

THE INFLUENCE OF SOIL CONDITIONS AND FERTILIZER
TREATMENTS ON THE GROWTH, CHEMICAL COMPOSITION, AND
ENZYME ACTIVITIES OF SUGAR BEETS.

BY

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INTRODUCTION

It is well known that certain soil conditions are suitable for the production of certain crops, and that other conditions may cause crop failures. Even unproductive soils may be made highly productive by the addition of only one fertilizer constituent, whereas others require more than one. Conversely the addition of one or two fertilizer salts may cause decrease in growth of plants on even productive soils.

The soil conditions and fertilizer treatments which cause such varying results in the growth of plants must cause some physiological change in the intake of nutrients by them which influences their life processes and growth. Evidently there are certain ratios of nutrient elements which are optimum for the development of the plant and for the functioning of the physiological processes within it.

The investigations reported in this paper were undertaken to study the influence of soil conditions on the growth of the beet root, on the ratios and percentages of mineral nutrients absorbed by the leaves and roots of beets, on the sugar contents of the beet roots, and on the enzyme activities of the leaves of beets. More and more importance is being attributed to enzymes by plant physiologists and biochemists who believe "the mechanisms of those chemical transformations taking place in the life processes of plants and animals are affected principally by the actions of enzymes."

REVIEW OF THE LITERATURE.

Literature dealing with the influences of nutrient conditions on the growth and composition of plants, and on the activities of enzymes is so voluminous that it is necessary to limit this review to those papers which bear most directly upon the questions under consideration.

Variations in the amount of mineral elements absorbed by the plants have been reported by investigators since after Humphrey Davy (1) drew attention to the fact that mineral constituents were essential for the development of plants. Wolff (2) in a review of plant ashes states that "the quantitative composition of one and the same plant varies according to the soil upon which it is grown."

Plant physiologists attribute the intake of mineral nutrients to the two processes, osmosis and imbibition. It is well known also that plant tissues exhibit selective absorption towards minerals in the nutrient solution surrounding them. Loew (3) remarked "it is well known that plants cultivated in the presence of more sodium than potassium, nevertheless absorb a greater quantity of the latter than of the former, and some plants grown on soils rich in potassium will absorb almost no sodium".

The permeability of the cell walls of living organisms, according to McDougal (4), is influenced by the action

of salt ions in solution around them. It is quite probable that the different ions in solution change the permeability of the cell walls in this way when the soil solution is altered in any manner, and cause changes in the rate and ratio of absorption of mineral nutrients. This undoubtedly is the reason why magnesium is not readily absorbed by plants in the absence of calcium, and is injurious, while in the presence of calcium it is taken up and the life processes of the plant proceed in a normal manner.

This toxic and antitoxic effect of salts was observed by Loew (3) who stated that "magnesium salts can perform their nourishing functions only in the presence of calcium, while in its absence they exert an injurious effect." McCool (5) found that magnesium, sodium, and potassium present in pure solutions were very toxic to seedlings. This toxicity was greatly reduced in full nutrient solutions and in soil cultures. Antagonism resulted when certain cations were present together in solution, among which were sodium and potassium, and calcium and magnesium. Calcium was the most effective of all the substances studied.

Breazeale (6) reported the absorption of phosphoric acid to be increased by the presence of nitrogen in the nutrient solution, while the absorption of calcium was not increased by the presence of nitrogen, phosphoric acid, or potash. Potassium absorption was increased by the presence of other plant foods, especially nitrogen.

Hoagland (7) grew barley in water cultures and found a marked absorption of nutrient elements at all periods up to the final stages of growth, when suitable concentrations of ions were maintained. Intense absorption during the later stages of growth led to no important increases in crop yield, which seemed to be conditioned in a large measure by a favorable supply and concentration of nutrients during the early stages of growth. The percentage and total quantity of nitrogen and potassium per plant was decidedly increased in tops with increased concentrations of the nutrient solutions. Loew (3) reported that plants absolutely require a certain minimum of each nutrient mineral, and in most cases besides this minimum they take up not only an excess of these various compounds, but also substances which are perhaps useful, but not absolutely essential for plant functions. This surplus, he explains, depends upon the intensity of the current of transpiration to a large extent.

Burd (8) described a progressively increasing absorption of nitrogen, potassium, calcium, and magnesium by barley, grown in soils under controlled moisture conditions, ending about the time heads began to form, after which there was a definite loss of nutrients. This loss of nutrients was accompanied by a lowering of the concentration of the nutrients in the soil extract. Later in the growth the nutrients were again absorbed by the

plants when the water extractable nutrients were increasing. The phosphorus absorbed by the plant and that in the water extract did not decrease during this period. This is in agreement with the results obtained by True and Bartlett (9) which showed "a definite concentration for each salt or mixture of salts at which roots of peas absorb and excrete electrolytes at the same rate. If the culture solution is initially less concentrated than this equilibrium concentration, excretion from the roots over balance absorption. If the solution is initially more concentrated than this equilibrium, absorption overbalances excretion".

Schreiner and Skinner (10) secured results which show that "the higher the amount of any constituent present in the solution, the more the plant growing in that solution takes up this constituent, although it does not seem able to use this additional amount economically.

Andre and DeMoussey (11) advanced the idea that the difference in potassium and sodium content of plant tissues is partially due to the unequal mobility of the two alkali metals in solution.

Much attention has been given to the influence of fertilizer treatments upon the sugar content of beet roots, but there is very little agreement on their effect. Wiley (12) found a vast difference in the yield of beets on various soils but the composition of the soils had

little effect upon the sugar content of the beets.

Saillard (13) reported "that potassic fertilizers gave good results in regards to purity, richness, and yield of sugar beets. Large applications of nitrate of soda retarded maturity and decreased sugar content".

Weibull (14) found "the sugar content was increased slightly, but decidedly by nitrate of soda, while phosphoric acid and potash depressed the purity and percentage of sugar in beets".

Frankfurt (15) improved the yield of sugar content of beets by the use of nitrate of soda and superphosphate in combination. Small applications of nitrate of soda gave best results.

Vivier (16) concluded "that the beet crop increases with applications of nitrate of soda and the density of the juice decreases at about the same rate, so that the total amount of sugar is not altered. Phosphoric acid shows little effect on the yield of crop and density of juice".

Joulié (17) reported that phosphoric acid and the alkalies in the beet roots varied with the richness in sugar; the phosphoric acid increased with an increase in sugar, and the alkalies decreased under the same conditions.

McCool and Harmer (18) found the sugar content of beets to be greatly increased by the use of potash on muck. The increase was almost as great in beets from

plots fertilized with potash alone as in beets grown on plots which received both phosphate and potash.

Schneidwind, Meyer, and M^unter (19) increased the dry matter and sugar content by the use of potash on all soils investigated. The best results were obtained by fall applications.

Herke (20) reported that nitrate of soda applied in moderate amounts in connection with potash and phosphoric acid on soils poor in nitrogen increased the sugar content of beets without injury to the quality.

The chemical constitution of enzymes is as yet a matter of general speculation, so that investigators have measured only the relative activity of enzymes in preparations of plant tissues. Bunzell (21) has used the term "oxidase activity" rather than concentration of oxidases to denote the factors responsible for the complex reactions based upon oxygen absorption in the presence of plant juices and tissues. The decomposition of hydrogen peroxide by plant and animal tissues was first attributed to the action of a special enzyme by Loew (22). He termed it catalase, and since that time it has been demonstrated as present in all oxygen requiring cells. Anaerobic cells contain no catalase. The only known action of this enzyme according to Waldschmidt (23) is the decomposition of hydrogen peroxide into water and oxygen.

There appears to be a general agreement among investigators that there is a correlation between health and vigor in plants and the activity of catalase in the tissues. Heincke (24) found less catalase activity in apple leaf tissue from trees grown on sandy soil than in leaf tissue of trees grown on clay soil. The catalase activity was greater in leaves of trees grown in cultivated soil than in leaves of trees grown in sod. Applications of nitrate of soda to trees in sod increased the catalase activity of the leaves in proportion to the amounts applied up to eight ounces per tree. Knott (25) reported that nitrogen and phosphorus when applied to the plant through the roots resulted in increased catalase activity.

Conversely a correlation has been found between oxidase activity and retarded growth. Bunzell (26) found the oxidase activity to be much greater in sugar beets affected with curly top disease than healthy beets. He found increased activity of oxidase in every case where growth was retarded by natural or artificial means. Potato plants affected with curly dwarf disease (27) gave a much higher oxidase activity accompanied by greatly decreased growth as compared to healthy potatoes. Woods (28) reported a higher oxidase activity in tobacco plants affected with mosaic disease than in healthy plants.

