thereafter 4 more petioles were taken every 60 feet until a total of 40 petioles had been collected at 10 separate stations within each plot. The samples from all locations 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 analyzed for nitrate-nitrogen, phosphate-phosphorus and potassium (5) .

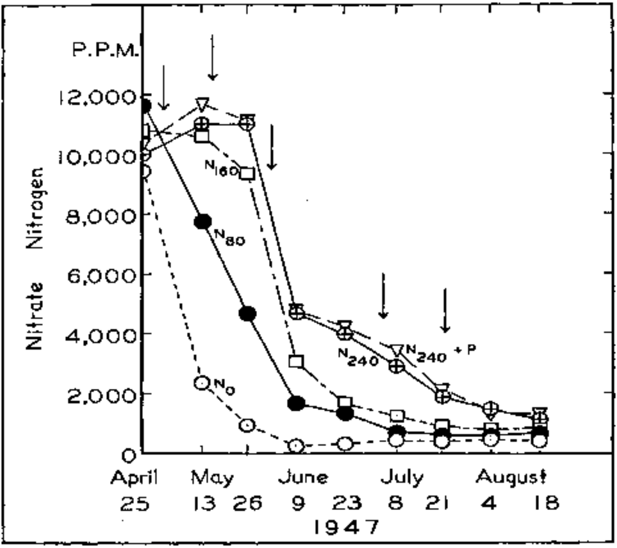


Figure 1. Nitrate-nitrogen (dry basis) of recently "matured" petioles for field R (Yolo fine sandy loam) as related to the amount of nitrogen applied and date of leaf sampling. N — pounds of nitrogen per acre applied as ammonium nitrate in the amounts indicated by the numbers in the subscripts thereto and P = 200 pounds per acre of P_2O_5 added to the soil as treble super phosphate. The arrows indicate the dates of irrigation subsequent to the fertilization of April 25, 1947.

Experimental Results

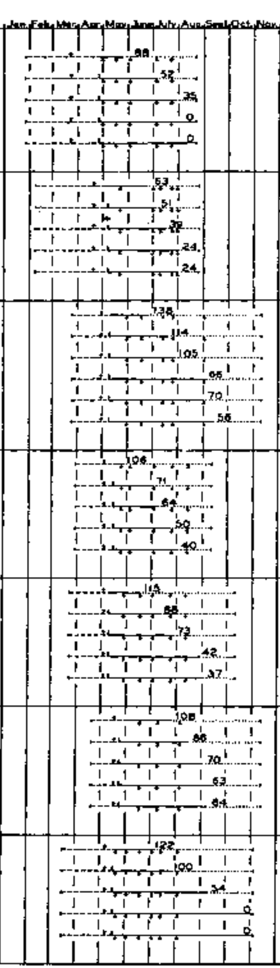
Field It.—The results of the nitrate-nitrogen analyses of the petioles collected at 2-week intervals from field R are presented in Figure 1. Fertilizer applied to this field on April 25, 1947, became effective shortly after the irrigation of May 1. Prior to fertilization, the nitrate-nitrogen values of the means for the proposed treatments varied from 9,600 to 10,800 parts per million, and as expected, none of these differences were statistically significant.

On the next sampling date, May 13, the plants fertilized with more than 160 pounds of nitrogen per acre did not decrease in nitrate-nitrogen concentration, whereas those fertilized with 80 pounds of nitrogen or less decreased sharply. These differences in nitrate-nitrogen concentration of the petioles taken from the fertilized and unfertilized plots indicate that the nitrogen applied to the soil had been absorbed readily by the beets and had accumulated to a relatively high concentration within the plant.

On the next sampling date, May 26, the nitrate concentrations of the petioles from the plots treated with 160 pounds of nitrogen or more were still at a high nitrate level, whereas further decreases took place for the beets fertilized with 80 pounds of nitrogen and for the unfertilized beets. On subsequent samplings the petioles of the untreated beets contained less than the critical nitrate-nitrogen concentration of 1,000 parts per million (6) and remained at this low level until the beets were harvested on August 18. The petioles of the beets fertilized with 80 pounds of nitrogen also decreased in concentration gradually, and after July 1 remained below 1,000 parts per million. The petioles of the beets fertilized with 160 pounds of nitrogen stayed above the critical concentration until July 17, whereas those fertilized with 240 pounds of nitrogen remained above this level until harvested.

