Marginal Nitrogen Deficiency of Sugar Beets and the Problem of Diagnosis

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Received for publication June 21, 1962

In recent years much has been learned concerning the response of sugar beets to changes in environment. Ulrich (9)[2], in a controlled climate facility, has shown that low night temperatures coupled with nitrogen deficiency can result in beet roots with 18% sucrose. This response is also apparent with sugar beets grown in pots outdoors; plants which had been nitrogen deficient for 6 to 8 weeks during an early fall growing period, produced as much total sucrose as comparable plants well supplied with nitrogen (5). Both the above studies involved growing sugar beet plants in vermiculite and watering with culture solution. In such a system it is possible to bring about a high degree of nitrogen deficiency as evidenced by a rapid decrease in growth rate of tops and roots within three weeks after nitrogen was removed from the culture solution.

Under field conditions lesser degrees of nitrogen deficiency are likely, depending on the balance between nitrogen demand (plant growth) and nitrogen supply (rate of nitrification and the nitrogen status of soil into which roots are extending). Early experiences with nitrogen fertilization of sugar beets in California, however, also indicated that fairly sharp nitrogen deficiency responses were obtained. This reflected the low residual nitrogen fertility of the soils at that time (6, 7). Under such conditions the length of the deficiency period prior to harvest appeared to be the most important factor in determining the quality of the harvested crop. This picture appears to have changed as the result of the great increase in the use of the nitrogenous fertilizers on field crops in California. More recent experiences with fields of high residual nitrogen fertility (3, and Loomis and Worker, unpublished) have indicated that sharp nitrogen deficiencies are not obtained under such conditions and that degree of deficiency may be as important as the length of deficiency.

This paper concerns the results from the first of a series of field experiments designed to assay the degree of nitrogen deficiency in several California soils and to relate the degree of

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deficiency to diagnostic techniques. The experiment was conducted in a field of commercial sugar beets in Kern County. In this area sugar beets are usually planted in late winter (January and February) and harvested in midsummer (July and August). Crops usually produce excellent root yields (20 to 35 tons per acre) but with low sucrose concentrations (12 to 14%).

Procedure

The field selected was on Hesperia fine sandy loam. The sugar beet variety Spreckels 202H was planted in 30-inch single-row beds in early January, 1961. Four rates of nitrogen (0, 80, 160 and 320 pounds N per acre) and five dates of harvest (May 24, June 16, July 6, 27, and August 17) were arranged in a split-block design (1). Nitrogen rates were main plots randomized in a 4 × 4 Latin square and dates of harvest were subplots 60 feet long × 4 rows wide. The subplots were randomized the full length of each column of main plots. On March 7, shortly after thinning, 80 pounds of N per acre were applied to all except control plots. On April 8, 80 and 160 pounds N per acre were applied, establishing the 160- and 240-pound rates, respectively; on June 7 an additional 80 pounds were applied to the plots which had already received 240 pounds to establish the 320-pound rate. The object was to provide N levels that would allow plants to become deficient at different times and to maintain one level where plants would remain adequately supplied all season. Fertilizer nitrogen was applied as ammonium sulfate except on June 7 when ammonium nitrate was used. Starting March 25, 15 to 20 petioles of recently matured leaves were collected at two-week intervals from the center two rows of each subplot and oven-dried for subsequent analysis for NO_3-N (2). At each harvest, beets of the center 50 feet of the two center rows of appropriate subplots were harvested. Fresh weights of roots and tops were determined and two samples of 15 roots each were taken for tare and sucrose determinations.

To determine "days of nitrogen deficiency prior to harvest," NO_3-N values of each subplot were plotted against dates. The number of days below 1000 ppm NO_3-N (dry basis) were averaged for replicates of the same nitrogen level and date of harvest.

Results

Table 1 gives the mean NO_3-N concentration in petioles for several sampling dates of subplots of each harvest and means for top yield, root yield and percent sucrose in roots for subplots of the respective harvest dates. In general the plants showed deficiency symptoms, and the concentration of NO_3-N reached the

Table 1.—Effect of nitrogen fertilization on growth of sugar beets, sucrose concentration of roots and on nitrate-nitrogen concentration of petioles of recently matured leaves. Values are means of four replications.