Ezell and Crist (29) on the other hand report "a slight correlation between oxidase activity and growth with a tendency to be negative in character. The correlation between catalase activity and growth was better and distinctly negative". The fertilizer treatments described by Ezell and Crist are extremely heavy and the absorption of these salts in excess may explain this reversal of the activity of the enzymes. Santesson (30) and Heincke (31) found that nitrates of sodium, calcium, and potassium added to plant tissues decreased their power to decompose hydrogen peroxide.

In the investigations reported in this paper the results of studies of the mineral nutrient content, sugar content, and activities of the enzymes, catalase and oxidase, of sugar beets as influenced by soil conditions and fertilizer treatments are presented. This data may contribute some knowledge to the problem of the action of fertilizer salts and throw some light upon the physiological role of nutrient elements.

Methods of Experimentation.

The mineral nutrient content of leaves and roots of sugar beets was determined on samples taken from

fertilizer plots on widely different soils. Samples were taken from plots on Rifle muck and Hillsdale sandy loam at four periods during the growing season of 1926, and from Miami loam at four periods during the season of 1927. Samples of roots and tops were taken from plots on Miami loam, Brookston silt loam, and Berrien sandy loam at harvest time in 1927. These samples were placed in moisture proof bags and taken to the laboratory as quickly as possible. Here they were washed free from adhering soil and dust, and spread out to dry. An electric fan was used to accelerate the drying and prevent decomposition of the material. After the samples were thoroughly dried they were ground in a Wiley Mill and preserved in glass bottles for analysis.

Determinations of the mineral nutrients were made according to the "Official Methods of the American Agricultural Chemists" (32) with the exceptions of potassium and sodium. Determinations of potassium were made by the cobaltinitrite method described by Addie and Woods (33). Sodium determinations were made by the method described by Blancheterie (34) and adapted to plant analysis by Bertrand and Perietzeanu (35). In this method the plant ash is dissolved in

water and neutralized with acetic acid. Phosphorus , the only element found in plant material which interferes with the precipitation of sodium, is removed by precipitation as uranium phosphate and centrifuging. The sodium is then precipitated as the triple acetate of uranium - magnesium - sodium. The precipitate is filtered through a weighed Gooch crucible, observing the precautions of Blancheterie, washed with the reagent and with alcohol, dried in the oven for one hour at $110^{\circ}\text{C}.$, cooled in a dessicator, and weighed. The writer used Pyrex glass instead of the silica dishes described by Blancheterie, and found that it was necessary to run blanks with each set as there was an appreciable amount of sodium in the glass which precipitated out. When this amount was subtracted from the weight of precipitate obtained by using 1 cc of N/10 NaOH the weight of sodium obtained checked very closely with the weight of sodium present and did not vary at any time more than .05 mg. Since beginning this work the writer has read Koltoff's description of an improved method employing uranium - zinc acetate instead of uranium - magnesium acetate for the precipitation of sodium. However the results obtained by the method described above have been so satisfactory that it was not considered desirable to change at this time.

Determinations of sugar content of sugar beets was made on beet roots taken from fertilizer plots on Rifle muck, Hillsdale sandy loam, Miami loam, Brookston loam, Brookston silt loam, and Nappanee silt loam in 1926, and from Miami loam, Brookston loam, Berrien sandy loam, and Nappanee silt loam in 1927. These samples were placed in moisture proof bags and transported to the College as quickly as possible, where the sugar content was determined by the Experiment Station Chemist.

Leaves of sugar beets were collected from the fertilized plots on Rifle muck, Miami loam, and Brookston silt loam for the study of the influence of soil fertilizer treatments on the activity of the enzymes, catalase and oxidase. These samples were placed in quart mason jars, sealed, packed in ice, and immediately taken to the laboratory. The preparation of the plant material was similar to the method described by Ezell and Crist. Discs were cut from the leaves with a cork punch. Two grams of the discs were placed in a mortar with an equal weight of pure calcium carbonate and sufficient distilled water to cause the calcium carbonate to spread evenly over the discs. The material was ground with a pestle until a uniform creamy mixture was obtained. The sample was then transferred to a 100 cc. volumetric flask and made up to volume with water. It was

then preserved in a refrigerator at about 4° C until used. This is the temperature reported by Knott (25) as being most favorable for the preservation of plant material to be used for measuring the activity of enzymes. The determinations were made according to the methods described by Ezell and Crist, except that the mercury was removed from the manometer of the Bunzell apparatus and the tube connected to a mercury displacement apparatus made from small graduated pipettes. The volume of oxygen split from hydrogen peroxide was determined at 5, 10, and 15 minutes. At 15 minutes this reading was usually constant and this amount was taken as the measure of catalase activity. The volume of oxygen absorbed by pyrogallol in one hour in the presence of the plant material was accepted as the measure of the oxidase activity. One cubic centimeter of material was used for determining catalase activity and three cubic centimeters for oxidase activity. The activity of each enzyme has been calculated to cubic centimeters of oxygen per gram of fresh plant material.

EXPERIMENTAL RESULTS

The Chemical Composition of Sugar Beets

The study of the chemical composition of the sugar beets was divided into the determination of the influence of season and fertilizer treatments on the

mineral nutrient content of the leaves and roots of beets grown on different soils, and the influence of fertilizer treatments on the sugar content of the beet roots grown on several soils.

I.

Seasonal Variation of Mineral Nutrients

The seasonal variations of the mineral nutrient content of the leaves of beets grown on Rifle muck and on Hillsdale sandy loam were determined for four periods of growth during the season of 1926, and similarly for beets grown on Miami loam for 1927. These data are presented in Tables I, II, and III.

Table I presents a summary of the seasonal variations of the mineral nutrient content of leaves of beets grown on Rifle muck in 1926. The percentage of phosphorus was high in the spring at thinning time, but decreased rapidly during the summer, and following this increased rapidly in the later stages of growth. The highest percentage was found in the beets grown on the plot which was fertilized with superphosphate alone and was slightly lower in beets which received potash in addition. The percentage of potassium was highest in the spring and shows a marked decrease during the successive stages of growth. An interesting phenomenon noted at this point and which will be discussed later is that there was less potassium than

Table 1

Seasonal Variations of Mineral Nutrient Content of Leaves of Sugar Beets grown on Rifle Muck.

1926

Fertilizer Treatment	% Ash				% Phosphorus				% Calcium			
	7/10/26	7/30/26	9/8/26	10/15/26	7/10/26	7/30/26	9/8/26	10/15/26	7/10/26	7/30/26	9/8/26	10/15/26
None	20.628	20.326	13.684	11.852	3.832	—	1.456	2.715	1.900	1.640	1.280	2.000
K 300	24.860	22.900	19.056	14.670	3.775	—	2.036	2.831	1.720	1.480	1.270	1.320
P 300	24.876	24.410	17.718	14.206	4.567	—	1.909	2.771	1.570	1.380	.820	1.280
P 300	20.714	19.316	12.184	12.160	5.061	—	2.475	3.450	1.890	1.560	1.070	1.820
	% Magnesium				% Potassium				% Sodium			
	7/10/26	7/30/26	9/8/26	10/15/26	7/10/26	7/30/26	9/8/26	10/15/26	7/10/26	7/30/26	9/8/26	10/15/26
None	1.872	1.896	2.088	1.440	4.189	3.848	1.832	1.193	2.685	3.059	1.770	.715
K 300	1.536	1.608	1.824	1.416	8.250	6.900	6.091	4.033	1.793	2.053	1.750	.682
P 300	1.440	.840	.776	1.200	8.280	7.892	5.393	3.555	1.863	1.960	1.565	.548
P 300	1.824	2.016	2.016	1.680	4.240	1.704	1.789	1.420	2.867	1.579	1.834	.682

K - Muriate of potash

P - Superphosphate (20%)

phosphorus in the leaves of beets from plots receiving no potash fertilization and that the potassium content was greater than the phosphorus content in leaves of beets from the plots which were fertilized with potash. The percentage of sodium was high during the early stages of growth and was higher in plants from plots which received no potash than in those from the potash treated plots. During the later stages of growth there was a decrease in the sodium content of plants from all plots. At this time the differences in percentages of sodium in leaves of beets from the different plots was slight. The percentages of calcium and magnesium were about equal during the first period of growth. The percentage of calcium decreased during the growing season and increased at harvest time. The percentage of magnesium followed a similar path in the beet leaves from the plot which received both potash and superphosphate. The percentage of magnesium increased in the leaves of the beets grown on the other plots during the season and decreased at harvest time.

The largest beets were produced on the plot receiving potash and superphosphate in combination. It is interesting to note the extremely high percentage of potassium, followed by a high percentage of phosphorus in the leaves from this plot, and that the percentage of calcium was greater than that of magnesium.

