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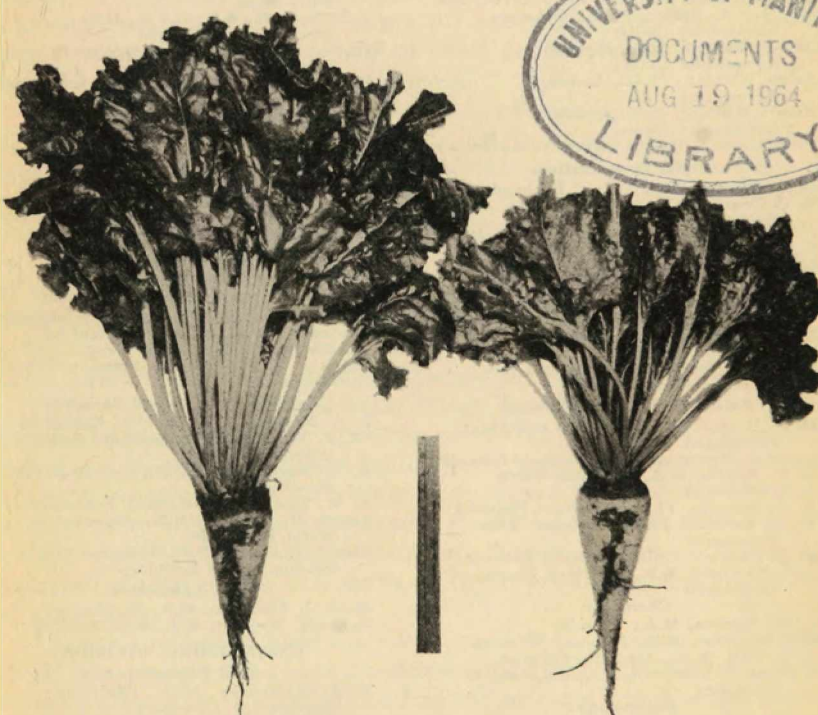
The Nitrogen Requirement of Sugar Beets

ROBERT GARDNER and D. W. ROBERTSON



A sugar beet fertilized with an excess of ammonium sulfate on the left is shown in contrast with a normal beet on the right.

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The Nitrogen Requirement of Sugar Beets

ROBERT GARDNER AND D. W. ROBERTSON

BOTH the acre yield of sugar beets and the sugar percentage in the beets are affected by soil fertility. However, the conditions which are favorable to high yields of beets are not always favorable to high sugar percentage. It is therefore important that sugar beet producers understand the conditions which are favorable to both yield and sugar content if they are to get the best results from their efforts to maintain soil fertility. Some of these conditions are known, but the problem needs further investigation.

In 1912 Headden (*5*) showed that a well-regulated nitrogen supply in the soil is particularly important in sugar beet production because beets need large quantities of this element for growth but suffer in reduced sugar percentage when the available supply is too large. Nees (*7*) and others have also shown the tendency of beets to be low in sugar if the nitrate content is high. A better understanding of the nitrogen requirement of sugar beets and of ways of controlling the supply to meet this requirement is needed to help farmers improve the yield and quality of their beets. This bulletin is a report of an effort to obtain additional information on the problem.

The experimental work upon which the report is founded was designed primarily to clear up much prevailing uncertainty regarding the effects of excesses of plant-available nitrogen and the approximate nitrogen requirement for maximum beet sugar production. Because of the many differences of opinion, it was considered advisable to make a study of these basic questions in advance of some more directly practical studies of the best kinds of fertilizers to use and best rates of application.

For many years there has been considerable uncertainty among sugar beet growers and many research men regarding the amount of excess nitrogen in the soil in the form of nitrates which is necessary to cause appreciable loss in sugar percentage and regarding the amount of available nitrogen necessary for maximum yield. Also there has been considerable uncertainty regarding the effect of manure on high nitrates and sugar percentage. For several reasons no attempt was made in this experiment to study the amount of nitrogen necessary to produce the most economical results in nitrogen-deficient soils. The first of these reasons is that the economical rate of application depends so much on the degree of nitrogen deficiency that it was not considered possible to study this phase adequately without an extensive study of the variable extent of nitrogen deficiency and nutrient balance over the sugar beet producing areas. It was necessary to limit this experiment to work which could be conducted on the Colorado Agricultural Experiment Station Agronomy Farm which, because of its natural fertility and previous cropping history, is comparatively well supplied with available nitrogen.

It appears logical to determine first the approximate level of available nitrogen in the soil which produces the maximum crop value. Such information can then be used as a basis of comparison in estimating the degree of nitrogen deficiency and the rate of fertilizer application necessary to bring any individual soil up to the optimum point. This is based on the assumption that means can be devised to measure with some degree of accuracy the amount of available nitrogen which a soil can be expected to contribute to the crop in addition to what is added as fertilizer. Fertilizer studies in the form of conventional field trials have proved somewhat unsatisfactory because of the great variation in soil fertility and the difficulty of predicting from a fertilizer trial what results will be obtained on a soil of different fertility level.

In making a study of the effect of excessive rates of fertilizer application, the necessity of limiting the work to a single farm was not such a handicap as in the case of nitrogen deficiencies. The rates of application were so large that differences normally occurring between farms are small by comparison. Generalizations from the excessive nitrate studies can therefore be considered to have a broader application. Many of the rates of application were so heavy that they would never be commercially feasible, but it was necessary to make these heavy applications to be sure that the high quantities of nitrates sometimes found in the field were reached and to observe the toxic effect (if any) of these high concentrations.

Experimental Methods

The experimental procedure followed in this investigation consisted of a study of the changes in growth, sugar content, and nitrogen content of sugar beets caused by variations of nitrogen in the soil. The study included the natural variations in the soils as well as artificial variations which were produced by the addition of fertilizer materials. One set of experiments was conducted in which widely varying amounts of calcium nitrate and ammonium sulfate were applied as soil fertilizers, and a second set consisted of manure and fallow treatments. The kinds of fertilizers used and the rates of treatments are shown in tables 1 and 2. The experiments were set up in randomized blocks with each treatment in triplicate in 1933, and in quadruplicate in 1934 and 1935. The 1935 commercial nitrogen experiment was continued through 1936 and 1937 to study the residual fertilizer effects. Small grain was grown the year previous to the sugar beets, except that beets followed beets in the 1934 nitrogen plots. The crop history of the land extending back 6 years is shown in table 3.

TABLE 1.—*Rate of fertilizer application.*

Rate of application (pounds of element per acre)					
1933	1934		1935		
N*	N*	P	N*	N**	P
0	0		0	0	
20	60		30	30	
30	90		60	60	
60	180		90	90	
90	270		180	180	
180	540		270	270	
270	810		540	540	
540	1,620		810	810	
810	2,430		1,620	1,620	
1,620	4,860	1,000	810		1,000
		1,000			1,000

*Applied as $Ca(NO_3)_2$.
**Applied as $(NH_4)_2SO_4$.

The soil on the Agronomy Farm where the experiment was conducted belongs to the Fort Collins Series, and with the exception of small areas of fine sandy loam in the 1934 manure plots the soil was all Fort Collins Loam.

Sugar beet yields were taken both on the basis of a perfect stand of competitive beets and on the basis of the actual yields. The results are reported on the latter basis to make the beet yields comparable with the top and sugar yields. Percentage sugar and purity[1] were determined from analysis of 10 or 20 beet samples of competitive beets taken in duplicate or triplicate from each plot. Top yields were estimated from the weight of tops in the sugar samples. At intervals during the growing season, soil samples and plant samples were collected from each plot. The soil was sampled by 6-inch or foot sections to the depth of 3 feet, and the plant samples consisted of 10 to 20 leaf petioles per plot.

The soils were tested for nitrate nitrogen and ammonium nitrogen by rapid colorimetric methods, and for available phosphorus by the methods of Hockensmith, *et al.* (*6*). Part of the soils were also tested by the method of Dahlberg and Brown (*1*). The petiole samples were tested for nitrate and phosphate by the procedure described by Gardner and Robertson (*3*). In addition to sugar and purity the beet samples collected at harvest were also tested for nitrate and phosphate, and part of them were analyzed for total nitrogen and phosphorus. Total nitrogen and total phosphorus were also determined in the 1933 beet tops.

[1]The authors are indebted to H. E. Brewbaker, formerly of the U.S.D.A., Bureau of Plant Industry, Division of Sugar Plant Investigations, and to G. W. Deming and J. O. Gaskill, of that division, for the percentage sugar and purity determinations.