Fertilizer nitrogen[1] (pounds/ acre)	ppm (dry wt. basis) NO_3-N in petioles									Tons/acre fresh wt.		% Sucrose in roots
	4/8	4/22	5/5	5/21	6/3	6/16	7/6	7/26	8/16	Tops	Roots	
					Plots harvested May 24							
0	1880	62	100	130						4.6	5.5	13.9
80	12900	3810	160	160						12.7	9.8	14.0
160	12500	6540	1300	650						19.6	10.2	12.2
320	13100	7300	3430	1820						22.4	9.5	12.1
					Plots harvested June 16							
0	1880	140	110	90	130	240				6.8	11.8	15.2
80	12900	2770	160	130	130	210				13.5	17.0	15.5
160	13500	6170	1530	520	520	270				21.9	18.6	14.2
320	13200	7220	1630	1640	1100	2240				29.6	19.4	12.7
					Plots harvested July 6							
0	1010	120	120	170	190	280	250			8.5	15.3	15.1
80	14500	3000	140	240	240	220	160			12.8	21.4	15.2
160	14800	5900	1320	990	550	850	420			23.4	23.0	14.1
320	12700	6470	2560	2450	1040	3210	3650			29.8	24.2	13.0
					Plots harvested July 27							
0	890	190	130	230	200	240	230	540		8.7	17.4	14.5
80	14200	2770	180	270	260	260	150	200		13.0	26.2	14.2
160	15100	5240	910	920	320	440	290	560		19.4	30.0	13.4
320	13100	7000	1530	1450	1270	3500	3010	1700		25.8	30.5	12.4
					Plots harvested August 17							
0	1030	190	110	180	160	200	300	1500	1910	5.6	19.0	14.7
80	14100	2680	180	230	210	650	200	540	1020	9.2	27.5	14.7
160	13400	6050	1520	640	440	340	400	700	500	12.5	32.3	13.6
320	13600	6670	2700	2060	1280	3140	2800	2200	1580	16.9	31.3	12.7
	LSD, 5%: Among N levels for same harvest date									4.4	4.1	0.8
	Among harvest dates for same N level									3.1	3.4	0.8
	Error (c) mean squares									5.09	1.99	0.269
	F values: N x Harvest dates									4.18**	6.59**	0.78
	N levels									75.62**	18.41**	128.62**
	Harvest dates									10.36**	111.89**	14.52**

[1] March 7, 80 pounds of N/acre applied to all but O-N plots. April 8, 80 pounds and 160 pounds of N applied respectively to 160 N and 320 N plots. June 7, 80 pounds of N applied to 320 N plots.

*, ** Value exceeds that required for the 5% and 1% level of significance respectively.

critical level, about 1,000 ppm (10), in early April for O-N plots, about May 3 for plants of 80 N plots and about May 15 for plants receiving 160 N. Plants fertilized with 320 N remained green and the NO_3-N content of their petioles remained above the critical level throughout the season.

An anomalous situation arose in connection with three subplots harvested on August 17. The NO_3-N concentration in petioles of one of the O-N subplots increased rapidly from 325 ppm on June 23 to 670 on July 6, to 5570 on July 26 and to 6830 on August 16. Similarly, the concentration of NO_3-N in two subplots of the 80 N rate rose from an average of 230 ppm on July 6 to 905 on July 26 and 1865 on August 16. The reasons for these increases cannot be precisely explained but were probably due to a sudden increase in soil nitrification in these plots. The result was a reduction in the sucrose concentration in the roots of plants harvested from these plots on August 17 and, therefore, a somewhat lower average sucrose concentration for the O and 80 N rates of this harvest date than would have been the case otherwise.

As top and root production indicate (Table 1) there was a marked response to nitrogen fertilization. Of particular interest is the rapid rate of root growth despite nitrogen deficiencies. As Figure 1 indicates, plants that were unfertilized grew at the rate of 1.1 tons of roots/acre week from June 16 to July 27; those receiving 80 pounds of N/acre grew at the rate of 1.5 tons/acre week. Plants receiving 160 and 320 N had the same root growth during this period of ca. 1.8 tons/acre week despite the fact that plants of the 160 N rate were nitrogen deficient throughout the harvest period while those of the 320 N rate were not..