Table II

Seasonal Variations of Mineral Nutrient Content of Leaves of Sugar Beets grown on Hillsdale Sandy Loam

1926

Fertilizer Treatment	% Ash					% Phosphorus					% Calcium				
	7/10/26	8/15/26	9/11/26	10/15/26	7/10/26	8/15/26	9/11/26	10/15/26	7/10/26	8/15/26	9/11/26	10/15/26	7/10/26	8/15/26	9/11/26
U ₃₃ P ₇₁	14.700	16.256	10.624	10.358	2.941	3.818	2.828	3.818	4.800	2.700	1.730	1.320			
U ₃₃ P ₇₁ K ₂ So ₄ 100	16.242	15.036	12.952	10.692	2.403	3.111	2.460	3.110	4.180	2.520	1.600	1.120			
U ₃₃ P ₇₁ KCL 100	15.542	15.776	13.536	10.170	2.432	3.167	2.234	3.167	3.900	2.560	1.860	1.040			
U ₃₃ P ₇₁ Lime 4000#	15.426	15.680	14.938	10.998	3.620	3.486	3.309	3.846	6.160	3.640	2.000	1.560			
U ₃₃ P ₇₁ L 4000	16.626	14.540	14.232	11.740	2.605	3.648	2.828	3.620	4.760	3.100	1.860	1.420			
U ₃₃ P ₇₁ K ₂ So ₄ 100	17.234	15.210	15.840	10.836	1.753	3.648	2.686	3.650	4.940	3.300	1.820	1.360			

L - Limestone

P - Mono - Calcium phosphate

K₂ So₄ Potassium Sulfate

U - Urea

KCL - Potassium Chloride

Table II

Seasonal Variations of Mineral Nutrient Content of Leaves of Sugar Beets grown on Hillsdale Sandy Loam.

1926

Fertilizer Treatment	% Magnesium				% Potassium				% Sodium		
	7/10/26	8/15/26	9/11/26	10/15/26	7/10/26	8/15/26	9/11/26	10/15/26	7/10/26	8/15/26	9/11/26 10/15/26
U ₃₃ P ₇₁	3.745	2.208	2.040	1.032	2.896	3.180	3.408	3.408	1.514	.634	.605 .715
U ₃₃ P ₇₁ K ₂ SO ₄ ₁₀₀	3.984	2.064	2.040	.960	3.124	3.948	4.004	4.004	1.350	.600	1.055 .662
U ₃₃ P ₇₁ KCL 100	3.456	1.680	2.004	.720	3.493	4.487	4.118	4.118	1.227	.530	1.295 .576
U ₃₃ P ₇₁ Lime 400	3.264	1.440	1.980	1.152	2.330	2.925	2.640	2.556	.940	.631	1.071 .763
U ₃₃ P ₇₁ Lime 4000 K ₂ SO ₄ 100	3.120	1.320	1.884	.912	2.982	3.067	2.698	4.202	1.314	.711	1.077 .611
U ₃₃ P ₇₁ L 4000 KCL 100	3.144	1.152	1.896	.792	3.040	4.402	3.436	3.920	.771	.645	1.416 .504

L - Limestone

P - Mono - Calcium phosphate

K₂ SO₄ Potassium Sulfate

U - Urea

KCL - Potassium Chloride

The results obtained from beets grown on the Hillsdale sandy loam are given in Table II. According to these data the percentage of calcium was extremely high in the leaves during the early periods of growth and decreased rapidly during the entire growing season. The percentage of calcium was highest in the leaves of beets produced on the plot which received lime without potash. The phosphorus content was low during the first period of growth, increased in August, decreased in September, and then increased in October. An exception to this was the phosphorus in the leaves from the plot which was limed, but received no potash. In these the percentage of phosphorus was high in the early stages of growth, showed a slight decrease during the summer, and then increased in the fall. The percentage of potassium was lowest in the leaves of the beets from all plots in early July. The percentage of potassium increased in August, following which the beets grown on the plot fertilized with urea and phosphate were the only ones in which the percentage of potassium increased up to harvest time. A decrease in the percentage of potassium was found in the leaves sampled in September, but no further change occurred in October. The beets from the plot fertilized with urea, phosphate and potash, and limed showed an increase at harvest time. The magnesium

Table III
Seasonal Variations of Mineral Nutrient Content of Leaves of Sugar Beets grown on Miami loam - 1927

Ferti- lizer Treatment	% Ask				% Phosphorus				% Calcium			
	6/20/27	7/22/27	9/3/27	10/8/27	6/20/27	7/22/27	9/3/27	10/8/27	6/20/27	7/22/27	9/3/27	10/8/27
None	21.126	21.384	22.224	18.754	2.234	2.489	2.519	3.337	1.980	2.280	3.300	2.740
N100 K100	21.656	24.580	22.630	20.094	1.923	2.545	2.121	3.535	2.220	2.320	2.840	2.840
N100 P400	20.236	20.240	21.444	18.900	3.140	2.800	2.347	4.016	1.660	1.700	2.160	1.140
K100	16.270	19.544	16.274	17.720	4.015	3.110	2.404	3.167	1.720	1.740	1.840	1.500
P400 K100	18.676	20.822	21.516	17.348	3.082	2.828	2.404	3.846	2.000	1.880	2.040	2.080
Fertilizer Treatment	% Magnesium				% Potassium				% Sodium			
	6/20/27	7/22/27	9/3/27	10/8/27	6/20/27	7/22/27	9/3/27	10/8/27	6/20/27	7/22/27	9/3/27	10/8/27
None	1.656	2.160	2.496	1.800	5.880	4.941	5.566	5.310	1.161	1.595	2.117	1.950
N100 K100	1.680	2.064	2.592	1.800	5.395	3.408	3.550	5.112	1.633	2.019	2.167	2.547
N100 P400	1.464	2.112	2.088	1.392	5.566	3.805	3.862	6.302	2.162	2.593	2.637	2.176
K100	1.332	2.040	1.800	1.440	1.505	2.073	1.704	4.487	2.764	2.813	2.327	2.466
P400 K100	1.680	2.136	2.256	1.680	5.821	4.827	4.771	5.566	1.687	1.807	1.961	1.830

N - Chilean Nitrate of Soda
P - Superphosphate (20%)
K - Muriate of Potash

content was highest at thinning time, after which there was a gradual decrease, except in September, when there was a slight increase, followed by a decrease at harvest time. The percentage of sodium was lowest in the cases in which potassium was highest, and highest when the potassium was lowest.

Here again it is noted that the percentage of potassium was greater than that of phosphorus and that of calcium greater than that of magnesium in the beet leaves from the limed plot fertilized with urea, phosphate, and potash, and that this plot produced the largest beets grown on this soil. The same is true of the plot which was similarly fertilized but which was unlimed. In the beet leaves from the other plots the percentages of phosphorus were greater than the percentages of potassium.

The seasonal variations in the mineral nutrients in the leaves of beets grown on Miami loam are presented in Table III. These data show a high percentage of phosphorus in the leaves at thinning time, a decrease during the summer, and then a large increase in the fall, except in the case of beets grown on plots which received no phosphate fertilizer. The beet leaves on these plots contained a low percentage of phosphorus at thinning time, but it gradually increased during the summer, and was highest at harvest time. The percentage of phosphorus in the leaves from the phosphate treated plots was high at thinning time, decreased during the summer, and then

increased during the later stages of growth. The percentage of calcium was lowest at thinning time and increased gradually during the season except in the beets from the non-potash treated plots. In these cases there was a decrease in the percentage of calcium in the leaves at harvest time. The percentage of magnesium was low during the early periods, increased during the summer, and then decreased at harvest time. The percentage of sodium in the leaves was low at thinning time and increased during July and August, except in beets grown on the plot with nitrate of soda and superphosphate. The percentage of sodium decreased in the late stages of growth except in the beet leaves grown on the plot fertilized with nitrate of soda and potash. The leaves from the nitrate-phosphate plot showed a decrease in the percentage of sodium during the entire growing season, while there was an increase in the sodium content during the season in leaves from the nitrate-potash plot.

Here also we find a high percentage of potassium and a slightly lower percentage of phosphorus in the beet leaves associated with the optimum growth of the beet. The percentage of calcium in the leaves of the largest beets on the Miami loam was greater than the percentage of magnesium except in the case of the July samples. It should be noted also that the percentage of phosphorus in the leaves of the largest beets is greater than the percentage of calcium.