TABLE 2.—*Plan of manure experiment.*

Soil treatment No.	Soil treatment Material	Rate of application	Time of application
1	Green manure (field peas)		Fall preceding beets
2	Green manure (millet)		Fall preceding beets
3	Well-rotted manure	10 tons per acre	Spring, 1 year before beets
4	Well-rotted manure	10 tons per acre	After barley crop, before beets
5	Well-rotted manure	10 tons per acre	Fall before beets
6	Well-rotted manure	10 tons per acre	Spring of planting beets
7	Strawy, fresh manure	15 tons per acre	Spring, 1 year before beets
8	Strawy, fresh manure	15 tons per acre	After barley crop, before beets
9	Strawy, fresh manure	15 tons per acre	Fall before beets
10	Strawy, fresh manure	15 tons per acre	Spring of planting beets
11	No treatment		
12	Fallow		Year preceding beets

TABLE 3.—*Previous crop history of plots used in experiment.*

Years previous to beets	1933				1934		1935	1935-37
	Manure plots		Nitrogen plots		Manure plots	Nitrogen plots	Manure plots	Nitrogen plots
	Block 1	Blks 2, 3	Block 1	Blks 2, 3				
1	Barley	Barley	Barley	Barley	Barley	Beets	Barley	Oats
2	Beets	Fallow	Beets	Fallow	Alfalfa*	Barley	Alfalfa	Fallow
3	Small grain	Beets	Small grain	Beets	"	Alfalfa	"	Alfalfa
4	" "	Wheat	" "	Wheat	"	"	"	"
5	" "	Fallow	" "	Fallow	"	"	"	"
6	" "	Corn	" "	Corn	Oats**	"	Barley	Barley

*Third cutting of alfalfa plowed under.
**10 tons of well-rotted manure plowed under previous fall.

In statistically analyzing the data it was found that they were not sufficiently homogeneous to permit the use of a generalized standard error in determining the statistical significance of differences between treatments. It was found that the plots receiving high fertilizer applications were very much more variable than the ones receiving light treatments or no treatments. The data, however, were well adapted to the study of the regression of crop response variables on soil variables. Where the data were not too numerous and too scattered, the actual data have been plotted and a smooth curve fitted to the data by sight, but where the data were somewhat numerous or scattered the best fit curves were calculated by the method of least squares and these curves presented either in the form of graphs or equations.

Experimental Results

Effect of Nitrogen on Percentage Sugar

A study of the results of the nitrate and ammonium sulfate treatments shows that where nitrogen was applied in excess of the amount that could be utilized by the beet plants before harvest a surplus of nitrate nitrogen remained in the plant sap, preventing storage of a high percentage of sugar. Within any one field where other factors besides nitrate were relatively constant, the sugar content was found to be inversely proportional to the nitrate content of the beets. However, it is evident from the scattered position of the curves in figure 1 that other factors than nitrates are involved in determining the sugar content.

The quadratic regression was calculated for each curve, but was not found to be significantly better than the linear regression in any case. It is therefore assumed that within the range of nitrate content studied the relationship is approximately linear. In every field studied the regression was statistically significant as determined by the 5-percent point. It will be noted in the graph that there is considerable difference in the slopes of the curves. The average slope indicates that a very small change in nitrate content causes a relatively large change in sugar content. The average sugar content is reduced approximately 1 percent for each .025 percent nitrate nitrogen in the beets, which is equivalent to about 10 pounds nitrate nitrogen in 20 tons of beets. The difference between nitrogen applied to the soil and nitrogen actually in the beets must be distinguished in considering this relation, since only a fraction of the nitrogen applied to the soil will appear in the beets.

Figures 2 and 3 show the rate of change of sugar content in the beet with increasing additions of nitrogen to the soil. The curves indicate that nitrates continue to decrease the sugar percentage in beets until very large amounts are added. However, the depression rate decreases with rate of application and approaches zero; in other words the point is approached where further addition of nitrate will produce only an insignificant effect. The difference in sugar percentage between no treatment and the highest applications is about 3.5 percent. A similar difference exists between normal green beets early in the season when they are still high in nitrates and the same beets at harvest time after the nitrates have been virtually exhausted. It appears from these results that the increase in sugar normally occurring in the fall is associated with exhaustion of the soluble nitrogen supply in the beets. The curves in figures 2 and 3 are, of course,

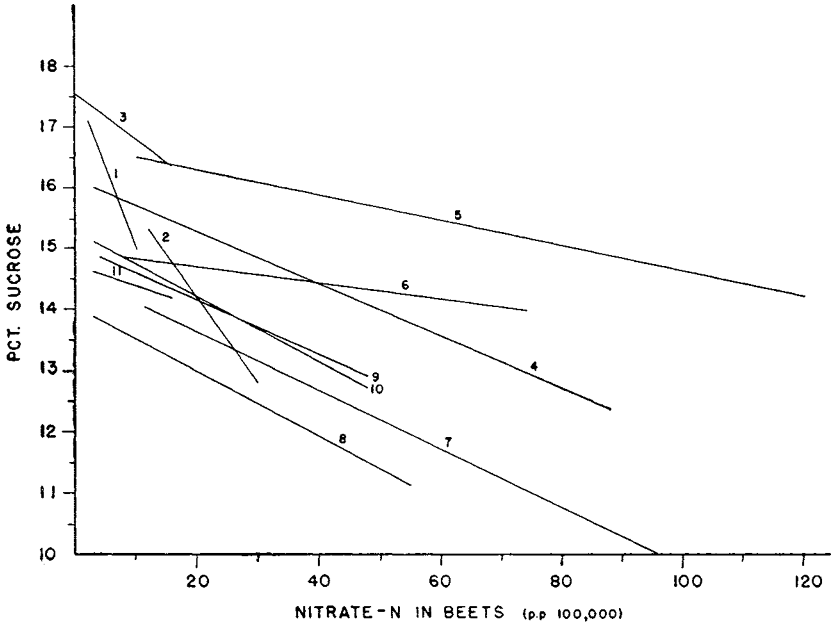

FIGURE 1.—The best fit linear curves by the method of least squares showing the decrease in percentage of sucrose with increase in nitrate nitrogen in sugar beets. The curves 1 to 11 are: Nos. 1, 2, 3, manure plots, 1933; No. 4 nitrate plots, 1933; No. 5, nitrate plots, 1934; No. 6, manure plots, 1935; No. 7, nitrogen plots, 1935; No. 8, nitrogen plots, 1936; No. 9, nitrogen and phosphate plots, 1936; No. 10, nitrogen plots, 1937; No. 11, nitrogen and phosphate plots, 1937.

not complete, because they include only the nitrogen applied in the fertilizers and take no account of the portion of the curve which would result from changes between zero available nitrogen and the unknown amount which the soil furnished exclusive of what was added. A nitrogen-deficient soil likely would not have shown the sharp drop at the extreme left of the graphs.

Although excess nitrogen consistently lowers the sugar percentage in sugar beets, the results of this experiment (fig. 2) indicate that the amount required to produce serious loss from this cause, as measured by the nitrogen in the soil in the spring, is comparatively large.

The curves in figure 2 show that it required applications of from 50 to 100 pounds or more of available nitrogen to produce a drop of as much as 0.5 percent in sugar content. These applications would be equivalent to from 250 to 500 pounds of ammonium sulfate or 5 to 10 tons of manure, assuming that half the nitrogen in the manure is immediately available to the crop. From these figures, it can be seen that not more than a slight sugar depression can be expected from an application of commercial nitrogen fertilizer unless the application

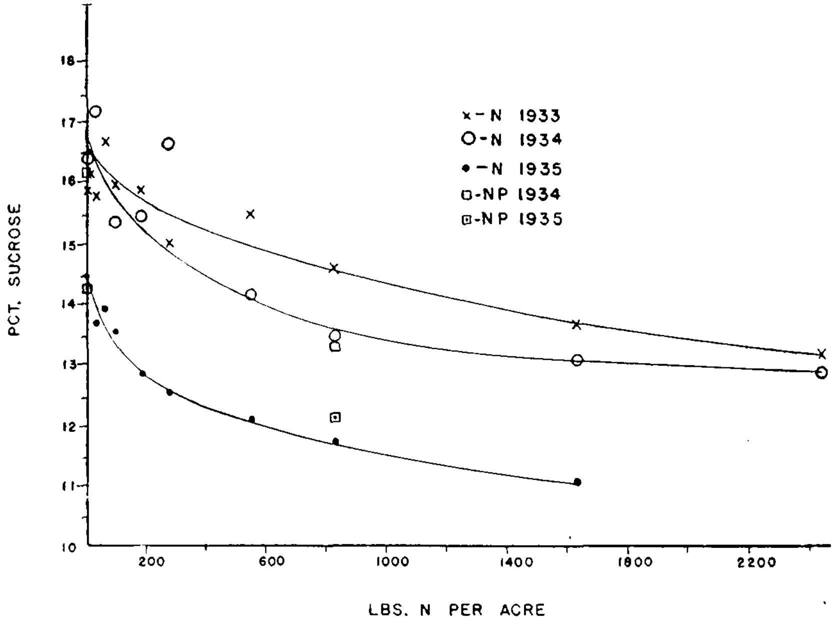

FIGURE 2.—This graph shows the effect of heavy applications of nitrogen in the form of calcium nitrate and ammonium sulfate on the percentage of sucrose in sugar beets. The 1935 graph is the average results of nitrogen treatments as calcium nitrate and ammonium sulfate. The 1933 and 1934 results are for calcium nitrate only. The rates of application in this and subsequent graphs are expressed as pounds of nitrogen per acre and not as pounds of fertilizer.

is extremely heavy. Continuous heavy applications of manure can be expected to lower the sugar content; moderate applications, however, should have little effect. This conclusion is in agreement with the experimental results obtained by Hastings, *et al.* (*4*). Allowing the land to be fallow a year often results in the accumulation of from 100 to 200 pounds of available nitrogen as nitrate, which could be expected to lower the sugar content in some cases as much as 1 percent, but seldom more.

