Nitrogen Fertilization of Sugar Beets In the Woodland Area of California

I. Effects upon Glutamic Acid Content, Sucrose Concentration and Yield

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The importance of nitrogen in a fertilizer program for efficient sugar production has been demonstrated in numerous studies on the nutritional requirements of sugar beets. Deficiencies of nitrogen are known to result in low tonnages of beets having high sucrose concentration, while excesses of nitrogen under conditions favorable to growth give high tonnages with beets relatively low in sugar and purity, thereby making sugar recoveries at the refinery more difficult. Evaluation of the nutrient status of the crop has been based usually upon yield and especially sugar data. Occasionally, plant absorption of applied nutrient as determined by leaf petiole analysis has also been taken into account. The present study, made possible by combining the interests of several research groups, includes an additional measurement, that of glutamic acid content of the beet root.

Plant nutrient surveys in California have indicated that the Woodland area of the Sacramento valley is low in nitrogen, although casual tests with this element under field conditions have given both positive and negative results. Alfalfa preceding beets in crop rotation frequently results in a high tonnage of sugar produced and in a high glutamic acid content. In order to obtain a clearer picture of the response to fertilizer in this area, a series of experiments was undertaken cooperatively during 1947 and 1948 by the Spreckels Sugar Company, International Minerals & Chemical Corporation, and the College of Agriculture of the University of California. In this series of 11 fields it was thus possible not only to study the amount of nitrogen required for maximum sugar production, but to observe the relationship of various amount of nitrogen fertilizer to the nitrate concentration of the petioles and to the glutamic acid concentration of the beet roots.

Petiole studies will be reported in the second paper of this series (1)[4]. The effects of nitrogen fertilization on beet and sugar yields and upon sucrose and glutamic acid concentrations at harvest will be considered here. It appears that the glutamic acid might serve as a basis for a rough estimate of the amount of nitrogen available in the soil. Certain differences in the effects of nitrogen upon sugar become apparent when glutamic acid measurements are taken into consideration: it is possible that some changes in sugar concentration have previously been incorrectly ascribed to nitrogen. This must be taken into account in working out a long range program for

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predicting accurately the best fertilizer usage for each field. The sugar-glutamic acid relationship is suggested tentatively as a useful indicator of the type of crop giving the most profit to the grower.

Procedure

Sis. fields were included in the 1947 experiment and five in 1948. All of the fields were located near Woodland. Attempts were made, though not too successfully, to select fields of initial low, medium and high fertility for these studies. The experimental design was a randomized complete block with 8 replications of 5 fertilizer treatments. Ammonium nitrate was applied with a Fairbanks experimental applicator as a side dressing at thinning time. In 1947, treatments of 0 (machine check), 80, 160, 240 pounds of nitrogen per acre, and 240 pounds of N + 200 pounds P_20_5 (as treble superphosphate) were used. Plots were 6 rows wide and 100 feet long, the center 160 row feet being the harvest area. In 1948, 50, 75, 100, 125, and 175 pounds of nitrogen per acre were applied to plots 8 rows wide and 60 feet long. The harvest area was the center 200 row feet.

The fields studied, the growers who cooperated in each trial, and the dates of planting, application of fertilizer, and harvest are listed in the following summarization:

Field	Grower	Planting Date	Fertilizer Date	Harvest Date
R	Reel, A.	1-26	4-25	8-21-37
M	Moore, A.	2-7	5-6	8-25-47
W	Wilder, W.	3-29	5-14	9-11-47
H	Hass, B. and Ullrich, E.	3-22	5-9	10-20-47
K	Knaggs, J. and Oeste	3-15	5-16	11- 3-47
C	Carlson, H.	4-19	5-23	11-11-47
Ri	Rigney, W.	2-21	4-26	10- 2-48
L	Lowe, K.	1-31	5-1	10-14-48
G	Gill, R.	2-12	5-12	10-27-48
B	Barry, G.	3-10	5-11	11- 9-48
Be	Bender, G.	1-18	4-24	11-11-48

Variety U.S. 15 was used in fields R, L, G, and Be; U.S. 22 in M, Ri, and B; and U.S. 33 in H, W, K, and C. Judging from the appearance of the fields, they were supplied adequately with moisture. Some wilting was noted in fields K and Ri, however.