The beet yields from field R, given in Figure 2 and in Table 1 (7), were in accord with the results of the petiole analyses. Beets with the lowest nitrate-nitrogen concentration produced the lowest yield and the highest sugar concentration. A significant increase in beet yield was observed only for the 80-pound nitrogen treatment, and thereafter more nitrogen failed to increase the yields. Sugar concentrations, in contrast to beet yields, were

Figure 2 (see page 375). Summary of results for seven fertilizer experiments conducted with sugar beets on fields R (Reel), M (Moore), Y (Pockman), W (Wilder), H (Hass and Ullrich), C (Carlson) and K (Knaggs and Oeste). Each horizontal line begins with the date of planting and ends with the harvest. The broken line to the left indicates the period when the beets were in the seedling stage and not sampled; the solid line, the period when the petioles were above 1,000 parts per million of nitrate-nitrogen; and the broken line to the right, the period below 1,000 parts per million of nitrate nitrogen. The numbers above the broken line to the right indicate the days duration of nitrogen deficiency. The arrow upwards indicates the thinning date; the vertical bar to the right of the arrow, the date of fertilization; and the arrows downward, the dates of irrigation. L.S.D. equals least significant difference at the 5% level and n.s. indicates the differences noted were not statistically significant. N — nitrogen derived from ammonium, with the exception of 60 pounds from ammonia in field C. P = 200 pounds P_2O_5 per acre derived from treble super phosphate.



Field	lb. N/acre	Tons beets per acre	Per cent sucrose	Tons sucrose per acre
R	0	25.0	17.5	4.38
	80	27.9	16.9	4.71
	160	28.0	16.1	4.52
	240	28.7	15.5	4.47
	240+P	27.8	15.4	4.28
	L.S.D.	2.1	0.5	n.s.
M	0	20.4	18.0	3.66
	80	23.9	16.9	4.01
	160	26.2	16.5	4.30
	240	27.3	14.6	3.99
	240+P	28.0	14.5	4.05
	L.S.D.	1.8	0.8	0.30
Y	0	13.9	16.0	2.21
	40	15.8	16.2	2.56
	80	17.5	15.4	2.69
	160	19.2	14.4	2.76
	240	20.6	14.5	2.98
	240+P	20.0	14.8	2.96
	L.S.D.	1.4	0.6	0.25
W	0	5.9	17.3	1.03
	80	13.2	17.1	2.26
	160	17.3	16.9	2.93
	240	19.6	16.4	3.22
	240+P	19.6	15.8	3.11
	L.S.D.	3.3	0.7	0.60
N	0	16.3	18.3	2.99
	80	22.1	17.7	3.92
	160	23.8	17.3	4.12
	240	23.8	16.3	3.90
	240+P	23.9	16.1	3.86
	L.S.D.	1.3	0.5	0.23
C	60	19.3	17.0	3.29
	140	21.7	16.5	3.49
	220	24.8	16.1	4.02
	300	25.4	15.4	3.98
	300+P	24.7	15.4	3.81
	L.S.D.	1.9	0.5	0.41
K	0	20.0	17.2	3.45
	80	22.6	17.0	3.86
	160	22.3	15.9	3.54
	240	23.3	15.5	3.60
	240+P	22.4	14.9	3.36
	L.S.D.	n.s.	0.8	n.s.

Figure 2.

highest for beets from the untreated plots and thereafter decreased in concentration with each increment of nitrogen. The net effect was no significant change in sucrose production because the decreases in sucrose concentration cancelled the increases in yield.

Further inspection of the petiole analyses (Figure 1) indicates that fertilizer should be applied on this field so as to be available to the beets by the first part of May. Prior to May, the beets were well above the critical concentration and accordingly were supplied adequately with nitrogen. On the basis of the petiole analyses alone, the fertilized beets should have been allowed to grow longer than August 18 in order to permit a maximum accumulation of sugar. Unless the growing period is extended, the results of the petiole analysis suggest that approximately 80 pounds of nitrogen per acre would be satisfactory for this field. Through systematic petiole sampling, adjustments in the amount of nitrogen applied to this field could be made either during the current season or in succeeding crops, thereby utilizing nitrogen more effectively in the production of sugar by the beets.

Field M.—The results of the petiole analyses for field M arc presented in Figure 3. Fertilizer was applied on May 6 and the field was irrigated for the first time thereafter on May 21. On May 5, which was prior to fertilization, the beets had a very high nitrate concentration. On May 20, which preceded the first irrigation, the nitrate-nitrogen concentration of the petioles had decreased considerably but was still above 5,000 parts per million for beets of all treatments. None of the differences occurring on May 5 and May 20 were statistically significant. On the first sampling after irrigation there were large increases in nitrate-nitrogen concentration of the fertilized beets.

These increases were in accord with the amount of nitrogen applied, with the lowest increase for the 80-pound application and the highest for the 240-pound application. As in field R, the nitrate-nitrogen concentrations of the petioles from the untreated plots decreased sharply, being slightly above 2,000 parts per million on June 2 as contrasted with figures of 10,000 or more for the fertilized beets. On June 17 the nitrate-nitrogen concentrations of the petioles of all beets decreased precipitously. Further decreases occurred on July 7, with the petioles for the untreated and the 80-pound-nitrogen-treated plots being below 1,000 parts per million. The petioles for the other treatments were still above this critical concentration. On July 28 the nitrate-nitrogen concentrations of the petioles decreased still more for all nitrogen-treated plots, and finally on August 11 the petioles from all plots were well below the critical nitrogen concentration.