The effect of manure on the available nitrogen supply in the soil is considerably more complicated than the effect of inorganic fertilizers. Part of the nitrogen in the manure (usually one-half or more) is in the form of protein or other insoluble compounds and is not immediately available to plants. Manure also has a high percentage of straw and some other materials low in nitrogen. Some of the soluble nitrogen may be taken from solution to supply the soil micro-organisms during the process of decomposing these low nitrogen materials. For this reason only a fraction of the nitrogen in the manure is immediately available, and the other fraction becomes available gradually as the organic matter is decomposed. This process may take several years.

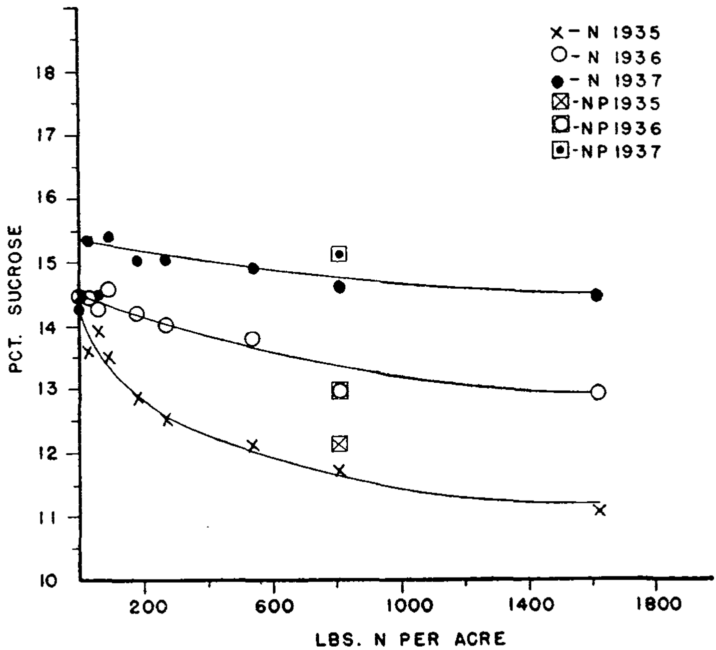

FIGURE 3.—The effect of high applications of nitrogen in the form of calcium nitrate and ammonium sulfate on sucrose content of sugar beets the first, second, and third seasons after applications.

The total weights of dry matter, nitrogen, and phosphorus found in some of the manures used in this experiment are given in table 4. The amounts in the table are expressed as pounds of these constituents contained in the 15 tons of strawy manure or 10 tons of well-rotted manure applied per acre. The strawy manure was taken directly from cattle feed yards, and the well-rotted manure was taken from a large pile where it had stood for a year or more and had undergone considerable decomposition. The average amount of nitrogen applied in these applications was 222.4 pounds per acre, though the applications varied from 100 to more than 400 pounds. The strawy manure in this experiment contained a higher nitrogen content than did the well-rotted manure.

The manure treatments and percentage sugar found per treatment are given in tables 2 and 5, respectively, for the years 1933, 1934, and 1935. The fallow treatment produced the lowest average percent sugar, which was 0.82 points lower than the untreated check. This reduction was about what the predicted value would be from the curves (fig. 2), considering the fact that 2 years' supply of nitrogen resulting from nitrification was available for the crop. The average percentage of sugar on the manure plots was almost the same as that

TABLE 4.—*Composition of manure used in experiment.*

Manure	Date of Application	Beet crop	Wt. dry matter	Wt. N	Wt. P
			Pounds	Pounds	Pounds
Strawy	4-15-32	1933	9,999	163	31
Well-rotted	4-15-32	1933	13,332	218	59
Strawy	7-30-32	1933	15,444	273	63
Well-rotted	7-30-32	1933	17,332	227	69
Strawy	9-24-32	1933	23,076	288	80
Well-rotted	9-24-32	1933	17,142	202	69
Strawy	3-18-33	1933	13,845	201	51
Well-rotted	3-18-33	1933	7,286	133	30
Strawy	4- 7-33	1934	16,666	242	49
Well-rotted	4- 7-33	1934	12,038	149	42
Strawy	7- ?-33	1934	15,000	373	64
Well-rotted	7- ?-33	1934	17,000	277	69
Strawy	9-27-33	1934	15,600	265	67
Well-rotted	9-27-33	1934	17,000	227	71
Strawy	3-12-34	1934	13,326	228	37
Well-rotted	3-12-34	1934	6,188	111	24
Strawy	3-12-34	1935	13,326	228	37
Well-rotted	3-12-34	1935	6,188	111	24
Strawy	9-27-34	1935	19,635	436	107
Well-rotted	7-27-34	1935	7,175	100	29
Peas	Fall 1932	1933	748	41	4
Millet	Fall 1932	1933	824	53	7
Peas	Fall 1933	1934	2,302	21	2
Millet	Fall 1933	1934	824	15	2

on the no-treatment plots, indicating that considerably less than half the nitrogen applied was made available for the crop during the season.

Millet as green manure produced the highest percentage sugar, which could be expected from the fact that it would require nitrogen from the soil to decompose the non-nitrogenous compounds in the millet. The beet tops after millet were noticeably smaller and paler green than those after the other treatments.

TABLE 5.—*Results of manure treatments on yield and quality of beets.*

Treatment no.*	Yield beets Tons			Yield tops Tons		Sugar pct.			Purity pct.		
	1933	1934	1935	1933	1934	1933	1934	1935	1933	1934	1935
1	17.9	15.0	17.1	12.2	10.4	16.74	14.85	15.59	91.0	89.1	92.19
2	20.0	19.2	18.2	13.0	11.6	16.85	15.92	15.53	88.5	90.0	92.37
3	21.2	19.9	17.7	13.4	12.2	16.60	14.95	14.40	89.8	88.3	90.80
4	23.1	20.9	18.4	16.6	12.7	16.28	14.50	14.62	88.4	88.0	90.46
5	23.2	22.2	17.6	14.1	13.1	16.42	14.95	14.89	89.0	86.6	90.56
6	21.0	16.7	17.6	15.6	12.0	16.09	14.60	14.26	87.6	87.9	89.32
7	21.0	22.1	18.4	14.1	13.8	16.71	14.98	14.49	89.1	87.7	90.89
8	21.7	23.4	18.7	14.1	16.2	16.67	13.75	14.44	89.9	88.5	89.46
9	23.1	22.1	19.1	19.7	12.9	15.89	14.80	14.33	88.0	88.2	89.57
10	22.3	20.2	18.7	13.3	12.7	16.40	14.18	14.77	88.3	86.6	90.46
11	19.5	16.0	16.8	13.5	10.1	16.83	14.88	14.40	91.3	89.2	90.35
12	22.5	22.2	17.2	18.1	14.9	15.44	14.30	13.90	86.0	87.2	89.87

*See table 2.

Effect of Nitrogen Supply on Total Yield of Beets and of Sugar and on Percentage Purity

The reason high concentrations of available nitrogen cause low sugar percentage is primarily that the nitrogen causes so much stimulation of growth (particularly of tops) that sugar which would otherwise be stored in the roots is used to produce this extra growth. A nitrogen supply which would produce the maximum plant yields would, therefore, be too high for the maximum sugar content. The greatest total yield of sugar is, for that reason, not likely to be found under conditions which would produce either maximum sugar content or maximum plant growth, but somewhere between these two extremes, though it is conceivable that an approach to the two maximums could be reached by maintaining an optimum nitrogen content for growth until nearly the end of the season and then reducing it to allow maximum sugar storage for a short time before harvest. It is believed that this condition is approached in the fields where high yields of good beets are obtained.

In 1935, plots which received nitrogen treatments were apparently adequately supplied with available nitrogen before treatment, which would be expected from the previous crop history of the land (see table 3). None of the fertilizer applications gave significantly better yields as a result of treatments the first year. However, increased yields were obtained from the lower rate of treatment in 1933 and 1934; these increases could not be proved significant because the generalized standard error could not be used. The heaviest applications resulted in significant root and sugar-yield decreases, which was shown by a significant regression. The results for root and top growth and yield of sugar are shown in figures 4, 5, 6, 7, and 8.

In 1936 the nitrogen from the high treatments had been sufficiently reduced so that the residual supply increased the yield of beets and sugar (fig. 8). By 1937 the extra available nitrogen from the 1935 applications had so completely disappeared that slight effect, if any, was shown in the sugar percentage or yield of beets. The two preceding beet crops and leaching had reduced the available nitrogen to a point below the optimum for the 1937 crop.

On June 28, 1937, 90 pounds of nitrogen were added to the plots receiving 90 pounds in 1935, and also to the plots receiving both nitrate and phosphate in 1935 (fig. 5). The increase in yield of beets as a result of these treatments was 1.4 tons for the nitrate alone and 3.8 for the nitrate and phosphate together (fig. 5). The corresponding increases in yields of sugar were 385 pounds and 640 pounds (fig. 8). These results show a very marked drop in available nitrogen between the first and third crops of beets on land high in available nitrogen for the first crop. It is probable that the high nitrogen can be attributed to the alfalfa and fallow preceding beets.

This marked change in available nitrogen illustrates a point which may be very important in the use and care of manure. For the third crop the soluble nitrogen in the manure would have been very valuable, while it likely would have been of little value to the first crop. On farms where available nitrogen in the soil is normally high, such as on land where alfalfa is grown frequently in rotation, the wasting of liquid manure would be less serious than on farms with soils low in available nitrogen. In figure 4 an apparent increase in yield is shown in the 1933 and 1934 curves for the lower rates of nitrogen application, while no increase is evident in the 1935 curve.