Sucrose and glutamic acid determinations (2) were made on 40 beet samples taken at random from the harvest areas. Apparent purity determinations were also made on all samples, but are not reported here. Yields were obtained from the weight of all the beets in the harvest area.

Calculations of net return to the grower on the basis of average conditions in the Woodland area were carried out using data on smooth curves passed through the experimental averages. Payments on beets were based on sugar at a net value of §6.50, government benefit included, and values of tops at $0.40 per ton of roots. Average costs per acre were estimated on the basis of $0.12 per pound of nitrogen plus $1.00 for application; net loading and hauling at $0.625 per ton of roots, and harvesting at the usual contract machine harvest rate of $15.00 plus $0.70 per ton of beets.

Discussion

The effects of the various fertilizer treatments upon percent sucrose and glutamic acid, and upon beet and sugar yields, are listed in Tables 1 and 2. The most marked effects of nitrogen fertilizer are on the glutamic acid and sucrose concentrations. Effects on tons 'of beets, tons of sugar and on crop value can be measured with much less accuracy (note the lower F values), because of the relatively large error *in* yield measurements.

Table 1.—The Effects of Nitrogen Fertilization upon Sugar Beets Grown in the Woodland, California, Area in 1947.

Field	Treatment Lbs. N/Acre	Per Cent Sucrose	Per Cent Glutamic Acid	Tons Beets per Acre	Tons Sugar per Acre
K	0	17.5	0.08	25.0	4.38
	80	16.9	.14	27.9	4.71
	160	16.1	.17	28.0	4.52
	240	15.5	.22	28.7	4.47
	240+P	15.4	.25	27.8	4.28
	L.S.D. (19:1)	0.5	23%	2.1	(0.40)
	F value	22.4	36.4	4.1	1.4
H	0	18.3	0.07	16.3	2.99
	80	17.7	.12	22.1	3.92
	160	17.3	.16	23.8	4.12
	240	16.3	.22	23.8	3.90
	240+P	16.1	.25	23.9	3.86
	L.S.D. (19:1)	0.5	14%	1.3	0.23
	F value	23.2	137.7	51.2	30.6
W	0	17.3	0.03	5.9	1.03
	80	17.1	.04	13.2	2.26
	160	16.9	.06	17.3	2.93
	240	16.4	.08	19.6	3.22
	240+P	15.8	.09	19.6	3.11
	L.S.D. (19:1)	0.7	32%	5.5	0.60
	F value	5.7	27.9	23.1	17.0
K[1]	0	17.2	0.12	20.0	3.45
	80	17.0	.20	22.8	3.86
	160	15.9	.31	22.3	3.54
	240	15.5	.37	23.3	3.60
	240+P	14.9	.37	22.4	3.36
	L.S.D. (19:1)	0.8	24%	(2.5)	(0.50)
	F value	13.9	41.4	2.1	0.8
M	0	18.0	0.12	20.4	3.66
	80	16.9	.20	23.9	4.01
	160	16.5	.24	26.2	4.30
	240	14.6	.34	27.3	3.99
	240+P	14.5	.35	28.0	4.05
	L.S.D. (19:1)	0.6	13%	1.6	0.30
	F value	53.5	113.8	31.7	4.6
C	60	17.0	0.12	19.3	3.27
	140	16.5	.21	21.7	3.59
	220	16.1	.31	24.8	4.01
	300	15.4	.35	25.4	3.93
	300+P	15.4	.38	24.7	3.80
	L.S.D. (19:1)	0.5	11%	1.9	0.35
	F value	14.1	157.7	16.5	6.0

[1] Nine replications instead of the usual 8.

L.S.D. (19:1) are in parentheses when the F values are not significant.