The beet yields given in Figure 2 again confirm the indications of the plant analyses. The lowest yields were obtained from the untreated plots and a significant increase in yield took place for the plots treated with 80 pounds of nitrogen. When more nitrogen was added to the soil, further increases in yield over the 80-pound application took place which were significantly greater for the 240-pound application, but not for the 160-pound application. Again the sucrose concentrations decreased with the nitrogen applications. These decreases in sucrose concentration were more than offset by the yield increases, and the net effect was an increase in sugar production.

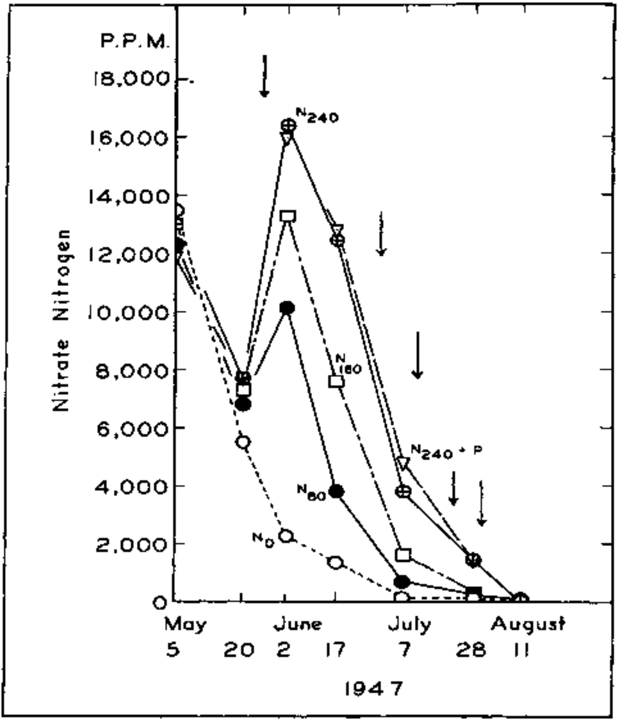


Figure 3. Nitrate-nitrogen (dry basis) of recently "matured" petioles for field M (Sacramento fine sandy loam) as related to the amount of nitrogen applied and date of leaf sampling. N = pounds of nitrogen per acre applied as ammonium nitrate in the amounts indicated by the numbers in the subscripts thereto and P = 200 pounds per acre of P_2O_5 added to the soil as treble super phosphate. The arrows indicate the dates of irrigation subsequent to the fertilization of May 6.

The plant analyses indicate that when beets are planted on this field in February nitrogen may be added as late as the latter part of May without impairing the nitrogen levels of unfertilized beets. Again, as in field R, a delay in harvesting might have resulted in greater sugar production because the beets receiving the highest amount of nitrogen were not deficient in nitrogen long enough to result in maximum root development and sugar storage.

Field Y.—In contrast to the fields which had relatively high yields for the untreated plots and a relatively high nitrogen status during the growing season, other fields had very low yields from the untreated plots (figure 2) . The beets in field Y were fertilized on May 7 and 8 and irrigated on May 30. Analyses of the first petiole samples, taken on June 10, represent the condition of the beets after the fertilizer became effective (Figure 4) . The nitrate concentrations of these petioles again reflected the fertilizer treatments, being lowest for the untreated plots, intermediate for the 40- and 80-pound treatments and highest for the 160- and 240-pound treatments. By the second sampling date, June 24, the nitrate-nitrogen values had decreased rapidly in approximately the same proportion for all treatments, with the petioles of the untreated plots being at the critical concentration of 1,000 parts per million. Thereafter the values for the petioles from the untreated plots were well below this level. The petioles of the other plots, 40-pound, 80-pound, 160-pound, 240-pound and 240 + P, decreased to the critical concentration on July 19, July 28, September 1, September 5 and September 15, respectively.

The beet yields obtained from this field (Figure 4) again confirm the results of the petiole analyses, and just as in fields R and M, the nitrogen treatments resulted in decreases in sugar concentration. These decreases in sucrose concentration were unexpected because, judging from the results of pot experiments conducted at Berkeley (2) , the beets had been below the critical nitrogen level long enough to restore their sugar concentration. Since similar decreases in sugar concentration were observed in other fields of comparable nitrogen starvation periods, this discrepancy between the results of pot and field experiments should be reviewed critically.

According to results of the beet and sugar yield (Figure 2) and the petiole analyses (Figure 4) , more nitrogen appears to be desirable on field Y. In addition to the nitrogen deficiency, the phosphate analyses of the petioles indicate that phosphorus should be considered in the nitrogen program: the beets were low in phosphate-phosphorus and the phosphorus added as fertilizer to the soil had not been absorbed by the plants. Potassium was found ample in this field at all times. (Phosphorus and potassium analyses not reported here) .