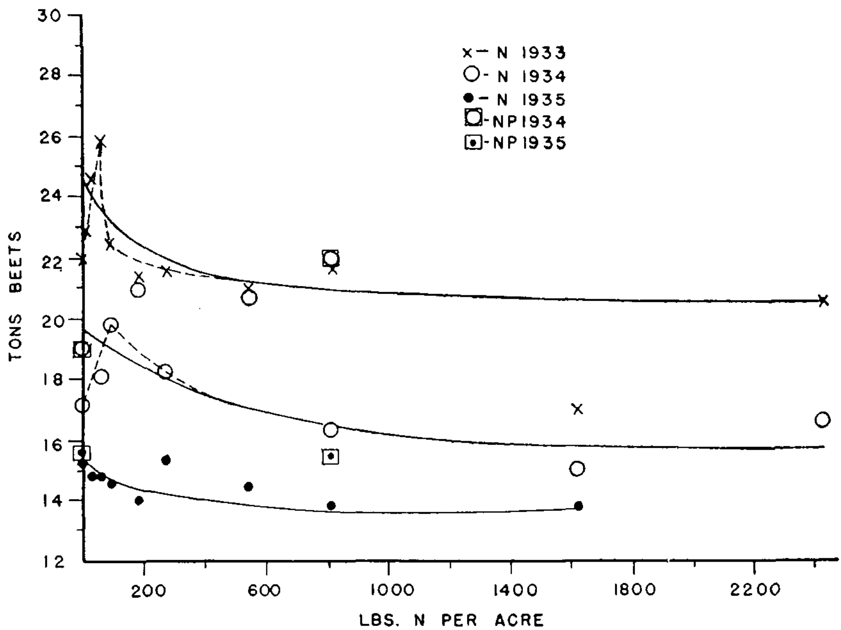

FIGURE 4.—The yield of beets as affected by increasing rate of nitrogen applications to the soil. The dotted lines show increases due to the smaller applications which could not be shown to be statistically significant.

The reason for this difference in results can likely be found in the fact that alfalfa had preceded beets in the rotation on the 1935 plots but not on the others (table 3).

Probably the most significant fact brought out in the experiment was that even though decreases in yield of sugar are caused by large excesses of nitrates these decreases are very small compared to those caused by small deficiencies of available nitrogen. This is shown by the very steep portion of the curve in the deficiency range and the comparatively flat portion near and beyond the maximum in figure 7. This brings out the fact that greater losses are obtained by a shortage of only a few pounds of nitrogen than by an excess application of from 100 to 200 pounds more than the amount necessary to produce maximum yields. There is very little drop on the right-hand side of the curve until after 200 pounds of N have been added over that necessary for maximum production. Furthermore the loss in sugar by excess nitrates is partly compensated for by the increased yield of tops which are valuable as livestock feed.

If figure 7 is considered in connection with the curves in figures 1, 2, 3, 4, 5, and 6, it appears that the decrease in yield of sugar is largely associated with the great stimulation of top growth and is not a result of any injurious effect of nitrogen on the beet plants

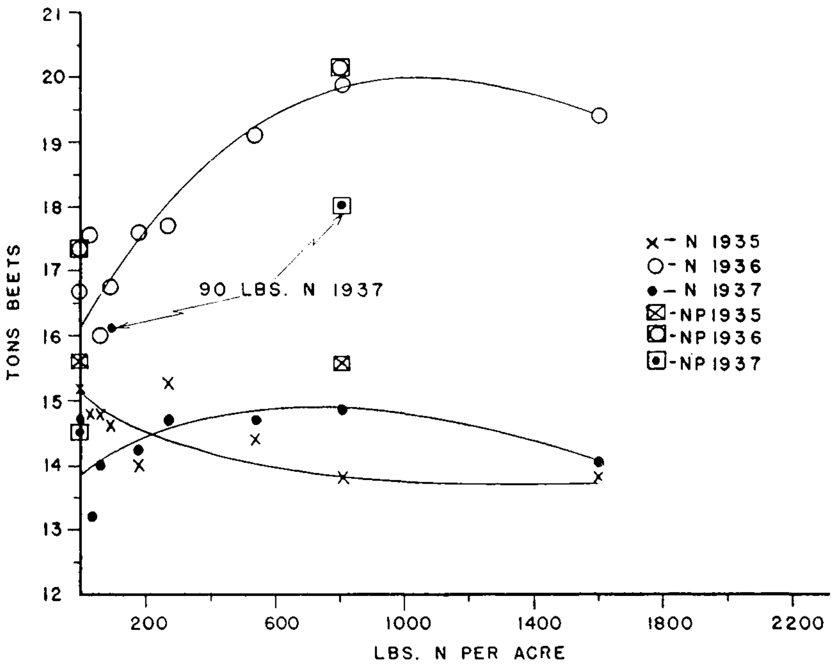

FIGURE 5.—The effect of varying rate of nitrogen on sugar beet yields the first, second, and third seasons after application. The marked increase in yield from a nitrogen application the third year is also shown in the figure.

from the standpoint of health or vigor. On the other hand, deficiencies of nitrogen result in a starvation of the plants, which causes the yield to drop from maximum to zero in a small range. These results indicate that extreme caution should be used in any attempts to control nitrates within a narrow margin, since producing a comparatively slight deficiency would seriously cut down the yield.

The manure treatments shown in table 4 gave higher yields than were obtained in the check plots, but there was very little difference between the effect of strawy or well-rotted manure or the time of application. The best results were obtained from the summer and fall applications previous to the beet crop year, and the poorest results were from strawy manure applied just before planting. Part of the unfavorable results from the strawy manure just before planting was due to weeds and a trashy seedbed.

In applying wet manure at definite rates per acre, a great variation resulted in the amount of dry matter and fertilizer constituents added. These variations proved to be more important in the results than the time of application or kind of manure. A significant correlation (1-percent point) of 0.82 was found between the amount of dry matter applied and the yield. The best fit curve showing the regression of yield on dry matter was found to be: Y=17.35+.000318X, where Y = yield, and X = the dry matter per acre in pounds. Within the limits of the experiment this amounts to an average increase of 1.5 tons of beets per 5 tons of dry matter added. It is obvious that the law of diminishing returns applies to this relationship and that the linear equation does not express the facts accurately. However, the calculated quadratic equation did not fit the data significantly

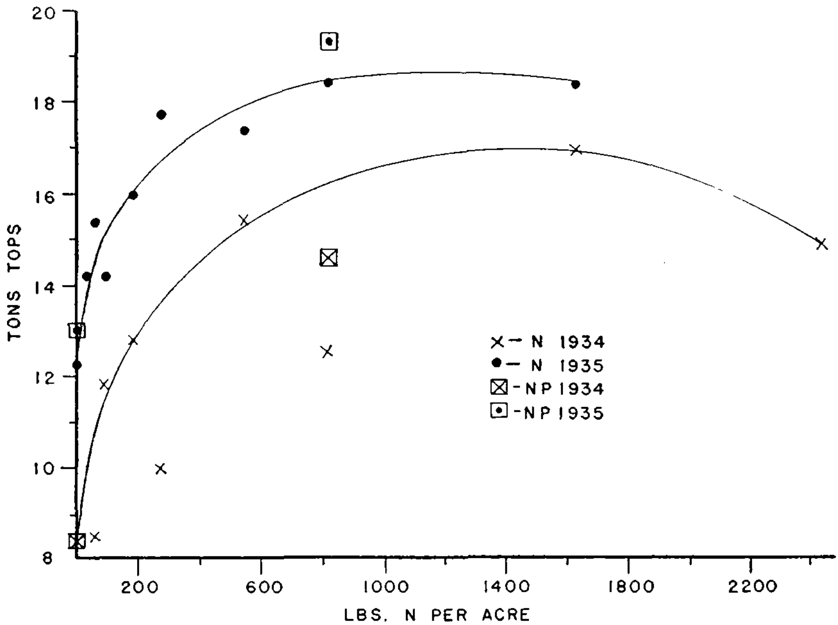

FIGURE 6.—The effect of varying rates of nitrogen applications on yield of beet tops. The higher application nearly doubled the yield of tops as is shown in the figures. The curves reach an apparent peak near the 1,400-pound point of nitrogen application.

better than the linear. It is therefore assumed that the curve was approximately linear over the range studied. The nitrogen and phosphorus in the manure were highly correlated with the dry matter and therefore were also correlated with yield. An attempt was made to estimate the separate effects of nitrogen and phosphorus on the yield by partial correlations, but no significant partial correlation was found.