Glutamic Acid Concentration: Glutamic acid shows a striking response to nitrogen fertilization, a response that is more marked than any other character observed in harvestable beets. The percentage increase is greater, and the chances of the effect being a real one, as measured by the errors involved[5], are considerably better than those for sugar, yield or purity measurements. The average response, judging from the present series of experiments, can be expected to be between a 30 and 70% increase per 100 pounds of nitrogen applied at thinning time. The actual average increase (between the limits of 50 and 175 pounds of nitrogen per acre) for the 11 fields described was 49% per 100 pounds of N applied. This implies that an unfertilized crop yielding 0.1% glutamic acid would have given 0.149% glutamic acid after fertilization with 100 pounds of nitrogen, if its response had been average; one yielding 0.2% would have given 0.298%.

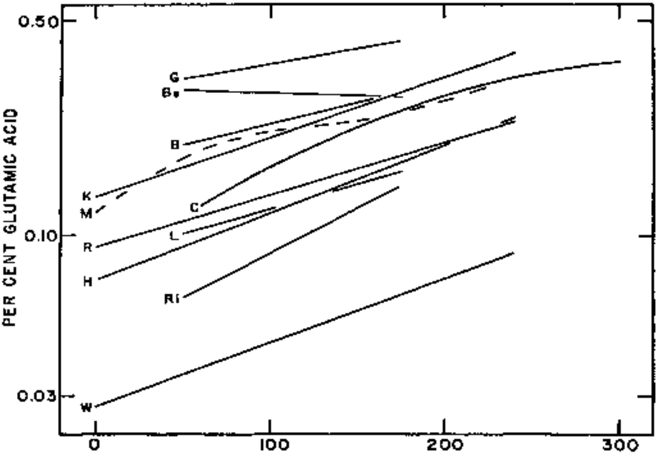

FIG. 1

Figure 1. Response of Glutamic Acid to Nitrogen Fertilizer.
Glutamic acid content of beets at harvest time plotted against the amount of fertilizer nitrogen applied as ammonium nitrate at thinning time. Each line depicts the response in a single field in 1947 (240 pound N range) or in 1948 (125 pound N range).

The significant effect of fertilizer nitrogen upon glutamic acid obtained in all except one field (Be) are shown in Fig. 1. There were wide variations not only in the average glutamic acid concentration (0.05 to 0.37 at 105 pounds of N per acre) , but also in the magnitude of the response (from **a** 4% decrease to a 95% increase) . Only two fields, M and C, showed any

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[5] See F values in Tables 1 and 2.

significant deviation from a straight line response when glutamic acid was measured on a logarithmic scale[6], and only field C showed a tendency toward decreased response at the higher levels. It may be concluded that the amounts of fertilizer used were far short of those which would be needed to bring glutamic acid to a maximum.

Sugar Concentration: All fields except Be showed regular decreases in percent sugar with increasing nitrogen, although the results were not so highly significant as the glutamic acid increases. The decrease in sugar in most cases tended to accelerate at higher fertilizer levels. The only indication that a minimum sugar concentration was being approached was in the very unusual field, Be.

Tonnage of Beets: Yield of roots showed significant changes in only 6 of the fields (R, M, W, H, C, and Ri) , and covered a wide range of possible responses from a straight line increase in field Ri to a probable decrease in G. The only fields in which plant population had a significant effect on the results were C, K, and W. Field C showed considerable difference in harvestable stand due to loss of beets during cultivation. Values reported for yield of beets and sugar have been equalized to the average stand. Field K contained 12 plots in which the border rows on one side were destroyed. The resulting loss of competition caused an average increase of 4.7 tons per acre. Values reported for tonnage of beets and sugar are estimates of the average tonnage after removal of this source of bias.