Field W.—The results for field W (Figures 2 and 5) are similar to those observed for field Y. The beets were also planted relatively late in the season and likewise gave very low yields at the time of harvest on September 3. The field was fertilized on May 14 and irrigated shortly thereafter. Analyses of the petiole samples taken on May 14, just before fertilization, showed that the beets from all plots were well supplied with nitrogen

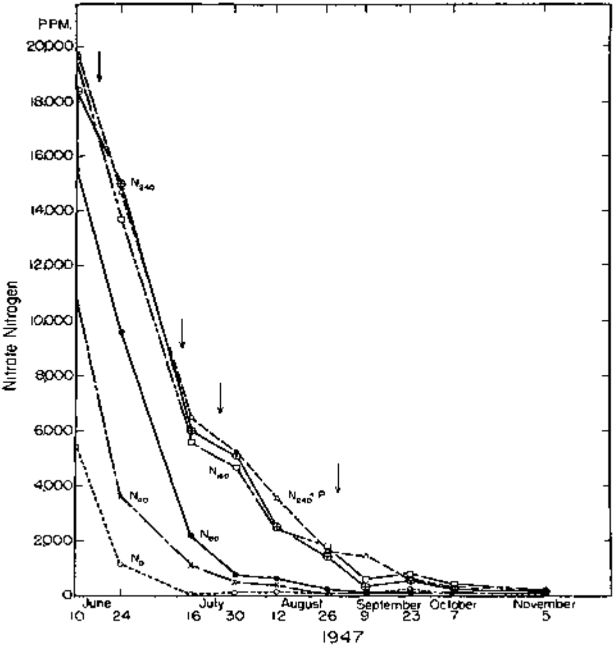


Figure 4. Nitrate-nitrogen (dry basis) of recently "matured" petioles for field Y (Sorrento clay loam) as related to the amount of nitrogen applied and date of leaf sampling. N = pounds of nitrogen per acre applied as ammonium nitrate in the amounts indicated by the numbers in the subscripts thereto and P = 200 pounds per acre of P_2O_5 added to the soil as treble super phosphate. The arrows indicate the dates of irrigation subsequent to the fertilization of May 7 and 8 and the irrigation of May 30.

(Figure 5) . On May 28, the first sampling after irrigation, there were large differences in the nitrate content of the petioles. On this date, the petioles from the untreated plots were at the critical concentration whereas those from all nitrogen-treated plots increased in nitrate-nitrogen concentration to about 10,000 parts per million, except the petioles from the plots treated with 80 pounds of nitrogen, which contained about 7,000 parts per million. Decreases in nitrate-nitrogen concentration took place rapidly for subsequent petiole samplings for the 80, 160, 240 and 240 + P treatments, and these declined to the critical concentration on July 2, July 9, July 23 and August 2, respectively.

An important factor associated with the low beet yields from the untreated plots in field W was the damage caused by root rot. The percentage of beets damaged in the untreated plots was significantly higher than in the plots treated with nitrogen (7) . The petioles which comprised the samples from these plots were taken from beet plants which had survived the root rot attack or had not yet succumbed to it. The nitrate-nitrogen concentration in these petioles reflected the amount of nitrogen which the beets could get from the soil and that which was not used in growth.

The nitrogen present in the beets which died, however, was not available, or at least not readily available, to the living beets; consequently, the rotted beets did not contribute greatly to the harvest yields nor to the nitrogen supply of the living beets. Accordingly, the nitrate-nitrogen concentration of the petioles for the untreated beets reflected largely the condition which would have existed in the beets without the presence of root rot. Since the untreated beets were deficient in nitrogen relatively early in the growing season, and since an increase in beet yield was observed in other comparable fields of this investigation, it is safe to assume that smaller increases in yield would have occurred on this field had root rot not been present. Clearer confirmation between the results of the petiole analyses and the beet yields was obtained, however, for the 80- and 160-pound nitrogen applications. Root rot damage for these two treatments was slight but the yields still differed significantly, thus confirming again the results of the petiole analyses.

The sugar percentages for field W were, on the average, one unit greater than for field Y. Since both fields were planted to the same variety (U. S. No. 33) at approximately the same time and were located in the same climatic zone, the difference in the sugar percentages of the two fields could be attributed either to harvesting the beets earlier in field W or to some inherent difference in the soils of the two locations.

In field W, just as in field Y, results of the petiole analyses indicate that more than 80 pounds of nitrogen could be used safely in meeting the nitrogen requirements of beets on this field. In both instances nitrogen fertilization might be delayed up to the time of thinning or shortly thereafter. Further study of this point, particularly a comparison of nitrogen applied at planting time with nitrogen applied at the time of thinning, would be of interest in these fields of low nitrogen content.