Table IV
Mineral Nutrient Content of Sugar Beets grown on Hillsdale Sandy loam and the average weight of the Roots, Oct. 11, 1926

Fertilizer Treatment	% Ask		% Phosphorus		% Calcium		% Magnesium		% Potassium		% Sodium		Average weight of roots of roots in Pounds
	Leaves	Roots	Leaves	Roots	Leaves	Roots	Leaves	Roots	Leaves	Leaves	Roots		
U ₃₃ P ₇₁ Ck	10.353	4.427	3.818	3.139	1.220	.370	1.032	.288	3.408	1.704	.715	.850	0.35
" K ₂ So ₄ 100#	10.692	4.157	3.110	3.139	1.220	.300	.960	.264	4.004	2.016	.662	.651	0.55
" Kcl 100#	10.170	4.330	3.167	2.913	1.040	.300	.720	.216	4.118	2.130	.576	.558	0.58
U ₃₃ P ₇₁ L4000 Ck	10.998	4.152	3.846	2.363	1.560	.410	1.152	.240	2.556	1.420	.763	.800	0.44
" K ₂ So ₄ 100#	11.740	4.111	3.620	1.980	1.420	.300	.912	.216	4.202	1.761	.611	.719	0.52
" Kcl 100#	10.836	4.081	3.650	1.824	1.360	.300	.792	.192	3.920	1.874	.504	.622	0.68
U - urea L - Limestone													
	P - Mono-calcium K ₂ So ₄ - Potassium sulfate												KCL - Potassium Chloride

II.

Variations in Mineral Nutrient Content of Beets at Harvest Time Due to Fertilizer Treatments.

A summary of the results of the investigations concerning the influence of fertilizer treatments and soil conditions on the percentage of mineral nutrients contained in the leaves and roots of beets are given in Tables IV, V, VI, VII, and VIII.

Table IV presents the data obtained from beets grown on Hillsdale sandy loam. The use of potash, especially muriate of potash, and of lime, either singly or in combination, on plots supplied with nitrogen and phosphate increased the yield of beets. On the unlimed plots the addition of potash increased the percentage of potassium in both leaves and roots, at the same time causing a decrease in the percentages of calcium, magnesium, sodium and phosphorus. The same phenomena occurred in the limed series. Lime in addition to urea and phosphate greatly decreased the percentage of potassium in the leaves and roots, but caused an increase in the percentages of phosphorus, calcium, and magnesium. The leaves of beets from the plots which produced the largest yield of beets contained the minerals in the following order $K > P > Ca > Mg > Na$, while in the roots the order was $K > P > Na > Ca > Mg$.

Table V

Mineral Nutrient Content of Sugar Beets grown on Rifle Muck and the average weight of Roots

October 15, 1926

Fertilizer Treatment	% Ash		% Phosphorus		% Calcium		% Magnesium		% Potassium		% Sodium		Average Weight of Roots in Pounds
	Leaves	Roots	Leaves	Roots	Leaves	Roots	Leaves	Roots	Leaves	Roots	Leaves	Roots	
None	11.852	4.680	2.715	1.244	2.000	.240	1.440	.768	1.193	.882	.715	1.065	0.45
K 300	14.670	7.000	2.831	1.865	1.320	.220	1.416	.744	4.033	5.052	.662	.584	0.70
P 100 K 300	14.356	7.563	3.110	2.064	1.360	.220	1.368	.720	3.975	4.688	.571	.566	0.85
P 300 K 300	14.206	6.746	2.771	2.178	1.280	.210	1.200	.720	3.555	4.630	.548	.517	1.10
P 300 K 100	13.110	5.765	3.422	3.280	1.400	.230	1.512	.720	2.612	4.437	.639	1.022	0.76
P 300	12.160	3.962	3.450	4.030	1.820	.240	1.680	.720	1.420	2.811	.682	1.346	0.50

K - Muriate of Potash

P - Superphosphate (20%)

Table V. presents the data concerning the influence of fertilizer treatments on the percentages of mineral nutrients found in the leaves and roots of beets grown on Rifle muck and sampled at harvest time. The percentages of phosphorus and of potassium were extremely low in the check plot. Addition of potash caused a remarkable increase in the potassium content, and a slight increase in the phosphorus content of both leaves and roots. Phosphate fertilization on the other hand caused a tremendous increase in the phosphorus content and a slight increase in the potassium content. Application of 300 pounds each of superphosphate and potash caused a large increase in production of both leaves and roots. The percentage of potassium was slightly less than in the beets from the plot fertilized with potash alone, and the percentage of phosphorus was considerably smaller than in the beets grown on the plot which received superphosphate alone. The percentages of calcium, magnesium, and sodium were highest in the beets from the plots showing the smallest growth and least in beets from the plot showing the maximum growth of both tops and roots. There was less variation in calcium and magnesium in roots than in leaves and greater variation in sodium.

The results of the experiment on Miami loam are given in Table VI. The application of "Chilean Nitrate" and potash in combination, caused an increase in the percentages of phosphorus, calcium, magnesium, and sodium and a

Table VI

Mineral Nutrients content of Sugar Beets grown on Miami Loam and the average weight of the Roots, October 8, 1927

Fertilizer Treatment	% Ash		% Phosphorus		% Calcium		% Magnesium		% Potassium		% Sodium		Average Weight of Roots in Pounds
	Leaves	Roots	Leaves	Roots	Leaves	Roots	Leaves	Roots	Leaves	Roots	Leaves	Roots	
None	18.754	3.817	3.337	1.527	2.740	.188	1.800	.729	5.310	1.136	1.950	.235	0.47
N100 K100	20.094	4.207	3.535	1.527	2.840	.156	1.800	.624	5.112	1.349	2.547	.335	0.56
N100 P200 K100		3.645		1.833		.236		.624		.994		.238	0.75
N100 P400 K100	18.900	3.314	4.016	2.121	1.140	.120	1.392	.528	6.302	1.165	2.176	.238	1.10
N100 P800 K100	18.024	4.258	4.525	2.234	1.280	.148	1.320	.634	4.884	.923	2.753	.286	0.80
N100 P400	17.720	3.320	3.167	2.093	1.500	.148	1.440	.461	4.487	.952	2.466	.304	0.82
N100 P400 K50	17.370	3.300	3.280	2.093	1.400	.144	1.392	.499	5.538	1.023	2.217	.248	0.87
N100 P400 K100	18.900	3.314	4.016	2.121	1.140	.120	1.392	.528	6.302	1.165	2.176	.238	1.10
N100 P400 K200	18.894	4.445	3.054	2.093	1.380	.112	1.512	.528	4.544	.966	2.380	.210	0.70
P400 K100	17.348	3.176	3.846	1.357	2.080	.144	1.680	.557	5.566	.952	1.830	.243	0.69
N100 P400 K100	18.900	3.314	4.016	2.121	1.140	.120	1.392	.528	6.302	1.165	2.176	.238	1.10
N300 P400 K100	17.248	4.027	4.383	2.093	1.660	.152	1.320	.615	4.998	.966	2.693	.347	0.75

N - Chilean Nitrate of Soda

P - Superphosphate (20%)

K - Muriate of potash

decrease in the percentage of potassium in the leaves. In the roots the percentages of potassium and sodium were increased, calcium and magnesium decreased, and phosphorus was unchanged. Additions of 200, 400, and 800 pounds of superphosphate with the Chilean Nitrate and potash caused corresponding increases in phosphorus content and decreases in calcium and magnesium in both roots and leaves with each successive increment. The percentage of potassium was decreased in the roots with successive addition of superphosphate. The greatest amount of potassium was found in the leaves from the plot receiving 400 pounds of superphosphate. Application of 800 pounds of superphosphate caused a decrease in the amount of potassium in the leaves. The percentage of sodium was low in leaves from plots receiving 200 and 400 pounds of superphosphate but increased in leaves from the plot receiving 800 pounds.

The percentage of potassium was lower in the leaves and roots of beets from the plots receiving nitrate of soda and superphosphate than in the beets from the check plot. Additions of 50 and 100 pounds of potash caused an increase in the percentages of potassium in the roots and leaves and of phosphorus in the leaves. 200 pounds of potash caused a decrease in both potassium and phosphorus in leaves and in potassium in the root. The above treatment had no effect on phosphorus content of the roots.

The percentages of calcium and magnesium in the leaves were decreased by addition of 50 pounds of potash, increased with application of 100 pounds, and then the 200 pound application caused a further increase in magnesium content and a decrease in calcium content. The percentages of calcium and magnesium were slightly decreased in the roots by additions of potash. The percentage of sodium was highest in the plot receiving nitrate of soda and superphosphate only and decreased with additions of potash.

Fertilization with superphosphate and potash only caused an increase in both potassium and phosphorus content and a decrease in the calcium, magnesium, and sodium in the leaves. In the roots this was accompanied by a decrease in the percentages of all the elements except sodium. Additions of 100 and 300 pounds of "Chilean Nitrate" caused an increase in the amount of phosphorus and sodium in the leaves and roots and a decrease in the percentages of calcium and magnesium. The potassium content was increased by the addition of 100 pounds of "Chilean Nitrate", but the percentage present in both leaves and roots was decreased by the addition of 300 pounds.

The order in which the percentages of the elements occurred in the leaves from the plot, which gave the maximum yield of beets, was $K > P > Na > Ca > Mg$ and in the roots $P > K > Mg > Na > Ca$.