The stimulating effect of the added nitrogen on top growth was most pronounced late in the season. Measurements taken June 25, 1936, and June 28, 1937, of the width of largest leaves in beets from

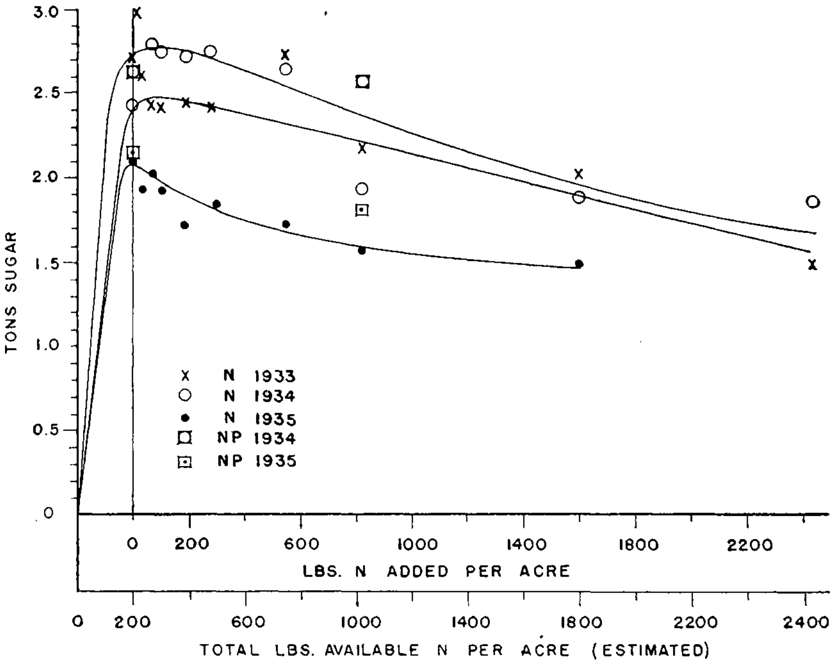

FIGURE 7.—The yield of sugar as affected by varying rates of nitrogen application and the yield extrapolated to zero available nitrogen on the basis of an estimate of 200 pounds of available nitrogen per acre before any additions were made. The curves in the deficiency range are necessarily steep compared with the portion of the curve above the maximum, regardless of the errors in extrapolation. This graph illustrates the rapid loss of tonnage as nitrogen deficiency increases and the comparatively small loss from too much nitrogen. The yields are expressed as total sugar in the beets and not as extractable sugar.

each plot showed a slight depression of leaf growth caused by the high nitrate or ammonium salt applications. A very marked stimulation from phosphate was found in these early measurements, though there was no significant difference in top weight at harvest time due to phosphate treatments. The results of early leaf measurements are shown in figure 9.

Lowering the percentage of sugar naturally lowers the purity factor in the juice since the purity factor is calculated from the ratio of the sucrose to the total solids dissolved in the juice. A comparison of the purity curves (figures 10 and 11) with the percentage of sucrose curves (figures 2 and 3) indicates that the effect of added nitrogen in this experiment was due partly to decreased sucrose percentage and partly to increase in the nonsucrose solids in the juice. If the other solids remained constant, the reduction of percentage of

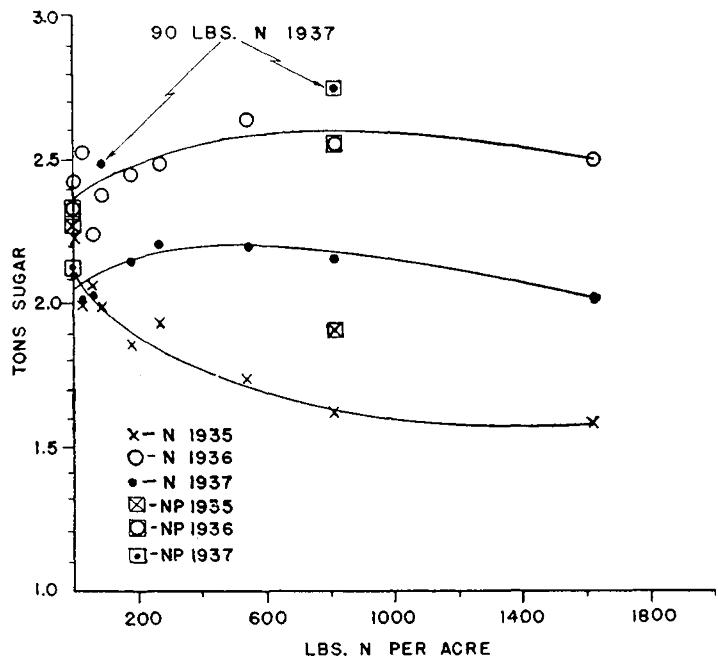

FIGURE 8.—The effect of varying rates of nitrogen treatments on the yield of sugar the first, second, and third years after treatment. The increase in sugar yield due to nitrogen applications the third beet year is also shown. Numbers 1 and 2 are 1937 yields and correspond to the middle curve.

sucrose shown in figure 2 should have resulted in slightly less reduction in purity than is shown in figure 10.

Nees (*7*) concluded that part of the harmful effects of high nitrates in the soil was due to stimulated absorption of chlorides and other harmful salts. In the present investigation, where the soils were normal and low in total soluble salts, this effect was apparently small. Gardner, *et al.* (*2*) showed that where nitrates are abnormally high in Colorado soils they are closely correlated with chlorides, and it seems reasonable to assume that part of the cause of a correlation between high nitrates and other salts in beets is the correlation between nitrates and other salts in the soil. This is particularly true in areas of poor drainage.

The data which have been presented show the need for an adequate supply of nitrogen in the production of sugar beets and the harmful effects of too much nitrogen. More information is needed on the control of the nitrogen in the soil to meet the needs of the

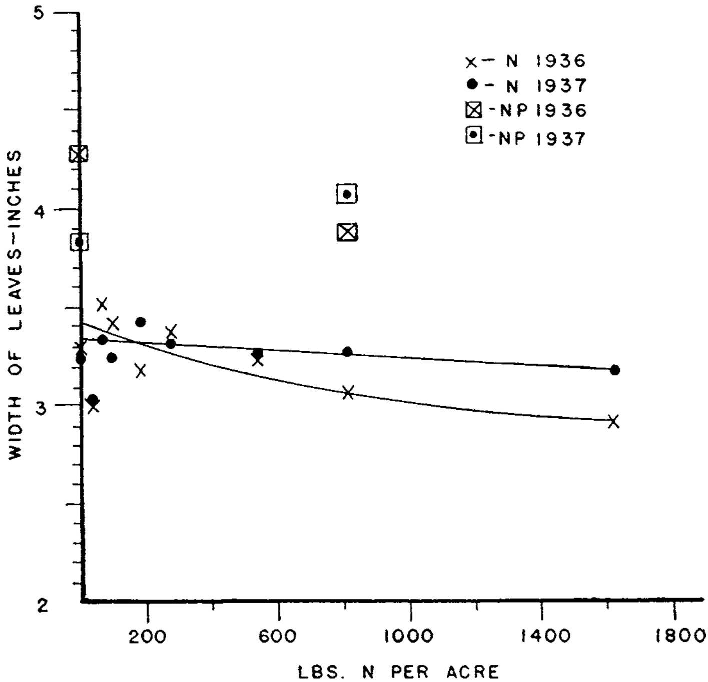

FIGURE 9.—The effect of varying rates of nitrogen application on early sugar beet growth as measured by the width of largest beet leaves, June 25, 1936, and June 28, 1937. The effect of phosphate applications is also shown in the figure.

sugar beets without the waste and injury resulting from a large excess. This need includes a better knowledge of fertilizer materials and their behavior in the soil, more facts regarding the optimum nitrogen level, and better methods of predicting fertilizer needs.

The nitrogen consumed by the plants is taken up principally from the nitrates and ammonium salts found in the soil. These compounds are very soluble and move through the soil with the soil water They are easily washed away from the reach of plant roots by irrigation (8). Regardless of the form in which nitrogen is applied to the soil it is mostly converted to the ammonia or nitrate form before it becomes available for plant use. The plants may absorb nitrogen in either of these forms, but ammonia generally is quickly converted to nitrates in the soil, and therefore nitrate nitrogen is the principal form used in plant production. Ammonium sulfate and the nitrate salts are the most common forms of commercial nitrogen fertilizers. The nitrogen contained in manures or other organic materials is changed to these forms during the decay process before they are taken up by the crops.

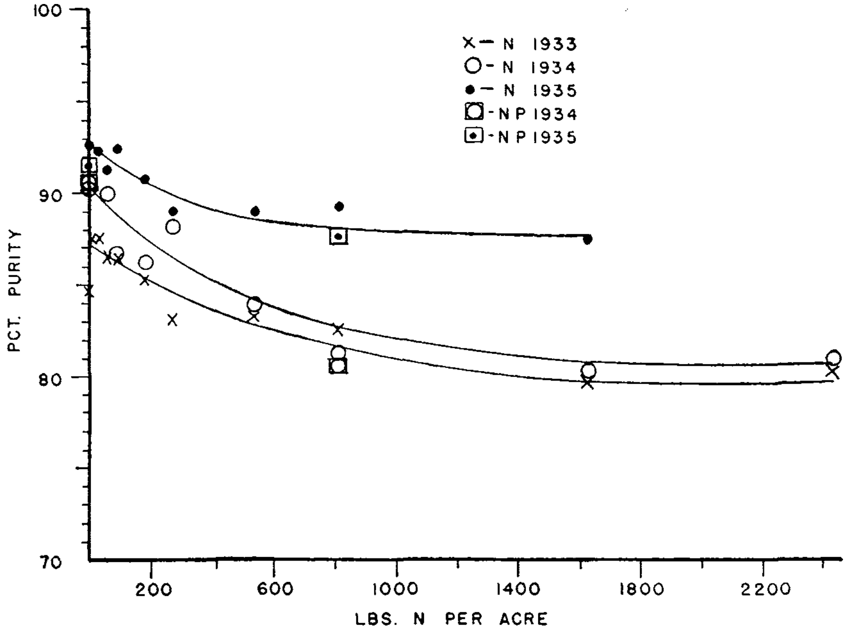

FIGURE 10.—The effect of various rates of nitrogen application on purity of the beet juices. Results for 3 separate years are shown in the figure.