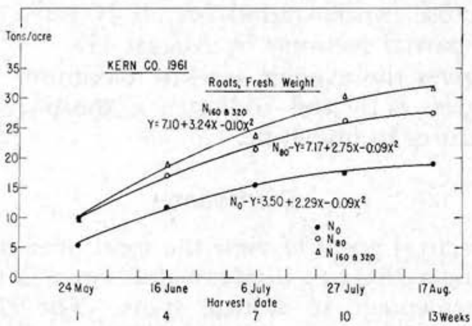

Figure 1.—Root growth as influenced by nitrogen fertilization and time of harvest. $N_{160 \text{ and } 320}$ are means of the combined nitrogen treatments. X in regression equations is the week of harvest.

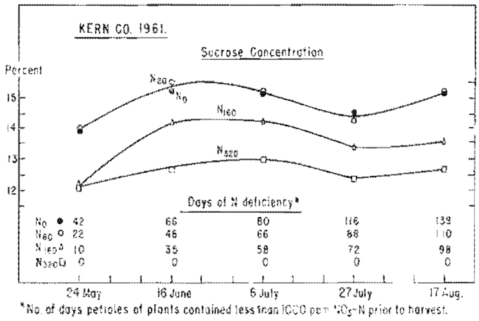

Figure 2.—Sucrose content of beet roots related to time of harvest, nitrogen fertilization and duration of nitrogen deficiency prior to harvest.

Figure 2 illustrates the time course of changes in sucrose concentration as influenced by nitrogen fertilization, and gives the associated days of nitrogen deficiency indicated by petiole analysis. Values for the three high nitrogen plots of the zero and 80 N rates were not included in plotting sucrose concentrations for the August 17 harvest and thus the values shown in the figure more nearly represent a typical situation. Plants not fertilized and those receiving 80 N had essentially the same sucrose concentrations. Both attained maximum concentrations of ca. 15% in mid-June after periods of nitrogen deficiencies of 66 and 46 days respectively. With 160 N the peak sucrose concentration also occurred in mid-June but at a lower level (ca. 14%) and after only 35 days of N deficiency. Thus, extending nitrogen deficiency beyond June 16 did not result in further increases in sucrose concentration suggesting that climate had an overriding influence. The sucrose concentration of roots of plants fertilized with 320 N did not change greatly throughout the season but was highest in early July. There was a general decline in sucrose concentration for all N rates at the July 27 harvest and a partial recovery by August 17.

Figure 3 gives the average weekly maximum and minimum air temperatures (11) and indicates a sharp rise in day and night temperatures in mid-June.

Discussion

From a practical point of view the most prominent feature of responses of sugar beets to nitrogen deficiency is the increase in the sucrose percentage in storage roots. The change may be visualized as resulting from inhibition of vegetative growth which permits a higher proportion of the sucrose produced in the leaves to accumulate in the roots rather than be utilized in growth

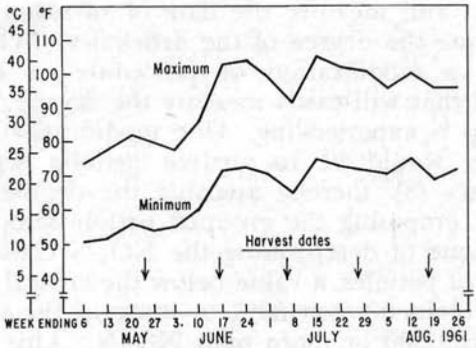

Figure 3.—Weekly mean temperatures, Kern County Airport. Data of U. S. Weather Station.

processes. The degree of the shift in this growth-storage balance is dependent upon many factors. Thus, the increase in sucrose concentration is dependent upon the length and degree of the deficiency, root size, and the amount of photosynthesis, as well as the temperature regime under which the response is studied.

In pot experiments, where the degree of the nitrogen deficiency can be controlled, extreme values may be obtained. Maximum sucrose concentration is usually obtained within 6 to 8 weeks after the beginning of the nitrogen deficiency and increases in sucrose have been found to be inversely proportional to the initial root size (4). The present field trial typifies the kind of nitrogen deficiency responses which are commonly observed on fields with high residual nitrogen. Under these conditions the sugar beet plants continue to make rapid root growth indicating that although they are deficient in nitrogen the degree of deficiency is slight, and the plants appear to be receiving a high percentage of the nitrogen that they require for maximum growth. The results of the present trial clearly indicate that the degree of deficiency is as important or more important than the length of the deficiency period under such conditions. This is particularly evident in the fact that roots of the nitrogen deficient plants of the 160 N rate grew as rapidly as did those fertilized with 320 N.