The results of the experiment on Berrien sandy loam

Table VII

Mineral Nutrient Content of Sugar Beets grown on Berrien Sandy loam and the average weight of the roots - 1927

Fertilizer Treatment	% Ash		%Phosphorus		%Calcium		%Magnesium		%Potassium		%Sodium		Average Weight of Roots in Pounds
	Leaves	Roots	Leaves	Roots	Leaves	Roots	Leaves	Roots	Leaves	Roots	Leaves	Roots	
None	17.244	3.155	1.668	.792	2.580	.128	1.800	.307	4.402	1.136	1.927	.240	0.45
N100 N100	17.644	3.295	1.696	.820	2.300	.140	1.728	.317	4.118	1.122	2.680	.335	0.31
N100 P200 K100	16.414	3.433	2.121	.820	2.300	.140	1.656	.245	4.203	1.250	2.382	.331	0.55
N100 P400 K100	15.674	2.420	1.980	.933	1.400	.116	1.032	.240	5.680	1.150	2.364	.154	0.68
N100 P800 K100	17.076	2.452	2.941	1.132	2.400	.120	1.632	.230	5.556	.838	2.590	.180	0.62
N100 P400	15.234	2.720	2.404	.962	1.840	.136	1.416	.231	4.487	.881	2.002	.256	0.60
N100 P400 K50	14.530	3.101	2.517	.933	1.560	.108	1.392	.230	4.771	1.250	2.005	.190	0.75
N100 P400 K100	15.674	2.420	1.980	.933	1.400	.116	1.032	.240	5.680	1.150	2.364	.154	0.68
N100 P400 K200	16.308	3.178	2.602	1.132	1.600	.132	1.224	.221	5.000	1.136	2.730	.189	0.66
P400 K100	14.250	2.586	2.404	.990	1.920	.124	1.440	.187	4.118	1.065	1.760	.150	0.60
N100 P400 K100	15.674	2.420	1.980	.933	1.400	.116	1.032	.240	5.680	1.150	2.364	.154	0.68
N300 P400 K100	16.192	2.690	2.970	.735	1.220	.104	.888	.250	6.820	1.023	2.628	.170	0.75

are given in Table VII. The addition of 200, 400, and 800 pounds of superphosphate increased the percentages of phosphorus in both leaves and roots and caused a decrease in the percentages of calcium, magnesium, and sodium as compared to the amount present in the plot receiving "Chilean Nitrate" and potash only. This latter treatment caused an increase in the percentages of sodium and phosphorus and a decrease in potassium, calcium, and magnesium. The addition of 200 and 400 pounds of superphosphate caused an increase in the potassium content of the leaves, while the 800 pound application caused a decrease. In the roots both the 400 pound and the 800 pound treatments caused a decrease in the percentage of potassium in leaves. The percentages of calcium and magnesium were lowest in the leaves and roots from the plot fertilized with 400 pounds of superphosphate.

"Chilean Nitrate" and superphosphate alone increased the percentages of phosphorus and sodium in the leaves and roots, and decreased the potassium, calcium, and magnesium. Additions of potash up to 100 pounds per acre increased the potassium in the leaves. 200 pounds of potash per acre decreased the percentage of potassium in both leaves and roots and caused an increase in the percentages of calcium, magnesium, phosphorus, and sodium as compared to the plot receiving only 100 pounds of potash. The percentages of calcium and magnesium present were low in this plot also.

Table VIII

Mineral Nutrient Content of Sugar Beets grown on Brookston silt loam and the average weight of the Roots - 1927

Fertilizer Treatments	% Ash		% Phosphorus		% Calcium		% Magnesium		% Potassium		% Sodium		Average Weight of Roots in Pounds
	Leaves	Roots	Leaves	Roots	Leaves	Roots	Leaves	Roots	Leaves	Roots	Leaves	Roots	
None	16.776	2.835	2.517	.735	2.500	.180	1.272	.226	8.008	.809	.913	.133	1.40
N100 K100	15.468	6.122	2.630	.650	2.540	.272	1.200	.403	6.928	1.477	1.257	.270	1.66
N 100 P 200 K 100	15.248	2.805	3.167	.792	1.920	.144	1.080	.216	7.100	.937	1.207	.175	2.00
N 100 P 400 K 100	12.892	2.820	3.394	.792	1.300	.148	.840	.211	6.846	.866	1.085	.133	3.00
N 100 P 800 K 100	15.458	2.633	3.535	1.132	1.360	.144	.720	.206	7.525	.909	1.408	.174	2.46
N 100 P 400	14.184	2.942	3.733	.990	1.100	.140	.600	.221	7.156	1.065	1.322	.158	2.20
N 100 P 400 K 50	15.080	3.427	3.790	.905	1.140	.140	.720	.192	7.270	1.270	1.566	.229	2.20
N 100 P 400 K 200	12.892	2.820	3.394	.792	1.300	.148	.840	.211	6.846	.866	1.085	.133	3.00
N 100 P 400 K 200	15.970	3.040	3.394	.764	1.200	.124	.672	.207	7.810	1.136	1.520	.181	2.08
P 400 K 100	14.964	4.244	2.573	1.461	1.100	.228	.528	.283	7.838	1.179	1.153	.188	2.40
N 100 P 400 K 100	12.892	2.820	3.394	.792	1.300	.148	.840	.211	6.846	.866	1.085	.133	3.00
N 300 P 400 K 100	14.990	2.665	2.291	.792	1.520	.124	.888	.202	6.105	.795	1.818	.190	2.90

Superphosphate and potash alone increased the phosphorus content of leaves and roots but caused a decrease in the percentage of potassium, sodium, calcium, and magnesium. 100 and 300 pounds of "Chilean Nitrate" per acre caused a marked increase in the potassium and sodium in the leaves, and a decrease in the percentages of calcium and magnesium in both leaves and roots, and of phosphorus in the roots. 100 pounds of nitrate caused a decrease in the percentage of phosphorus and 300 pounds caused a large increase in the leaves.

The percentages of elements in the leaves from the plot which received 100 pounds of "Chilean Nitrate", 400 pounds of superphosphate, and 100 pounds of potash occurred in the following order $K > Na > P > Ca > Mg$ and in the roots $K > P > Mg > Na > Ca$.

Table VIII gives a summary of the data obtained from beets grown on Brookston silt loam. The application of "Chilean Nitrate" and potash in combination caused a decrease in the percentages of potassium and magnesium in the leaves and an increase in the phosphorus calcium, and sodium, while the percentages of potassium, magnesium, calcium, and sodium were increased in the roots and the percentage of phosphorus decreased. Additions of 200, 400 and 800 pounds of superphosphate per acre caused marked increases of phosphorus in the leaves and roots and decreases in the percentages of calcium, magnesium, and potassium, with the exception of the 800 pound application which caused an

increase in the potassium in the leaves. The percentage of sodium was decreased by the addition of 200 and 400 pounds of superphosphate and then increased by the 800 pound application.

The percentages of potassium, calcium, and magnesium, in the leaves were reduced by the application of "Chilean Nitrate" and superphosphate and the percentages of sodium and phosphorus increased. The sodium, phosphorus, and potassium contents were increased in the roots by this same treatment and the percentages of calcium and magnesium lowered. Additions of 50 pounds of potash increased the content of the five elements in the leaves and of potassium and sodium in the roots. The 100 pound application caused a decrease in the percentage of potassium, sodium, and phosphorus, and an increase in the calcium and magnesium content in both leaves and roots, while the 200 pound addition caused the potassium and sodium content to increase, the percentages of calcium and magnesium to decrease, and had no influence on the percentage of phosphorus.

Leaves from the plot fertilized with superphosphate and potash show a decrease in the percentages of potassium, calcium, and magnesium, and an increase in the amount of sodium and phosphorus. The same treatment caused a marked increase in the phosphorus and potassium contents of the roots. Additions of 100 pounds of "Chilean Nitrate" per acre caused a decrease in the percentages of

potassium and sodium in both leaves and roots, an increase in the calcium, magnesium, and phosphorus contents of the leaves, and a decrease in the phosphorus, calcium, and magnesium in the roots. The addition of 300 pounds of "Chilean Nitrate" per acre caused a further decrease in the percentages of potassium in leaves and roots, a marked decrease in the percentage of phosphorus in the leaves, an increase in sodium in both leaves and roots and of calcium and magnesium in the leaves. There was a slight decrease in percentages of calcium and magnesium in roots.

The ratio of the elements in the leaves from the plot producing the largest beets was $K > P > Ca > Na > Mg$ and of the roots $K > P > Mg > Ca > Na$.

III.

Variations in Sugar Content of Roots Due to Fertilizer Treatments on Several Soil Types

The sugar contents of beets grown on several soils under different fertilizer treatments in 1926 and 1927 are given in Tables IX, X, XI, XII, XIII, XIV, and XV. A study of these tables shows a very slight and insignificant correlation between the fertilizer treatments and the percentage of sugar found in the beets. In some cases there is a slight decrease in the sugar content

Table IX

Influence of varying amounts of "Chilean Nitrate" on Sugar Content of Beets Grown on Miami loam, Brookston loam, and Brookston silt loam.