In field W, there were enormous differences in tonnage resulting from disease conditions which were corrected partially by the application of nitrogen fertilizer. Identification of the diseases present and counts of the "unmarketable" and "still marketable" infected beets were made by Dr. L. D. Leach[7]. Beets designated as "unmarketable" were those in which the infection had progressed to such an extent that they would not have been picked up during hand harvest. Three diseases were present: wet root rot *(Phytophythora drechsleri* or *Pythium aphanidermatum)* , southern sclerotium root-rot *(Sclerotiurn rolfsii)*, and dry-rot canker *(Rhizoctoriia solani)*. Wet root rot, which infected 4.2% of the beets and is predisposed by excessive soil moisture, was unaltered by fertilization. Data on sclerotium root-rot and dry-rot canker are given in the following summarization:

Infection	Treatment—Pounds of N per Acre				
	0	80	160	240	240+P
	Per Cent of Total Beets Infected				
So. Sclerotium Root-Rot					
Unmarketable	14.0	11.5	4.7	3.3	1.9
Still marketable	3.7	4.5	3.7	2.3	1.5
Dry Rot Canker					
Unmarketable	8.6	4.6	2.6	1.2	1.6
Still marketable	4.4	6.4	7.4	7.8	5.2
Missing at Harvest	22.0	3.6	-----	-----	-----

Percents are based on estimates of the total original population.

The beets missing at harvest were obtained by comparing thinned stands with the number of beets at harvest. It appeared that 22% had disappeared

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[6] The reasons for the use of logarithms are discussed in a paper reported previously (2).

[7] Plant Pathologist, California Agricultural Experiment Station, Davis, California.

in the unfertilized plots prior to harvest, whereas practically all of the beets in the 160 and 240 treatments could be accounted for at harvest.

The increase in the number of marketable beets by nitrogen fertilization was very significant; the effect of phosphorus at the high N level was not. The action of the fertilizer appears to be somewhat different in the two diseases. With southern sclerotium rot, the incidence of infection was reduced with each increase of nitrogen applied, as previously established by Leach (3) . Here the "still marketable" beets probably represent recent infections. In the case of dry rot canker, the total number of infected beets was nearly as large in the fertilized as in the unfertilized treatments, but the percentage of unmarketable beets was reduced strikingly by nitrogen application. In the heavily fertilized treatments most of the infections were arrested and the beets were still acceptable. Susceptibility to both infections became marked at a level of nitrogen fertility corresponding to a glutamic acid content of about 0.05%.

Table 2.—The Effects of Nitrogen Fertilization upon Sugar Beets Grown in the Woodland, California, Area in 1948.

Field	Treatment Lbs. N/Acre	Per Cent Sucrose	Per Cent Glutamic Acid	Tons Beets per Acre	Tons Sugar per Acre
Ri	50	16.5	0.06	17.4	2.88
	75	16.3	.08	18.5	3.01
	100	15.9	.09	18.8	3.00
	125	15.8	.10	20.7	3.27
	175	15.3	.15	23.0	3.56
	L.S.D. (19:1)	0.6	23%	2.1	0.35
	F value	5.1	19.4	9.5	4.5
G	50	15.7	0.32	32.2	5.05
	75	15.2	.35	32.1	4.88
	100	15.2	.36	32.0	4.87
	125	15.1	.38	31.7	4.77
	175	14.7	.43	30.9	4.53
	L.S.D. (19:1)	(0.8)	(22%)	(1.1)	(0.35)
	F value	1.4	2.2	2.0	2.5
B	50	15.5	0.20	31.3	4.84
	75	15.5	.21	30.6	4.72
	100	15.0	.23	32.0	4.80
	125	15.0	.25	30.8	4.60
	175	14.0	.30	31.5	4.43
	L.S.D. (19:1)	0.5	14%	(1.7)	(0.32)
	F value	11.8	11.5	0.9	2.2
L[1]	50	14.9	0.09	24.6	3.67
	75	14.7	.12	24.7	3.64
	100	14.3	.12	24.4	3.50
	125	14.2	.14	24.1	3.42
	175	13.3	.15	24.8	3.30
	L.S.D. (19:1)	0.6	21%	(1.1)	0.21
	F value	10.5	8.5	0.5	4.7
Re	50	13.2	0.29	30.9	4.07
	75	12.7	.31	31.9	4.05
	100	12.6	.31	31.5	3.96
	125	12.4	.26	30.3	3.76
	175	12.6	.29	30.7	3.84
	L.S.D. (19:1)	(0.8)	(14%)	(1.4)	(0.26)
	F value	1.0	2.7	1.8	2.2

[1] Only 7 replications instead of 8.