Under irrigation much of the nitrogen, either added in or converted to an available form, is ultimately washed from the soil unless it is first taken up by the plants. Any portion washed from the soil is wasted, and in the case of sugar beets the nitrogen consumed by the plants in excess of the optimum is not only wasted but results in a loss of sugar. For this reason the fertilizers applied should meet as nearly as possible the needs of the crop.

The amount of nitrogen consumed by a crop of sugar beets varies considerably, but the amount actually taken from the soil in the crop usually runs from 2.5 to 4 pounds per ton of roots and 4 to 5 pounds in the tops from a ton of roots. For example the beets in the 1933 manure plots contained 3.99, 2.98, and 2.78 pounds of nitrogen per ton of beets, and 5.26, 4.67, and 4.02 pounds in the tops per ton of beets. The weights of tops per ton of beets were 1,156, 1,150, and 1,326 pounds. The average amount of nitrogen removed by tops and beets per ton of beets was 7.88 pounds or approximately 118 pounds for a 15-ton crop.

On the basis of the preceding figure the highest nitrogen application in the fertilizer plots in 1933 contained enough nitrogen for 40 crops of beets and the highest application in 1935 for 13.7 crops. The results in table 6 and figure 13 indicate that after two crops of beets the supply of added nitrogen was practically exhausted. The

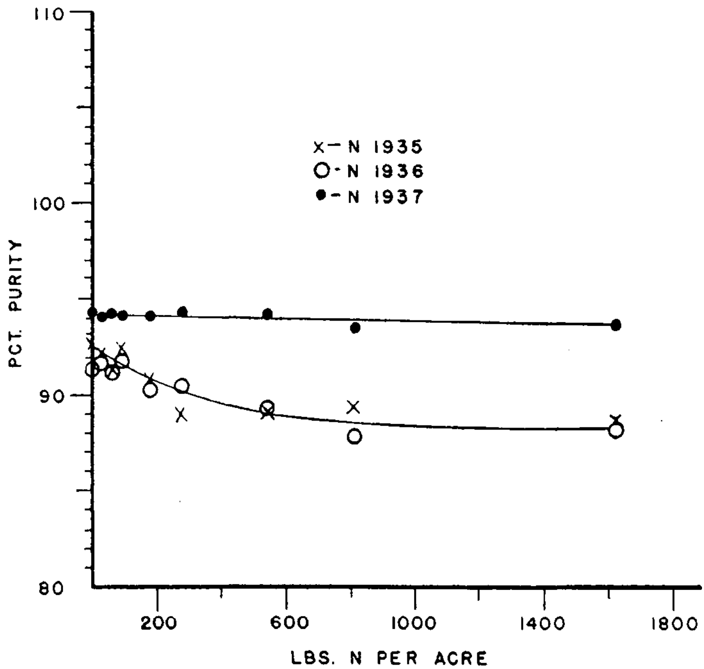

FIGURE 11.—The effect of varying rate of nitrogen application on purity of beet juices the first, second, and third years after application. A refractometer which tended to give high results was used in obtaining the estimates of purity. The graphs therefore should be considered as giving relative rather than actual purity values.

results show that nitrogen is subject to quick removal by irrigation water after it has been converted into the nitrate form.

Approximately half the nitrogen in fresh manure is soluble and subject to leaching in the soil. The other half is in complex compounds which are very slightly soluble and not available to plants until broken down by decay. A variable portion of the soluble nitrogen is temporarily taken out of solution by micro-organisms in the process of decay of the non-nitrogenous compounds in the manure, so prob-

TABLE 6.—*Nitrate and ammonium nitrogen found in soil after fertilizer applications to the 1935 fertilizer plots.*

		Nitrate nitrogen found				Ammonium nitrogen found			
		Nitrate plots		Ammonium plots		Nitrate plots		Ammonium plots	
Date	Depth	Lbs. per acre	Pct. of N added	Lbs. per acre	Pct. of N added	Lbs. per acre	Pct. of N added	Lbs. per acre	Pct. of N added
Aug. 14	0″-6″	113.92	25.31	65.40	14.53	4.14	0.92	21.01	4.60
	6″-12″	91.68	20.37	38.50	8.55	0.88	0.20	4.00	0.89
	12″-24″	150.80	33.51	68.92	15.32	0.88	0.20	5.76	1.28
	24″-36″	116.68	25.92	49.04	10.90	0.88	0.20	6.60	1.47
	Total	473.08	105.11	221.86	49.30	6.78	1.52	37.37	8.24
Sept. 24	0″-6″	21.62	4.80	12.68	2.82	3.36	0.75	1.60	0.36
	6″-12″	6.00	1.33	30.78	6.84	0.62	0.14	6.80	0.15
	12″-24″	21.20	4.71	36.12	5.80	1.64	0.36	2.60	0.58
	24″-36″	27.52	6.11	25.88	5.75	0.64	0.14	2.00	0.44
	Total	76.34	16.95	105.46	21.20	6.26	1.39	13.00	1.53

ably less than half the nitrogen in manure is immediately available for crops. This portion which is soluble is subject to immediate use by crops or to leaching, and the portion in the insoluble form is reserved for later use.

On the basis of 118 pounds of nitrogen per crop of beets and 100-percent efficiency in the nitrogen use, the average 15 tons of strawy manure applied in this experiment (table 4) contained enough for 2.3 crops and the 10 tons of well-rotted manure for 1.5 crops of 15 tons each. The average loss of nitrogen probably would reduce these figures by about 50 percent. If the tops are returned to the soil they should be calculated as manure for succeeding crops.

The question has sometimes arisen as to whether fresh, strawy manure would or would not result in depression of sugar beet growth because of the nitrogen which might be taken from the soil by bacteria that decompose the straw. The results from this experiment did not show any significant differences in the nitrates in the soil or beets between the plots treated with strawy or well-rotted manure applied just before beets were planted. Considerable nitrogen is lost from a manure pile, and some of the soluble nitrogen is used to decompose the straw regardless of whether it decomposes in the pile or field. It therefore appears that fresh strawy manure may supply more readily available nitrogen to the soil than will well-rotted manure. The disadvantages of spring application of strawy manure may not be in many cases the result of low available nitrogen.

Soil and Plant Tests

Soil and plant tests are frequently used in an effort to predict the nitrogen needs of crops. The greatest part of the immediately available nitrogen is in the form of nitrates which are readily determined with fair accuracy in either plants or soil. This makes it comparatively easy to estimate the amount in the soil at any specific time. However, the nitrates vary so much with time that it is not a simple matter to determine in advance the probable supply for the season from a soil sample.

Another complication is that the nitrates also vary with respect to position in the soil; therefore, availability with respect to position must also be considered. In the case of sugar beets the optimum concentration as well as the optimum position probably varies during the season. In the early stages an abundant supply is necessary for rapid growth, while an almost complete absence of available nitrogen may be desirable at maturity. The small beets are not so deeply rooted as larger ones and for that reason only nitrates near the surface may be available to the young beets but the nitrates at lower levels may become available as the beets become larger.

During this study the concentration of nitrates in the soil and in the sugar beet plants was determined at frequent intervals to find the effect of variations of nitrates on the growth and composition of the plants. The seasonal distribution in the top 3 feet of soil in the manure plots for 1933 and 1934 and in the nitrate plots for 1936 and 1937 are shown in figures 12 and 13. The 1933 figures are for one

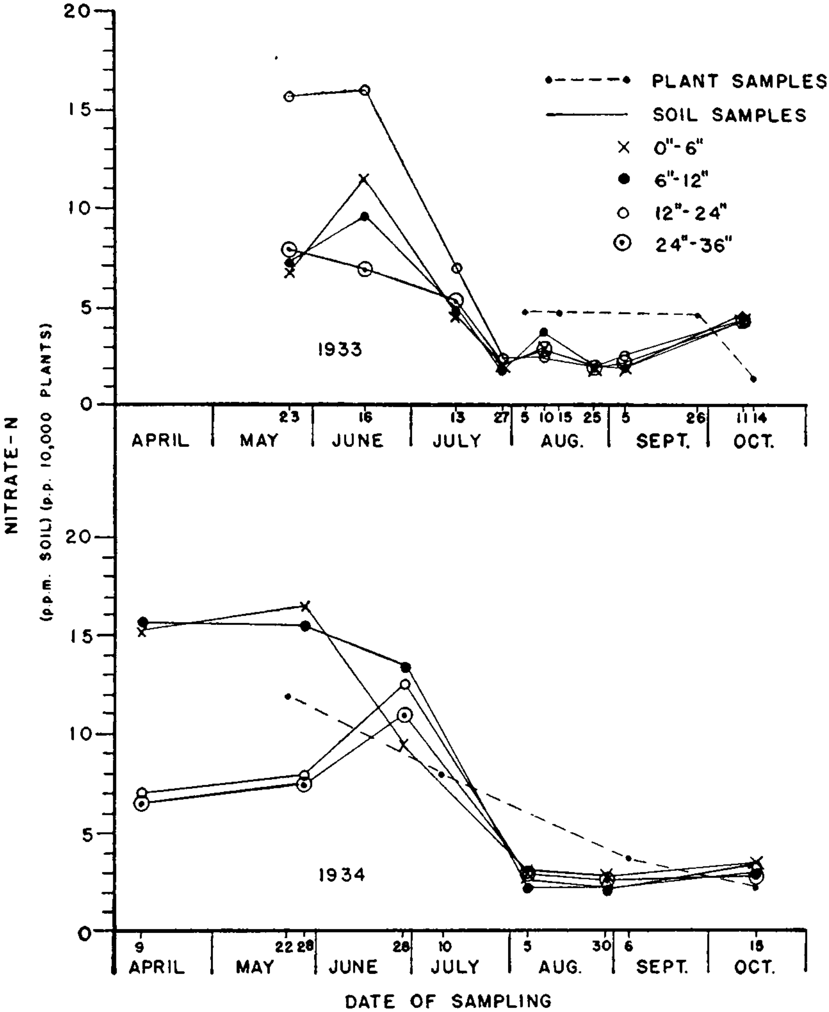

FIGURE 12.—The seasonal and depth distribution of nitrate nitrogen in the 1933 and 1934 manure plots (the average of all plots).