1926

Fertilizer Treatment	Miami Loam	Brookston Loam	Brookston Silt Loam
None	14.5	17.4	18.4
400# 0-12-6 N100#	16.2	17.4	17.9
None	15.1	18.0	17.4
400# 0-12-6 N200#	15.4	18.3	17.5
None	15.7	17.9	15.7
400# 0-12-6 N300#	15.6	17.5	16.9
None	14.7	18.4	17.6
400# 0-12-6 N100#	16.4	16.9	17.8
400# 0-12-6 N200#	15.7	17.2	18.1
400# 0-12-6	16.5	16.3	17.1
400# 0-12-6 N300#	16.5	17.4	17.5
400# 0-12-6 N100#	15.8	17.7	18.3
400# 0-12-6	16.0	18.1	17.8
400# 0-12-6 N200#	16.4	17.5	17.4
400# 0-12-6 N300#	15.0	17.6	16.5
400# 0-12-6	16.4	17.0	18.5

N - Chilean Nitrate of Soda

0-12-6 Composed of superphosphate and Muriate of Potash

Table X

Influence of Forms of Potash on Sugar Content of Beets grown on Hillsdale Sandy loam, Miami loam, and Brookston loam.

1926

Fertilizer Treatment	Miami Loam	Brookston Loam	Hillsdale Sandy loam *	
			Unlimed	Limed
U 50 P 100 ck	15.6	16.1	16.3	16.8
" " KCL 100	15.7	17.7	17.1	16.7
" " ck	16.0	16.1	--	--
" " K_2SO_4 100	16.6	16.9	16.0	16.1
" " ck	14.2	16.3	15.9	16.4
" " KCL 100	15.9	17.5	16.0	16.6
None	15.8	---	---	---
U 50 P 100 K_2SO_4 100	15.2	17.3	16.4	16.0
None	16.4	16.6	---	---
U 50 P 100 KCL 100	15.2	18.6	---	---
None	16.5	17.7	---	---
U 50 P 100 K_2SO_4 100	16.9	17.3	---	---
None	---	17.3	---	---

U = Urea

P= Anaconda 45%

* On Hillsdale Sandy loam urea was used at rate of 33# per acre and

$CAH_4(PO_4)_2$ at 71# per acre in place of U 50 P 100.

Table XI

Influence of Time of Applying "Chilean Nitrate" on Sugar
Content of Sugar Beets on Brookston silt loam

1926

400# 0-12-6 ck	18.0	No Fertilizer	17.3
" 1N 150#	16.5	400# 0-12-6 3N 50#	16.5
" 2N 75#	17.9	" 4N 38#	16.0
" ck	18.1	No Fertilizer	17.1
" 3N 50#	17.9	400# 0-12-6 1N 150#	16.3
" 4N 38#	16.4	" 2N 75#	17.5
" ck	17.7	No Fertilizer	16.6
" 1N 150#	17.2	400# 0-12-6 3N 50#	17.3
" 2N 75#	18.0	" 4N 38#	17.1
" ck	17.8	Fertilizer	18.0

1N 150 = 1 application of 150# Chilean Nitrate of Soda May 7

2N 75 = 2 " each of 75# " " " " May 7, & June 2

3N 50 = 3 applications each of 50# Chilean Nitrate of Soda May 7,
June 2 and 17.

4N 38 = 4 applications each of 38# Chilean Nitrate of Soda May 7,
June 2, 17 and 29.

0-12-6 composed of superphosphate and muriate of potash.

Table XII

Influence of Varying Amounts of Superphosphate and potash on Sugar Content of Beets Grown on Nappanee silt loam.

1926

Phosphate Treatments	Potash Treatments	Ko	K 50	K 100	K 200
N 100 Po		18.0	18.5	18.6	16.8
N 100 P 200		17.4	18.5	19.2	17.3
N 100 P 400		17.1	18.5	18.7	16.5
N 100 P 600		18.6	17.4	17.6	16.3
N 100 P 100		20.5	18.2	18.2	19.0
No Fertilizer		18.0	--	--	--

N = Chilean Nitrate of Soda

P = Superphosphate (20%)

K = Muriate of Potash

TABLE XIII

Influence of Varying Amounts of "Chilean Nitrate", Superphosphate, and Potash on Sugar Content of Beets in 1927.

Treatment	Brookston silt loam Tuscola County	Miami Loam Eaton County	Miami Loam Clinton County	Berrien Sandy Loam Bay County
No Fertilizer	17.2	17.2	15.8	17.2
No P400 K100	17.1	17.3	16.8	18.6
N50 P400 K100	17.0	18.7	16.3	18.6
N100 P400 K100	17.5	17.3	16.4	18.4
N200 P400 K100	16.9	17.4	15.4	17.3
N300 P400 K100	15.8	17.3	14.4	17.4
N100 P0 K100	16.0	18.1	15.5	17.4
N100 P200 K100	17.6	19.0	16.4	17.4
N100 P400 K100	17.5	17.4	17.3	18.4
N100 P600 K100	16.5	18.3	16.9	18.2
N100 P800 K100	17.4	18.1	16.1	18.7
N100 P400 K0	17.1	17.0	16.1	18.4
" K25	17.3	17.7	16.4	18.8
" K50	16.6	17.5	16.4	18.8
" K100	17.5	17.4	16.9	18.4
" K200	17.3	17.9	15.7	18.4

N 100 = 100 pounds "Chilean Nitrate."

P 400 = 400 pounds of 20% Superphosphate

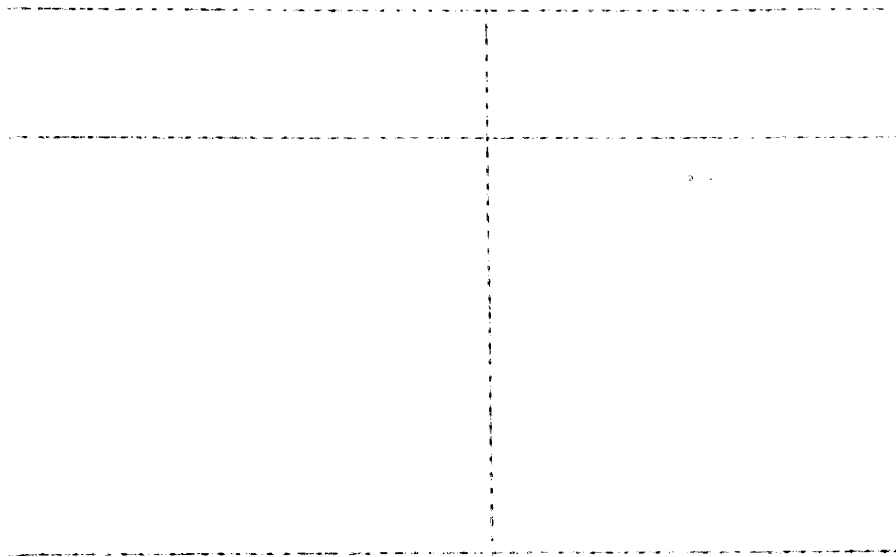
K 50 = 50 pounds of Muriate of Potash

Table XIV

Influence of Varying Combinations of "Chilean Nitrate,"
Superphosphate and Potash on the Sugar Content of Beets in
1927.

Fertilizer Treatment	Brookston silt loam	Nappanee silt loam
None	18.1	17.0
N0 P200 K50	18.0	17.9
N50 P200 K50	18.1	17.7
N100 P200 K50	17.8	16.9
N200 P200 K50	16.2	16.9
None	17.9	16.7
N100 P0 K50	17.4	18.1
N100 P0 K100	17.3	18.1
N100 P200 K0	17.8	17.4
N100 P200 K50	17.8	16.9
N100 P200 K100	17.7	16.9
N100 P400 K0	17.1	17.4
N100 P400 K50	16.3	16.9
N100 P400 K100	16.9	17.3
N100 P800 K0	17.0	17.1
N100 P800 K50	16.4	17.7
N100 P800 K100	17.7	18.2
None	18.0	16.8

N - Chilean Nitrate of Soda
P - Superphosphate (20%)
K - Muriate of Potash



of beets grown in the presence of extremely large amounts of nitrate. The plots which received delayed applications of nitrate on Brookston silt loam showed a lowered sugar content also.

The sugar content of beets grown on Rifle muck was greatly increased by the use of potash. The plot receiving 300 pounds each of potash and superphosphate produced the largest yield of beets and the percentage of sugar was highest in these. The results on mineral soils however are not significant.

It appears that the soil itself has a greater influence on the sugar content of the beets than does the fertilizer treatments, which is probably due largely to the moisture conditions.

The Influence of Fertilizer Treatment
on the Activities of Oxidase and
Catalase.