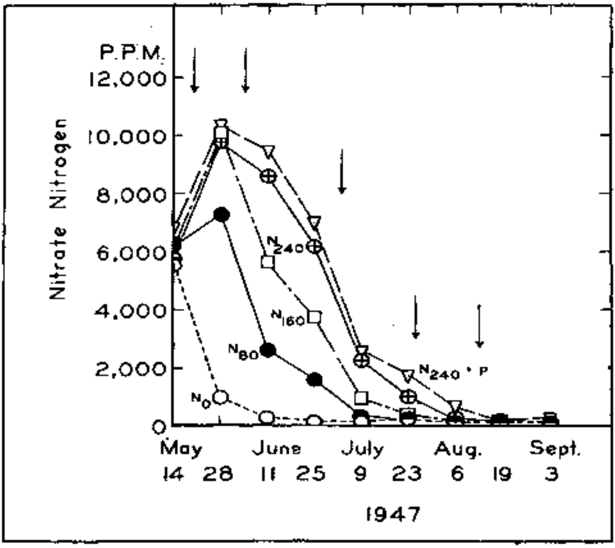


Figure 5. Nitrate-nitrogen (dry basis) of recently "matured" petioles for field W (Sacramento clay loam) as related to the amount of nitrogen applied and date of leaf sampling. N — pounds of nitrogen per acre applied as ammonium nitrate in the amounts indicated by the numbers in the subscripts thereto and P = 200 pounds per acre of P_2O_5 added to the soil as treble super phosphate. The arrows indicate the dates of irrigation subsequent to the fertilization of May 14.

Field H.—The results of the petiole analyses for field H are presented in Figure 6. The beets were planted on March 22, fertilized on May 9, and irrigated for the first time thereafter on May 28. Just as in fields M, W, R, C and K, the fertilizer was not effective until the beets had been irrigated. Thus in the samplings for April 29, May 15 and May 27, the differences in nitrate concentrations were not statistically significant, although the lowest values on May 15 and 27 were for the untreated beets. On June 10 petiole samples were taken for the first time after irrigation, and now the nitrate-nitrogen concentrations differed greatly. Values for the plots treated with 240 pounds of nitrogen per acre averaged approximately 18,000 parts per million, whereas those for the untreated plots averaged below 2,000 parts per million. On the next sampling, June 24, the beets from the untreated plots were well below the critical nitrate-nitrogen concentration, whereas the concentration for the beets treated with nitrogen decreased sharply since the previous sampling on June 10. On subsequent samplings, further decreases in nitrate-nitrogen took place, with the beets receiving treatments 80, 160, 240 and 240 + P reaching the critical concentration on July 14, July 29, August 29 and September 3, respectively.

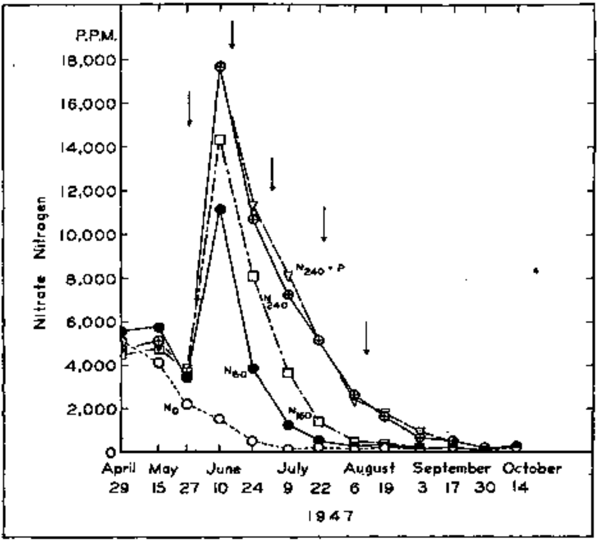


Figure 6. Nitrate-nitrogen (dry basis) of recently "matured" petioles for field H (Yolo fine sandy loam) as related to the amount of nitrogen applied and date of leaf sampling. N = pounds of nitrogen per acre applied as ammonium nitrate in the amounts indicated by the numbers in the subscripts thereto and P = 200 pounds per acre of P_2O_5 added to the soil as treble super phosphate. The arrows indicate the dates of irrigation subsequent to the fertilization of May 9.

The results of the petiole analyses (Figure 6) were again in accord with the yields (Figure 2). There was a large increase in yield for the first 80-pound nitrogen application, a smaller increase in yield for the 160-pound application, and thereafter no significant increases in yield took place. The untreated beets in this field gave an average sugar concentration of 18.3

percent, and as in the other fields the addition of nitrogen decreased the sugar percentages significantly. It is also of interest to note that in no case did the average sugar concentrations of the fertilized beets equal those of the unfertilized beets, even though the plants had been deficient in nitrogen for 3 months, as in the case of the 80-pound application. Again this is a problem for further study.

Judging from the results of the petiole analyses, the irrigation of May 28 occurred in time to maintain the nitrate concentration of the beets above the critical level, for shortly thereafter the untreated beets became deficient in nitrogen. The petiole analyses also illustrate the importance of adding water after fertilization. In this particular field the delay of approximately 4 weeks in irrigation after fertilization may not have been too serious because the fertility of the field was sufficient to provide the beets with enough nitrogen to keep them above the critical concentration until the beets were watered; but in other fields of this investigation such a delay most likely would have resulted in a decrease in beet yields.