L.S.D. (19:1) are in parentheses when the F values are not significant.

Tons of Sugar per Acre: Five fields (R, M, H, K, C) showed maximum values for yield of sugar, though in two of these (R, K) the changes were not large enough to be significant. All five occurred in the 1947 experiments, which illustrates the value of using unfertilized controls and a range of at least 240 pounds of nitrogen per acre in such experiments. Three (R, Ri, L) of the remaining 6 fields gave significant differences. Tests carried out on the unfertilized border area of field L indicated the probability of a sharp optimum at 50 pounds of nitrogen per acre.

Table 3.—The Estimated Fertilizer Level for Maximum Return to the Grower and the Per Cent Sucrose and Glutamic Acid of the Corresponding Crop.

Field	Pounds N/Acre	% Sucrose	% Glutamic Acid
H	120	17.5	0.18
K	70	17.0	.19
R	60	17.0	.12
M	110	16.9	.21
C	210	16.1	.30
G	50	15.7	.32
B	50	15.5	.20
W	240	16.2	.09
Ri	175	15.8	.15
Y	95	15.5	.13
L	50	14.7	.09

Crop Value: Calculations of net return from fertilizer applied were used to obtain estimates of the optimum level of nitrogen usage for the grower. The same procedure was applied to the field at Yolo, California, (Y) previously described (2) . These estimates are shown in the first column of Table 3. They average around 120 pounds of nitrogen per acre, but the spread of values from field to field is so great that the average fertilizer requirement for the area cannot be estimated with any precision from these data. It might also be concluded that use of an average fertilizer requirement for the area, even if known accurately, could result in fairly frequent losses to the grower of as much as $50 per acre through missing the actual optimum for his particular field.

Obviously much of the difference in nitrogen requirement was caused by differences in fertility before the application of fertilizer. Accordingly, it was hoped that the glutamic acid or sugar content, both changing rapidly with nitrogen supply, would give a measure of the quality of the crop giving the optimum return to the grower. Sugars and glutamic acids expected at the optimum N level for each field were estimated from smooth curves through the original data. These are also shown in Table 3. On the average, the results center at about 16.2% sucrose and 0.20% glutamic acid for the most profitable crop. Here again, the range of results is disappointingly large, from 14.7 to 17.4% for sugar and 0.09 to 0.3% for glutamic acid.

Much of this variation may be explained by a consideration of the relationship between sugar and glutamic acid in beets. This is shown in Fig. 2 where the lines represent the change in sugar and glutamic acid produced by varying amounts of nitrogen fertilizer. The crops responded generally in a similar fashion, the curves being nearly parallel, but there are highly significant differences in the relative positions of the curves for the various fields. The data fall into three sharply distinguished groups which may be characterized by the sugar obtained when fertilizer produced a glutamic acid concentration of 0.1%. The major group of seven fields has a sugar of about 17.6% at 0.1% glutamic acid; the second group, 16.0% sugar; and the lowest field (L), 14.7%. The fields seemed to maintain this difference at all levels of glutamic acid.

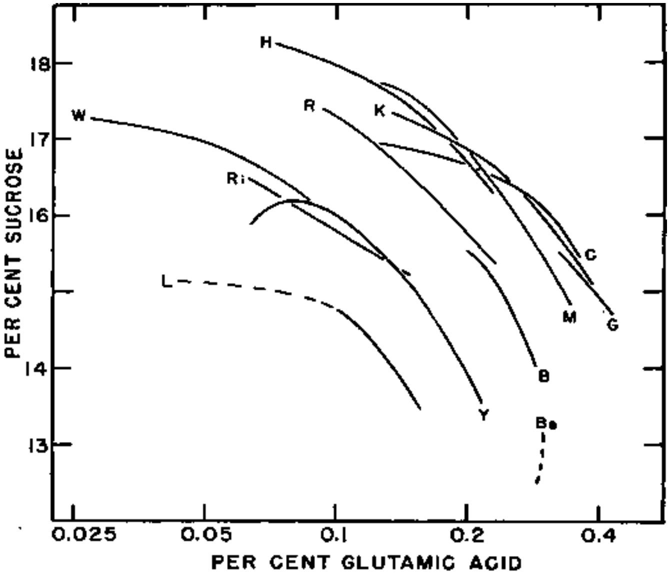

Figure 2. Changes in Sugar and Glutamic Acid Produced by Varying Amounts of Nitrogen Fertilizer.