In this experiment leaves were selected from average sized plants growing on fertilized plots on Rifle muck, Miami loam, and Brookston silt loam during the season of 1927. The beets on Rifle muck were grown with varying amounts of superphosphate and potash. The plot receiving 300 pounds of superphosphate and 300 pounds of potash produced the maximum growth of tops and roots. The catalase activity as shown in Table XVI was greatest and the oxidase activity least in leaves of beets grown

TABLE XVI

Enzyme Activity of Sugar Beet Leaves

Rifle Muck

Treatment	Catalase Activity		
	Oxygen Evolved From H_2O_2 by 1 Gram Fresh Beet Leaf		
	June 27	Aug. 13	Sept. 30
No Fertilizer	190 cc	150 cc	260 cc
K300	215 "	175 "	230 "
K300 P100	230 "	190 "	230 "
K300 P300	270 "	225 "	325 "
K100 P300	270 "	220 "	300 "
P300	255 "	225 "	305 "

Treatment	Oxidase Activity		
	Oxygen Absorbed by Pyrogallol In Presence of 1 Gram Fresh Beet Leaf		
	June 27	Aug. 13	Sept. 30
No Fertilizer	7.5 cc	8.3 cc	8.0 cc
K300	4.0 "	5.0 "	3.8 "
K300 P100	3.5 "	4.0 "	3.0 "
K300 P300	1.7 "	1.7 "	2.0 "
K100 P300	4.0 "	5.0 "	4.5 "
P300	5.0 "	5.0 "	6.4 "

on this plot at all three samplings. Additions of superphosphate appeared to have a marked influence on the activity of catalase as plots receiving 300 pounds of superphosphate exhibited a very high catalase activity, even though the application had no effect on the growth of the plant as in the case of the plot receiving superphosphate alone, since here the growth was about the same as that on the check plot. With this exception the activities of catalase and oxidase are quite closely correlated with vigor of growth. Beet leaves from fertilizer plots which showed increased growth exhibited high catalase activity and a low oxidase activity, the greatest catalase activity and the least oxidase activity occurred in leaves of beets from the plot producing the largest yield. The least catalase activity and the greatest oxidase activity occurred in leaves of beets grown on the plot receiving no fertilizer in which growth was very small. The activity of catalase was greatest in samples selected September 30 as compared to samples selected in June and August. The fall rains produced an increased vigor of growth which probably accounts for this increased activity of catalase. The activity of oxidase was not changed much, but remained more constant for the three samplings.

The plots on Miami loam were fertilized with mixtures of "Chilean Nitrate", superphosphate, and potash. Maximum yields of beets were secured on plots receiving 100 pounds Chilean Nitrate, 400 pounds superphosphate, and 50 pounds potash, although the largest leaves were produced on the

TABLE XVII

Enzyme Activity of Sugar Beet Leaves

Miami Loam

Treatment	Catalase Activity	Oxidase Activity
	Oxygen Evolved From H ₂ O ₂ By 1 Gram Fresh Beet Leaves Aug. 1	Oxygen Absorbed by Pyro- gallol in Presence of 1 gram Fresh Beet Leaves
No Fertilizer	125 cc	10.0
N100 K100	150 "	8.5
N100 P200 K100	200 "	6.0
N100 P800 K100	250 "	2.5
N100 P400	310 "	1.7
N100 P400 K50	330 "	1.7
N100 P400 K200	320 "	3.5
P400 K100	210 "	2.0
N50 P400 K100	310 "	1.6
N300 P400 K100	325 "	1.6

N = Chilean Nitrate of Soda

P = Superphosphate 20%

K = Muriate of Potash

plot receiving 300 pounds Chilean Nitrate in combination with superphosphate and potash. The smallest growth of tops and roots occurred on the plot receiving no fertilizer and on the one receiving nitrate and potash only. The extremely heavy applications of phosphate and potash retarded the growth of the beets. The data given in Table XVII shows the oxidase and catalase activities. The highest catalase activity was exhibited by the leaves of beets grown with 100 pounds Chilean Nitrate, 400 pounds Superphosphate, and 50 pounds potash. The lowest oxidase activity was produced in the leaves of beets grown on the plots fertilized with 50, 100 and 300 pounds of Chilean Nitrate in combination with 400 pounds superphosphate and either 50 or 100 pounds of potash. The leaf growth on these plots was all about the same. The lowest catalase and the highest oxidase activity was produced by leaves of beets grown on the check plot and the plot receiving Chilean Nitrate and potash only. On these plots an increased catalase activity and decreased oxidase activity are associated with more vigorous growth, and decreased catalase activity and increased oxidase activity with a retarding of growth.

The beets grown on Brookston silt loam were fertilized with varying amounts of "Chilean Nitrate", superphosphate, and potash. The plot receiving 100 pounds "Chilean Nitrate", 200 pounds superphosphate, and 100 pounds potash produced the largest yield of beets,

Table XVIII

Enzyme Activity of Sugar Beet Leaves

Brookston Silt Loam

Treatment	Catalas Activity	Oxidase Activity
	Oxygen evolved from H_2O_2 By 1 gram Fresh Leaf July 22, 1927	Oxygen Absorbed by Pyrogallol in Pre- sence of 1 gram Fresh Beet Leaf July 22, 1927
No Fertilizer	40	10.2
NO P200 K50	65	10.2
N100 P200 K50	125	6.8
N100 P200 K100	150	3.0
N100 P400 K0	100	8.5
N100 P400 K0	100	6.8
N100 P800 K0	140	3.0
N100 P800 K100	140	3.4

N - Chilean Nitrate of Soda

P - Superphosphate (20%)

K - Muriate of Potash

closely followed by the two plots receiving 800 pounds of superphosphate. The smallest beets were produced on the plot receiving no fertilizer and on the one receiving only 200 pounds superphosphate and 50 pounds potash. The activity of catalase and oxidase were here, too, quite closely correlated with vigor of growth as shown in Table XVIII. The highest catalase activity was found in beet leaves from plot receiving 100 pounds "Chilean Nitrate", 200 pounds superphosphate, and 100 pounds potash. The least catalase activity and the greatest oxidase activity was exhibited by leaves of beets grown on the check plot.

A comparison of the three tables shows a decidedly lower activity of catalase in beet leaves from the Brookston silt loam than in leaves of beets from Miami loam or Rifle muck, although the yield of beets was much greater. However, these samples were taken during a period of great drought, while the samples from Miami loam were taken after a rain. The samples from Rifle muck were secured at times when moisture conditions were conducive to good growth. This probably accounts for the difference in activity of catalase as the growth would be less vigorous during a dry period.

Discussion

The data presented show a marked variation in the mineral nutrient content, sugar content, and enzyme activities of sugar beets grown under various soil conditions and fertilizer treatments. There is a marked

correlation between the mineral nutrient content of beet leaves and roots, activities of enzymes, and the soil conditions and fertilizer treatments. There is no significant correlation between these conditions and the sugar content of the beets.

There is no definite seasonal absorption of the mineral nutrients on the three soils studied similar to the absorption described by Burd, but the percentages of the various nutrients present at any one time appear to be dependent upon the soil itself, the fertilizer applied, and the stage of growth. On Rifle muck the percentage of potassium in the plants was highest at the beginning of growth and then decreased rapidly. It appears that the available supply of potassium was absorbed from this soil by the plants in the early stages of growth and was then utilized during the rest of the growing season. There was no accumulation of potassium during the later stages of growth, so there must have been less available potassium in this soil than was required by the plants, since Loew has shown that plants require a minimum of each nutrient mineral and when this is supplied they usually take up not only an excess of these, but also quantities of other compounds present in the medium solution. Hoagland also found a marked absorption of nutrient elements at all stages of growth when suitable concentrations of ions were maintained.

The percentage of potassium in the beet leaves grown on Hillsdale sandy loam was lowest at the beginning of the growing season, although the beets from the plot which was limed, and fertilized with urea, phosphate and potash were the only ones which showed an accumulation in the fall. On Miami loam in 1927 all plots except the check showed an accumulation of potassium in the leaves during the final stages of growth. All of the plots on all three soils showed an accumulation of phosphorus in the leaves at harvest time. On Rifle muck calcium tended to decrease during the midseason and increase in the fall, while on the other hand magnesium increased during the summer and was much lower in the fall. Sodium like potassium was highest in the early season and lowest at harvest. The calcium and magnesium contents were highest during the first periods of growth and lowest in the final stages of growth on Hillsdale sandy loam. The percentage of calcium in the leaves of beets on Miami was lowest in the spring and tended to increase up to the date of final sampling on all plots receiving muriate of potash in the fertilizer. On the other two plots, there was a decrease in calcium at harvest. The magnesium increased during the summer, but decreased in the fall. It is quite evident from the above that the potash fertilizer must have released calcium by base exchange.