Field C.—In this field the beets were planted on April 19, fertilized on May 23 and irrigated for the first time thereafter on June 19. The first three petiole samplings prior to irrigation were made on May 27, June 3 and June 18. None of the differences in petiole nitrate observed on these dates was statistically significant, even though the values for the petioles of the untreated beets collected on June 18 are lower than any in this field (Figure 7) . The sampling of July 2, which was subsequent to the irrigation of June 19, showed that the beets had now absorbed the nitrogen added to the soil. The differences in petiole nitrate for the various amounts of nitrogen added, however, were the smallest of any experiment conducted during 1947. It is true that the 80-pound application produced a marked increase in nitrate concentration, but further increases from adding 160 and 240 pounds of nitrogen to the soil were relatively small. The untreated beets of field C reached the critical nitrate-nitrogen concentration on July 26, whereas the values for the remaining treatments, 80, 160, 240 and 240 + P, passed through this zone on August 17, September 2, September 8 and September 7, respectively.

The relatively small differences in nitrate-nitrogen values of the petioles from field C for the 80 and 160 applications may be associated with the inadvertent fertilization of all plots with 60 pounds of nitrogen applied as ammonia in the irrigation water on July 7. This explanation, however, is difficult to reconcile with the fact that there was no change in the slope of the nitrate curve for the untreated beets on July 15, the first sampling thereafter. Either the nitrogen was not absorbed by the plants, or it was not converted to nitrate so as to be reflected in the nitrate analysis of the petioles, or the growth rates of the beets were so rapid as to include in stride the extra 60 pounds of nitrogen applied.

In field C the beets of all treatments were below the critical concentration approximately 4 months before harvest, and accordingly no large differences in sugar concentrations should have been expected (2) . The sugar analyses for these beets, in contrast to those of pot experiments, showed that the concentrations of sugar decreased significantly with the nitrogen applications.

The beet yields (Figure 2) , as in the other experiments, confirmed the observations made in the petiole analyses. An increase in yield over the control beets (60-pound) was observed for the 80 + 60-pound application and still higher yields for the 160 + 60-pound application, but no further yield increases were observed for the 240 + 60-pound application either with or without phosphorus. From the practical standpoint the results of the petiole analysis indicate that the field was well supplied with nitrogen until the end of July. Apparently nitrogen applications to field C as late as June or July would be beneficial to the crop, if also, harvesting is delayed, as it was in this experiment.

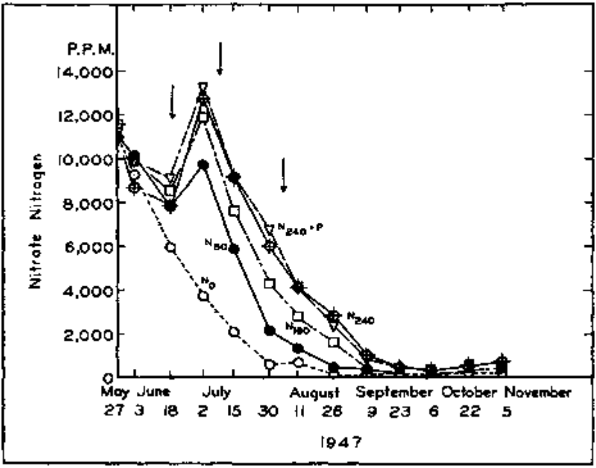


Figure 7. Nitrate-nitrogen (dry basis) of recently "matured" petioles for field C (Columbia clay loam) as related to the amount of nitrogen applied and date of leaf sampling. N = pounds of nitrogen per acre applied as ammonium nitrate in the amounts indicated by the numbers in the subscripts thereto and P = 200 pounds per acre of P_2O_5 added to the soil as treble super phosphate. In addition to these treatments, 60 pounds of nitrogen were applied inadvertently to all the plots as ammonia in the irrigation water of July 7. The arrows indicate the dates of irrigation subsequent to the fertilization of May 23.