replication only, which was chosen because the yield was very good (22.2 tons per acre) and the sugar content high (16.47 percent). The nitrate conditions during the growth of this crop can therefore be considered favorable. From the condition of the top growth during the season and the lower sugar percentage, the 1934 crop appeared to

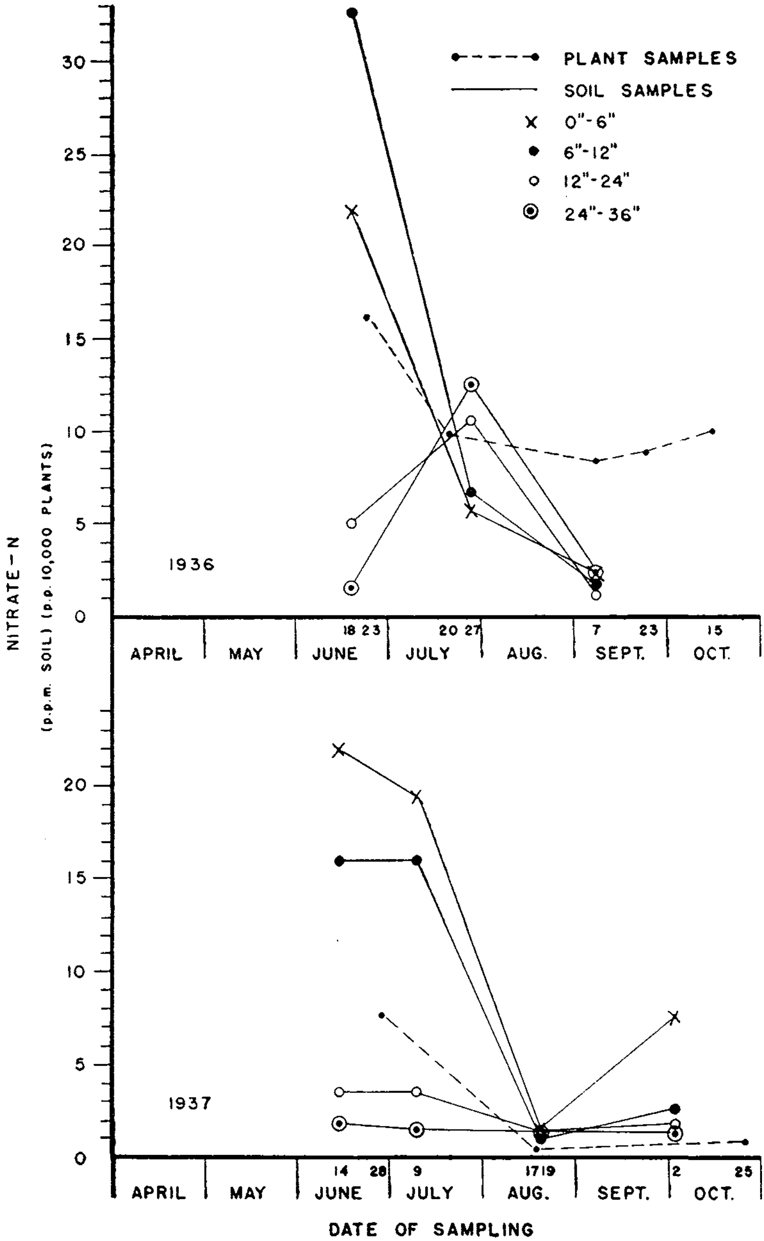

FIGURE 13.—The seasonal and depth distribution of nitrate nitrogen in some of the nitrate plots for the years 1936 and 1937. The residual effects of the highest treatments are shown for 1936 and the no treatment plots for 1937.

be somewhat over-supplied with available nitrogen. However, the nitrate curves are so nearly the same in the soil that it would be impossible to decide which series contained the highest supply. The difference in plant response could have been due to the fact that the available phosphate, as estimated from soil and plant tests, was lower in the 1934 crop.

The curves in the upper part of figure 13 show the amount of nitrate present during the season of 1936 in the soil of the plots receiving the highest nitrate treatment in 1935; the nitrate concentration during the season of 1937 in the no-treatment plots is shown in the lower part of the figure. The nitrates in the soil represented by the upper part of the figure were too high for high sugar content, while the soil represented by the lower part of the figure was too low in nitrates for good yields. A favorable sugar percentage was obtained from the plots represented in the lower part of the figure. Both sets of curves show nitrates high in the spring and low in the fall. It would be difficult to decide from the soil curves which soil had the most favorable nitrate content. The curves for the nitrates in the petioles, however, show a much higher nitrate content during 1936. Under the conditions of this experiment the plant samples gave the best indication of the nitrogen level. A probable reason for the failure of the plant and soil samples to agree in the 1936 figures was that some of the nitrates applied in 1935 remained in reach of the plants below the 3-foot level during 1936.

The curves in figures 12 and 13 indicate that the spring nitrate supply is not necessarily a good measure of the available nitrogen for the season. The level in the spring was not as high in the 1933 and 1934 curves as in the 1937 curves, yet the beets apparently were supplied with more nitrogen during the season. It is possible that nitrogen used by the beets as ammonia from the manure was an important direct source of nitrogen for the beets in 1933 and 1934.

Figure 14 shows the change of concentration of nitrate nitrogen in the plants and the top 6 inches of soil 12 days after the application of the fertilizers. The soil curve, as would be expected, is a straight line but the plants reached a maximum concentration at about 1,700 parts per million. Below this point the nitrate in the plant increased rapidly with increases in the soil. The rate of change is shown in the lower part of the curve in figure 15. In this graph, curves for four depths of soil were calculated separately. These are the best fit curves, and the regression is highly significant but the correlation is not high. For the top 6 inches, second 6 inches, second foot, and third foot, the correlation coefficients were .26, .38, .49, and .41. The highest concentration of nitrates was in the second foot which probably accounts for the higher correlation for that depth. The low correlation was probably due to the larger percentage error of sampling and analysis of the soil nitrates at the low concentrations in this range of the curve and to the fact that the relationship was not quite linear. The average soil concentrations for the four depths were 5.8, 4.9, 6.7, and 6.4 parts per million. The error of analysis alone is one part per million or more, and the error of sampling is still greater. It can be seen that the concentration in the plant samples in this range is from 75 to 90 times as high as the concentrations in the soil when the concentrations are calculated as plotted on the basis of the green weight of the plant and the dry weights of the soil. The concentration in the plant sap is about 10

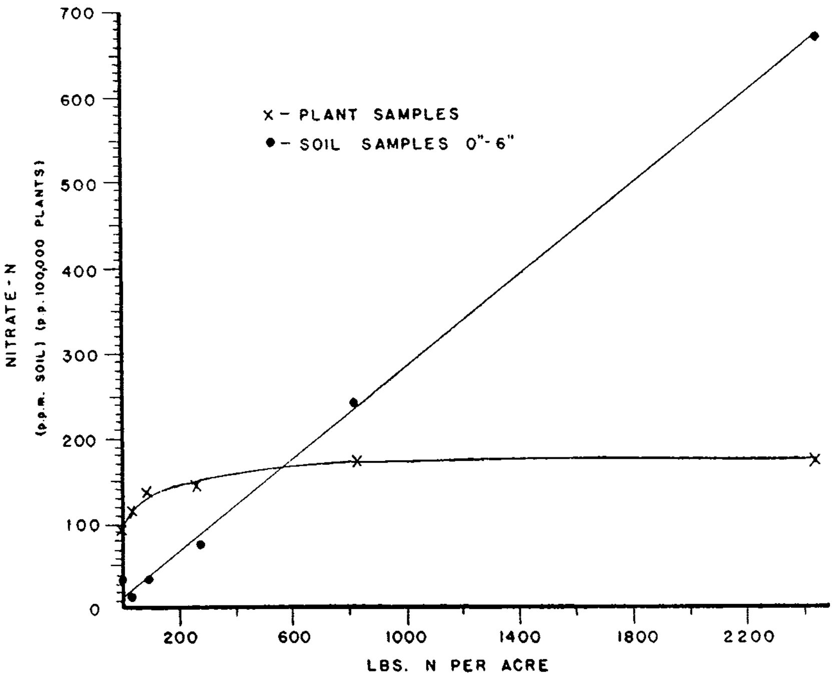

FIGURE 14.—The concentration of nitrate nitrogen in sugar beet petioles 12 days after soil treatment and the concentration in the top 6 inches of soil as affected by rate of treatment.

times as high as in the soil solution. This tends to reduce the percentage error in the plant samples.