At present such a situation can be assessed only by observing nitrogen deficiency responses, i.e., by measuring crop growth. Soil analysis procedures which would predict the nitrogen supplying power of a soil, or the rate at which nitrogen might be supplied do not exist. While plant analysis, utilizing the average content of nitrate nitrogen in a group of petioles, serves admirably to predict and measure the date of nitrogen deficiency, it does not indicate the degree of the deficiency. What appears to be needed is a modification of procedure or an additional diagnostic tool that will easily measure the degree of deficiency a particular crop is experiencing. One modification, although an expensive one, would be to analyze petioles separately from individual beets (8), thereby assessing the degree of deficiency among plants composing the grouped petiole sample. With the present technique of determining the NO_3-N content of a composited group of petioles, a value below the critical level of 1,000 ppm can be obtained when 50% or more of the petioles in the sample contain 1,000 or more ppm NO_3-N. This is due to the considerable variability that occurs from plant to plant in a field (8). In such a case the degree of deficiency is less than when a larger percentage of the petioles are below the critical value. Another possibility would be to analyze for other forms of nitrogen; e.g., soluble nitrogen in blade or petiole tissue might more clearly indicate the degree of deficiency.

This experiment affords an interesting comparison of the effect of fertilizer nitrogen on top growth compared to root growth (Table 1). As early as June 16, plants that were fertilized with 320 N produced more tops than those that received 160 N. This growth differential continued through the last harvest on August 17, yet the higher N rate never resulted in more root growth. Thus when soil nitrogen is low it appears that roots take precedence over tops for the use of nitrogen in growth.

Several other important practical conclusions may be drawn from the present experiment. It is of interest to compare the control plants which received no supplemental nitrogen with those that were fertilized. The nonfertilized plants were nitrogen deficient for only about three weeks longer than plants receiving 80 N and about 4 weeks longer than plants receiving 160 N (Table 1) yet their growth rate (Figure 1) during the period of nitrogen deficiency was much less than the fertilized plants. There are many possible explanations for this occurrence, two of which are worth mentioning at this time. The O-N plants became nitrogen deficient about April 10, just as the crop was beginning to make its most rapid growth, as a result these plants never achieved good foliage development, and thus appeared to have insufficient photosynthetic area to support the crop during the subsequent growth at low nitrogen. In addition, plants in these plots may have had poor fibrous root development, and thus did not have access to nitrogen released by the soil during the summer period.

Another important observation relates to the magnitude of the increases in sucrose concentrations which were observed. The plants which received zero and 80 N became nitrogen deficient in April and the small roots rapidly increased in sucrose concentration to over 15%; whereas plants of the 160 N plots which became nitrogen deficient in mid-May with a much larger root size, and with tops and roots growing at a more rapid rate attained a lower maximum of 14.2%. It appears that after June 16 temperature had an overriding effect and the combination of rapid root growth and reduced photosynthetic surfaces prevented further gains in the sucrose concentration of nitrogen deficient plants.

Summary

A field experiment involving four rates of nitrogen fertilization and five dates of harvest was conducted to determine how long sugar beets should be deficient in nitrogen prior to harvest to attain high sucrose concentrations. The sucrose content of roots did not exceed 15.5% even though some plants were deficient for 139 days prior to the last harvest on August 17. With an onset of nitrogen deficiency, maximum sucrose contents were reached in from 4 to 6 weeks. The failure to attain high sucrose concentrations in roots was related to high temperatures, rapid rates of root growth and reduced photosynthetic surfaces of nitrogen deficient plants.

Midseason nitrogen deficiences were readily detected by petiole analyses. However, there was little or no effect of such a deficiency on the rate of root growth indicating that the plants were taking up most of the nitrogen they needed for maximum root growth. Such results indicate the desirability of modifying current procedures or finding a new diagnostic tool to more accurately reflect the degree of nitrogen deficiency.

Acknowledgement

We thank Mr. N. L. Ritchey for furnishing the land for this experiment and for carrying out the cultural practices and the Spreckels Sugar Company for assistance in harvesting and for laboratory analyses of root samples.

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