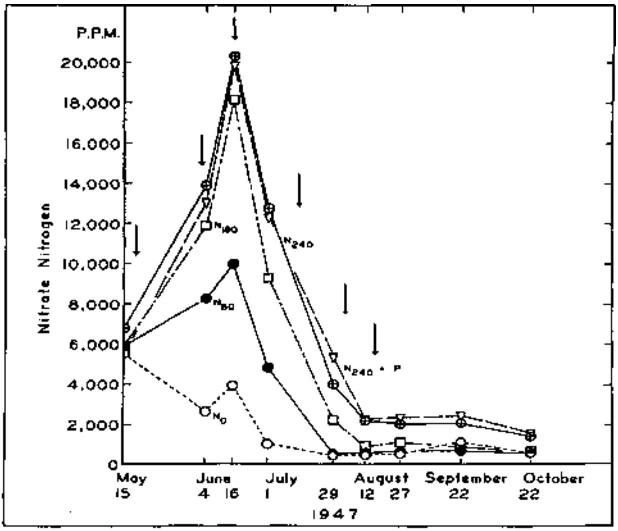


Figure 8. Nitrate-nitrogen (dry basis) of recently "matured" petioles for field K (Yolo fine sandy loam) as related to the amount of nitrogen applied and date of leaf sampling. N = pounds of nitrogen per acre applied as ammonium nitrate in the amounts indicated by the numbers in the subscripts thereto and P = 200 pounds per acre of P_2O_5 added to the soil as treble super phosphate. The arrows indicate the dates of irrigation subsequent to the fertilization of May 16.

Field K.—The results of the petiole analyses of field K are presented in Figure 8. This field was planted on March 14, fertilized on May 16 and irrigated on May 20. The petioles taken on May 15, just prior to fertilization, did not differ significantly in nitrate concentration. On June 4, following the irrigation of May 20, the nitrate concentrations of the petioles, as in the other experiments, were related to the amounts of nitrogen added to the soil. On June 16 the nitrate concentrations of the petioles again increased, and this time, in contrast to the results of the June 4 sampling, the values also increased for the untreated plots.

From this increase in nitrate, one may conclude that the rate of nitrate formation in the soil was temporarily greater than the rate of its utilization by the plants, thus resulting in an increase of nitrate within the plants. By

July 1, the nitrate concentrations had decreased to such an extent that the beets of the untreated plots were now below the critical concentration, whereas all others were still well above this level. Thereafter the beets for the 80- and 160-pound applications reached the critical concentration on July 26 and August 12, respectively. The beets for the higher nitrogen applications failed to reach this level even at the time of harvest.

This unusual condition of the petioles for the 240-pound applications may be associated with a shortage of water which took place shortly after the beets were irrigated for the last time on August 8. Again, this water shortage was most likely responsible for the failure to obtain a significant increase in beet or sugar yields for any of the nitrogen-treated plots. While the sugar concentrations of the beets in this field were not influenced by 80 pounds of nitrogen, significant decreases were observed for the larger amounts applied. It is of interest, too, to mention that frequent observations of a field during the growing season may often explain apparent anomalies between plant analyses and final yields, such as took place in this field. Although the nitrate analyses of the petioles from this field were similar to those in which large differences in yield had been obtained, the shortage of water prevented the full utilization of the nitrogen which had been absorbed by the beets earlier in the growing season.

Discussion

In reviewing the beet yields observed in the present series of experiments, it is of interest to note that significant increases in yield were obtained from the use of nitrogen in all but one of the 7 locations in the Woodland area of the Sacramento valley for 1947. These increases in yield are in accord with the expectations of the plant nutrient surveys made some years ago in this area (3) and are also in harmony with the results of the present petiole analyses, even though the yields of the untreated plots were as low as 5.9 tons per acre for field W and as high as 25.0 tons per acre for field R (Figure 2) - The low yield of 5.9 tons in field W was largely the result of root rot damage to the beets. Allowing for this damage, the lowest yield for the untreated plots would have been 10.6 tons per acre, which is still less than half of the highest untreated plot yield for field R.

In spite of this wide variation in yield, the first 80-pound application of nitrogen gave significant increases in all but one field. The smallest increase in yield, 2.4 tons per acre, was observed for field C, where 60 pounds of nitrogen had been applied inadvertently throughout the experimental field; whereas the largest increase, 5.8 tons per acre, took place in field H. For the plots treated with 240 pounds of nitrogen per acre, the lowest average yield, 19.6 tons per acre, was observed in field W, and the highest, 28.7 tons per acre, for field R. Yield increases over the untreated plots for the 240-pound nitrogen application were 9.0, 7.5, 6.9 and 6.7 tons per acre for fields W, H, M and Y and only 3.3 and 3.7 tons per acre for fields K and R.

Some of the variations in yield for the untreated plots and the variations in response to nitrogen for the fertilized plots at the different locations are undoubtedly associated with local differences in climate within the Woodland area. Of greater significance in producing variations in yield increases for the same nitrogen treatment, however, are crop histories and cultural practices, including previous fertilizations at each location. In relation to the cultural practices, variations in the date of planting, thinning, irrigating and harvesting are quite likely to have had a profound influence upon the yields obtained at the time of harvest.

In the present experiments, the small yield increase from nitrogen for field K was clearly associated with a shortage of water as observed late in the growing season, whereas for field R the beets were harvested prematurely. That such large differences in yield and responses to fertilization exist within an area should serve as a challenge to growers, field men and scientists to attempt to raise production for all fields to the highest level possible for a given climatic zone.