The problem of determining the optimum soil nitrogen conditions from soil samples is further complicated by the fact that the beet plants are able to utilize nitrogen in the form of ammonium salts as well as nitrates. In alkaline, well-aerated soil the ammonia is rapidly converted to nitrate, but there is always a trace remaining which is more difficult to determine than are nitrates because it is absorbed to a greater extent by the soil.

In 1935 ammonium sulfate and calcium nitrate both were used as sources of nitrogen in equivalent amounts. The results from these two sources of nitrogen were practically identical so far as the effects in the plants were concerned, which may be accounted for by the fact that a great part of the ammonium sulfate was so quickly converted to nitrate. The plots were all treated about June 15 and half of them were treated a second time on July 25. On August 14 all plots were sampled to a depth of 3 feet and were tested for nitrate and

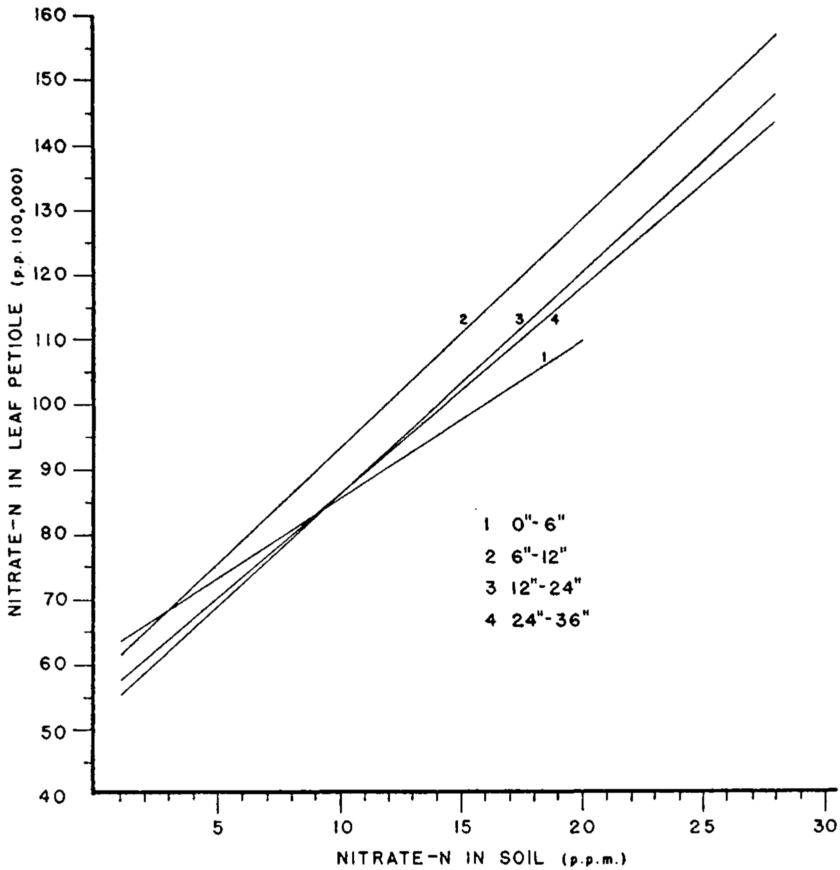

FIGURE 15.—The nitrate nitrogen in the sugar beet petioles plotted against the concentration in the top 6 inches, second 6 inches, second foot, and third foot of soil (1936 beets on 1935 fertilized plots).

ammonia, the rapid spot plate methods with diphenylamine and Nessler's reagent being used. The results are shown in table 6.

These results show the rapidity with which ammonia is nitrified in the soil and the rapid loss of soluble nitrogen in well-drained, irrigated soil. Another fact which is quite apparent is that either because the analytical methods used with the soil extracts were not sufficiently accurate or the nitrogen was not completely removed from the soil by the extract only about half the ammonium sulfate applied could be accounted for by the analysis. On August 14 the tests (table 5) showed all of the nitrate applied (within the error of sampling) to be still present in the top 3 feet of soil. The accuracy of the tests is probably not better than 10 percent, so the 105 percent is a reasonable figure. Approximately 50 percent of the nitrogen applied as ammonia was found as nitrate and only 8 percent as ammonia, leaving 40 percent unaccounted for. On September 9 only between 16 and 22 percent of the nitrogen applied in either form was found in the soil, virtually all of which was as nitrate. The amount of nitrate or ammonia in the untreated plots was subtracted from the figures in the table. The average of the check plot samples ran 1.6 parts per million ammonium nitrogen and 2.6 nitrate nitrogen.

These results show that under the soil conditions studied ammonia is rapidly converted to nitrates, but they also indicate that when the nitrates are low the ammonium nitrogen may equal the nitrate concentration and be an important source of direct supply to the crop.

Conclusions

The results of this investigation show that an excess of nitrates above the amount required by the beets consistently reduces the percentage of sugar in the beets. The reduction approaches a maximum of about 3.5 percent (based on the weight of the beets). However, within the range of nitrate concentration found in normal soils the reduction in percentage of sugar is more than offset by an increase in the yield of beets, so that the net result is a gain in yield of sugar.

Because of the extreme variability of nitrates during the season and within the depth of the soil profile, and because of an unmeasurable loss by leaching, it was not possible in this investigation to define within narrow limits the optimum nitrate conditions for beet sugar production. However, it has been shown that the curve showing yield of sugar as affected by nitrates is comparatively flat beyond the point of maximum benefits but very steep below the maximum. This fact is evident, though only a few data were obtained in the deficiency portion of the curve in this investigation. The 1936 and 1937 data show a rapid drop in yield of sugar with a slight deficiency of nitrogen. Furthermore, since nitrogen is an essential element in growth, the curve can be extrapolated to zero yield for no available nitrogen, which causes the lower portion of the curve to be very steep (fig. 7). A small reduction in available nitrogen, therefore, results in large decreases in yield in the deficiency portion of the curve. On the basis of these facts the conclusion is drawn that the safest procedure in beet sugar production is to maintain a comparatively high nitrogen level even though a slight reduction in percentage of sugar may result.

Manure, at the rate of 10 or 15 tons per acre, increased the yield of sugar in proportion to the amount of fertilizer material added in the manure and did not significantly reduce sugar percentage. From the observed effects and from the nitrogen content of manure it can be concluded that comparatively large applications would be necessary to seriously lower the sugar percentage or yield of sugar.

On soils producing low yields of good quality beets, nitrogen is likely to be deficient, and any available manure should be incorporated into the soil with as little loss of available nitrogen as possible. If manure is not obtainable for such soils the use of ammonium sulfate would, in many cases, be profitable. When the yields are good and the quality is low, caring for manure to preserve the available nitrogen is not so important.

The seasonal variation and the variation with respect to depth in the soil profile were so great within this investigation that no definite relationship could be established between the nitrate content of the soil and the response by the plants to nitrates, except where large applications of nitrogen fertilizers were made. As a result of the variations observed it is considered that soil tests for nitrates are not capable of indicating within a narrow range the need for nitrate fertilizers, though large excesses are easily detected.

Summary

A study of the effects of various nitrogen treatments applied to the soil on quality and yield of sugar beets and on the nitrate content of the soil has shown the following results:

1. The sugar percentage was decreased by nitrates when nitrates were present in excess of the amount which could be utilized by the beets before harvest.

2. The reduction in sugar percentage was approximately a straight line function of the nitrate nitrogen in the beets at harvest time, and each .025 percent of nitrate nitrogen in the beets reduced the sugar by an average of approximately 1 percent.

3. From 50 to 100 pounds excess nitrate nitrogen applied to the soil was necessary to reduce the sugar 0.5 percent.

4. The yield of beets tended to increase with increased nitrate as the percentage of sugar decreased until a maximum sugar yield was reached.

5. The yield of sugar was affected less by excesses of nitrates than was yield of beets, and comparatively large reduction in sugar percentage occurred before any significant reduction of sugar yield occurred.

6. Manure treatments of from 10 to 15 tons per acre increased the yield of beets without any significant lowering of the sugar percentage.

7. Manure applied the summer or fall before planting beets gave slightly better results than manure applied a year before or immediately before beets. The poorest results were with fresh manure applied just before planting.

8. There was slight difference in the effects of fresh, strawy manure and well-rotted manure when applied at the same rates based on the dry matter in the manures.

9. Nitrogen applied as ammonium sulfate gave nearly the same results per unit of nitrogen as did nitrogen applied as calcium nitrate.

10. Nitrogen applied as ammonium sulfate was practically all converted to nitrates during the first season.

11. Large excesses of nitrates applied to the soil were practically all leached from the soil during the first 2 years after application.

12. The nitrates in the soil varied greatly during the season. A marked drop occurred late in the season when the beets were making the greatest demands and remained at a low level during the rest of the season.

13. A comparatively high available nitrogen level during the first year of beets after alfalfa was indicated in the experiments, with a rapid decrease occurring the second and third years.

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