Lines depict the fall in sugar and the increase in glutamic acid in various fields as fertilizer nitrogen is increased.

All fields tended to produce the optimum crop near the shoulder of these curves; best crops were never obtained with too low sugar or too low glutamic acid. The three groups gave optimum return from fertilizer at the following average values:

Group	% Sucrose	% Glutamic Acid
I (H, K, R, M, C, G, B)	16.8	0.19
II (W, Ri, Y)	15.7	0.12
III (L)	14.8	0.09

The stratification of fields on the basis of both sugar and glutamic acid appears to improve greatly the accuracy of estimates of the best fertilizer usage. Thus, the larger group varies only from 16.1 to 17.5% in sucrose concentration producing the best crop. Inaccuracy in yield data and need for further stratification probably account for much of the remaining error.

The tendency for the optimum sugar to increase as the optimum glutamic acid increases is probably a continuous change, the three groups noted in these experiments being due to chance field selection. The magnitude of the increase in sugar is such that the purity would be higher in the higher sugar fields, other things being the same.

There is little evidence in the data as to possible causes of the differences between the three groups. Soil nitrogen has no possible connection. Seed variety or the amount of irrigation had no apparent effect. There is a slight tendency, probably not significant, for the higher sugar fields to show higher tonnage, and for them to have an optimum tonnage more closely approaching the maximum obtainable with increasing nitrogen.

The only factor known to affect the sugar-glutamic acid relationship is that of age of beet (2). The rate of change of sugar during the harvest season is such that it can explain only a small part of the differences between fields noted. It seems probable that environmental factors (such as stage of growth during thinning operations, minor elements, etc.) regulating speed of early growth may be important.

A general picture of the changes described may be obtained from the concept of both sugar and glutamine (precursor of glutamic acid) as storage compounds. Factors producing good storage conditions, such as slow growth rate prior to harvest, tend to raise the concentration of both compounds, and may be grouped together as the *storage potential* of the crop. Soil nitrogen affects the two compounds in the opposite direction, but in very similar fashion. Sugar at harvest is determined by the storage potential less the nitrogen effect, and glutamic acid by the storage potential plus the nitrogen effect (in this case nitrogen is relatively more important). The sum of the two measurements, taken in proper proportion, eliminates the large nitrogen effect altogether, and gives a quantity proportional to the storage potential of the crop.

The findings help to explain why early nitrogen determinations have been of such little value in predicting best nitrogen fertilizer levels, since the manner of utilizing the nitrogen varies so much from field to field. Fields with a high storage potential will require more nitrogen to reach their most profitable crop.

Summary

Glutamic acid undergoes a geometric increase with nitrogen fertilizer averaging 49% increase per 100 pounds of nitrogen per acre. Actual glutamic acid values varied from 0.03 to 0.44% in different fields at different fertilizer levels. The response of glutamic acid to nitrogen bears a striking correlation to that of sugar, though in the opposite direction. Fields at the same glutamic acid concentration show significant differences in the amount

of sugar present. Those with relatively high sugar at a given glutamic acid level maintain their relative advantage in sugar as fertilizer is increased. This new relationship may be useful in distinguishing between fields with too much nitrogen and those low in sugar for other reasons.

The best crop of beets, from the grower's standpoint, is the one produced with that amount of nitrogen resulting in the highest net return. From the average of these experiments, the best crop in the Woodland area contains about 16.2% sugar. This figure varies from field to field with the capacity to store up nitrogen, being 16.8% in beets containing 0.19% glutamic acid and 14.8% in beets of 0.09% glutamic acid.

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