The use of petiole analysis as a tool for observing the nutritional changes taking place within the plants prior to and subsequent to fertilization has been of great value in the present experiments. As a rule, nitrate supplies *in* the petioles were found to be adequate for beet growth early in the growing season, but as the season progressed, the nitrate concentrations decreased rapidly *in* the petioles of all unfertilized beets, causing thereby decreases in beet growth. In the fertilized beets, the rapid decline in nitrate concentration early in the season stopped well above the critical concentration of 1,000 parts per million of nitrate nitrogen; and, in fact, the nitrogen added to some fields was sufficient to maintain the nitrate concentrations of the petioles above the critical level even to the time of harvest (Figures 1 and 8).

The need for the addition of water shortly after fertilization was demonstrated clearly by the results of the petiole analyses. It was only after water had been applied that the ammonium nitrate was effective in causing large increases in nitrate concentration of the petioles (see particularly Figures 3, 6, 7). Most likely, other sources of nitrogen would have produced similar increases in nitrate concentration of the petioles. This has been found to be true for ammonium sulfate in pot experiments (2) and more recently in a field experiment (1) for calcium nitrate, sodium nitrate and urea.

The amount of nitrogen required to maintain the nitrate concentration above the critical level is also indicated by the petiole analyses. In fields R and M (Figures 1 and 3) the 80-pound application maintained the nitrate concentration above this level for most of the growing period. In all others the 80-pound application was soon depleted by the plants, whereas in field W (Figure 5) even the 240-pound application appeared to be insufficient to meet the needs of the crop. On the basis of these observations it is possible to select the approximate amount of nitrogen for maintaining a satisfactory nitrate level in the plants up to and prior to harvesting the beets. Similarly, nutrient inventories taken yearly would aid materially in making adjustments in the fertilizer program for each crop grown on a field.

The results of the petiole analyses indicate that all fields were adequately supplied with potassium, and all but field Y, with phosphorus (unpublished data of our laboratory). In field Y the phosphate concentrations in the petioles from all plots were near the critical level for part of the growing season regardless of the fertilizer treatment, which included the addition of 200 pounds of P_2O_5 with 240 pounds of nitrogen per acre.

Apparently in field Y, in which a different method of application was used, the phosphorus added to the soil either failed to reach the root zone of the beets, or perhaps the amounts added were insufficient to overcome the fixation of phosphorus by the soil and still leave enough for plant growth. If one judged the need for phosphorus in field Y from the yields alone, the supply of phosphorus, as in the other locations, would have been assumed to be adequate.

The petiole analyses, however, indicated that there is a definite phosphorus problem on this field, such as placement within the root zone, fixation by the soil and time of application. In all other fields the beets were high in phosphorus and the phosphorus fertilizations had no effect on the yields or on the petiole phosphorus, even though the method of fertilization was effective in other experiments on fields low in phosphorus.

The relationship of the nitrate content of the petioles to the sugar concentration of the beets and to beet yield is of particular interest in sugar production. The greater the number of days the beets are below the critical concentration of 1,000 parts per million of nitrate-nitrogen, the higher the concentration of sugar in the beets and the lower the beet yields (Figure 2). Conversely, the more days the beets are above the critical concentration, the higher the beet yields, which occasionally may not result in more sugar production because of the lowering of the sugar concentrations of the beets (field R, Figure 1). These decreases in sugar concentration following nitrogen fertilization, as in fields Y, H and C (Figures 4, 6 and 7), occurred even after long periods of nitrogen starvation prior to harvest, which is contrary to that which would have been anticipated from the results of pot experiments (2).

Summary

Petiole samples from 7 fertilizer experiments were collected at 2-week intervals during 1947, starting from the time of planting and continuing until harvest. The results of the analyses showed that the fields were at different degrees of nitrogen deficiency and this was related to beet yields and sugar concentrations. In general, the earlier in the growing period the nitrate values fell below the critical concentration of 1,000 parts per million of nitrate nitrogen and the more days the values remained below this level, the lower the yield and the higher the sugar concentration. Conversely, the longer the beets remained above the critical concentration, the higher the yield and the lower the sugar concentration.

The petiole analyses, aside from indicating a need for nitrogen fertilization, gave useful information as to the time of fertilization, the amount of nitrogen required for a given beet field, the need for water after fertilization and the kind of nutrients absorbed from the fertilizer applied, as for example, in the field low in phosphorus, the phosphorus added was not taken up by the beets. In the 6 fields high in petiole phosphorus, the phosphorus fertilization had no effect on the yields, even though the fertilizations in these fields were made by a method proven to be effective on fields low in phosphorus. All fields, on the basis of the petiole analyses, were well supplied with potassium.

Significant increases in beet yields from the nitrogen fertilizations were observed in 6 out of 7 fields investigated. This was in accord with earlier findings obtained through petiole analyses of fields in the Woodland area. A shortage of water was largely responsible for the failure to get a signicant increase in yield in the seventh field, even though the petiole analyses and field observations indicated a need for nitrogen.

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