It is evident also that the seasonal fluctuations in the mineral nutrient content of beets are influenced largely by the two factors, concentration of the ions in the soil solution and the stage of growth. The concentration

of the soil solution is controlled by the nature of the soil itself, the fertilizers applied, moisture conditions, temperature.

It is shown in this work that the mineral nutrient contents of sugar beets, vary not only with the soils upon which they are grown but also with the fertilizer treatments afforded each soil. The percentage of a mineral nutrient present is also influenced by the growth of the plant. Fraps (36) states "no relation can be traced between the additions and the phosphate content of crops. When the crops are unusually small the phosphoric acid usually runs higher than the average". Under the conditions of the experiments reported in this work, however, it has been shown that the phosphorus content of sugar beets was greatly increased by every addition of superphosphate although the size of the beet was doubled in some cases.

Fudge (37) and Spurway (38) have both pointed out that sodium nitrate exerts a beneficial effect in rendering soil phosphate available. The applications of "Chilean Nitrate" on Miami loam each caused a correspondingly great increase in the phosphorus content of the roots and leaves of beets. On Berrien sandy loam the smaller application caused a decrease in the percentage, while the larger application caused an increase in the phosphorus content. On Brookston silt loam the results were just the reverse.

It is evident therefore that nitrate of soda exerts a remarkable influence in rendering the phosphate in the soil more available to plants.

Potash salts added to a soil deficient in potassium and with a low supply of available phosphorus cause a decrease in the phosphorus content of the beet plants. This is not due to the phosphorus becoming unavailable but to the fact that the increased growth of plant utilizes the amount of phosphorus more economically. The smaller amounts of potassium added in conjunction with nitrate and phosphate increased the phosphorus but the heavy application reduced it except in the Berrien sand. Here the 100 pound application decreased and the 200 pound application increased the phosphorus content.

On Miami loam the fertilizer treatments which resulted in increased growth caused an increase in the percentage of potassium in the leaves of the sugar beets. The excessive applications of potash as well as of nitrate and superphosphate caused a decrease in the percentage of potassium in the leaves, and resulted in a decrease in the growth of the beet root. The same is true in the case of beets grown on Berrien sandy loam except in the comparison of applications of 50 and 100 pounds of potash.

On Brookston silt loam each fertilizer treatment which resulted in increased growth caused a decrease in the potassium content, and each treatment which resulted in a

decrease in growth gave an increase in potassium content of the leaves.

Fertilizers containing no sodium applied to beets, such as phosphate and potassium caused a decrease in the percentage of sodium in the plant. When sodium was applied however there was an increase in the sodium content. Every successive increment of sodium nitrate caused a like increase in the sodium content of the leaves. Lime, potash and phosphate caused decreases in sodium in cases where no sodium was applied in the fertilizer.

In most cases the percentages of calcium and magnesium were lowest in the leaves and roots of the largest beets.

The addition of varying amounts of the different nutrient elements to the soil usually resulted in a corresponding increase in the percentages of these elements found in the beet plants, except in the case of additions of large amounts of potash. Excessive applications of potash generally caused a decrease in the percentage of potassium in both leaves and roots of beets.

Additions of any one fertilizer constituent which resulted in an increase in the growth of the beet plant usually resulted in an increase in the percentage of this element in the plant, and a decrease in the percentages of other elements in it. However as in the case of additions of sodium nitrate which causes the phosphate to become

more readily available this is not true.

The fertilizer treatments in which the ratio of constituents was most suitable for the production of the crop resulted in an economical utilization of all the elements needed in the growth of the plant.

The decrease in the growth of beets noted in most cases in which excessive amounts of the various fertilizer constituents were applied may possibly be due to a too high concentration of the soil solution. According to True and Bartlett (39) there is a definite concentration of the solution at which plants absorb and excrete ions at the same rate. If the concentration of the solution is greater than this there is an excretion of the ions from the plant. In case the concentration approached this equilibrium concentration it is likely that the plant would not secure a sufficient supply of the nutrient.

The relative percentages of the elements as they occur in the beets from plots which produced the largest growth on the five soils investigated were found in the following order $K > P > Ca > Mg$ in the leaves. In the roots the order is $K > P > Mg > Ca$. The relative amounts in the leaves of beets from the plot on the Brookston silt loam yielding the largest beets were 14:7:2.5:1.5. On Hillsdale sandy loam the lowest yielding soil the relative amounts were 8:7:3:1.5 and on Rifle muck 8:6:2.5:2.5. There is evidently a definite ratio of the

mineral nutrients used by the plant which is optimum for the production of that plant, and with sugar beets studied the relative amounts given for beets grown on Brookston silt loam seemed to be the best, as the beets on this soil greatly out yielded those on all other fields studied.

The ratio of elements in beet leaves of the check plot on Rifle muck was $P > Ca > K > Mg$; on Hillsdale sandy loam $P > K > Ca > Mg$ although at the beginning of the season it was $Ca > Mg > P > K$; on Berrien sandy loam $K > P > Ca > Mg$, and on Brookston silt loam $K > P > Ca > Mg$. It would appear from this that toxicity might have some influence in the small yield of beets on the soils and plots in which the magnesium content of the leaves becomes greater than the calcium content, and in which the potassium content becomes lower than the P or Ca content.

It has been quite generally conceded that phosphorus is needed in the fertilization of the crop but that it has little influence on the sugar content, while potassium has acquired a reputation for improving it, and sodium nitrate for having a detrimental effect on it. While it is well known that potassium is essential in the production of sugar in the plant, there does not appear to be any correlation between the fertilizer applied and sugar content even in cases in which the potassium content is greatly increased, except in the case of Rifle muck in which the

potassium content is extremely low. The sugar content was slightly decreased in some cases by heavy fertilization with nitrate of soda, and not in others. Addition of phosphate to the fertilizer increased the sugar content slightly but not significantly. There is evidently little danger of injury to the sugar content of beets under the conditions of this experiment.

The hypothesis that oxidase activity is associated with decreased growth and as has been suggested in this work and in the work of Bunzell (17) (18), Woods (19) and Ezell and Crist (20) seems to be correct. In every case reported (Table X) the oxidase activity was greatest in the leaves of beets from those plots which produced the smallest growth. Likewise the hypothesis that catalase activity is associated with increased growth as pointed out by Heincke (15), also appears to be correct. The data presented in Table X shows the catalase activity was greatest in the plots producing the greatest growth. In case of beets on Rifle muck the catalase activity was associated with phosphate fertilization. It is quite evident that there was a positive correlation between the catalase activity and vigor of growth of the beets and a negative correlation of oxidase activity. Similar results were obtained (unpublished data) by the writer in studying the influence of light intensity on growth and enzyme activities of sugar beets, in which

there was also a positive correlation between vigor of growth and catalase activity and a negative correlation with oxidase activity.

Summary

In these investigations the influence of soil conditions and fertilizer treatments on the mineral nutrient content at four periods of growth and at harvest time, on the activities of the enzymes, oxidase and catalase, and on the growth of sugar beets have been studied. The results were as follows:-

1. There are certain soils which are especially adapted to the growth of sugar beets and others are unsuitable for their production. Brookston silt loam is the best producer of sugar beets and Hillsdale sandy loam, Berrien sandy loam, and Rifle muck lowest producers naturally of sugar beets.

2. Elements which are deficient in soils when supplied in sufficient amounts cause the poor soils to become fairly productive.

3. Complete fertilizer plus lime gave highest yields of beets on Hillsdale sandy loam.

4. 300 pounds each of superphosphate and potash applied in combination gave largest beets on Rifle muck.

5. A ratio of 100 pounds of Chilean Nitrate, 400 pounds of 20% superphosphate, and 100 pounds of potassium muriate produced the largest beets on Miami loam, Berrien sandy loam, and Brookston silt loam.

6. The percentages of mineral nutrients in the leaves of beets from above mentioned plots in the following order $K > P > Ca > Mg$ and in the roots $K > P > Mg > Ca$.

7. The ratio of the elements in the leaves, in the order named, from the plot on Brookston silt loam yielding the largest beets was 14:7:2.5:1.5. On Hillsdale sandy loam and Rifle muck, soils producing small roots, the ratios were 8:7:3:1.5 and 8:6:2.5:2.5 respectively.

8. When the ratio of fertilizer elements applied is such as to cause an increase in growth of the beet plant there is a more economical utilization of the other minerals taken from the soil.

9. Applications of incomplete mixtures usually cause an increase in the content of the elements applied and a decrease in the percentages of other elements.

10. Mixtures of two fertilizer salts (such as nitrate and potash) sometimes cause decreases in the yield of beets as in the case with Berrien sandy loam.

11. Soils and fertilizer treatments had very little influence on the sugar content of beets except in the case of Rifle muck.

12. There is a positive correlation between catalase activity and vigor of growth in sugar beet leaves.

13. There is a negative correlation between oxidase activity and vigor of growth in sugar beet leaves.

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