INTERRELATIONSHIPS OF NITROGEN PHOSPHORUS, SULFUR, SODIUM AND CHLORINE ON THE GROWTH AND COMPOSITION OF SUGAR BEETS

by

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SUGAR BEET NUTRITION

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ABSTRACT

An irrigated field experiment studying the effect of nitrogen phosphorus, sulfur, sodium and chlorine on the yield and chemical composition of sugar beets was conducted on a calicareous soil in the Beka'a, Lebanon. Nitrogen fertilization had a large positive effect on the yields, nitrate concentration of petioles and nitrogen content of beet roots. Sugar beet yields could be profitably increased up to the highest applied amount of nitrogen, but the increase above an application rate of about 450 kg./ha. was small and the adverse effect on quality and sugar concentration of roots made application rates higher than that unwarrented. The effect of sulfur and phosphorus on sugar beet yields was small when sodium and chlorine were applied at high levels. Sodium was beneficial, particularly at lower levels of applied phosphorus and sulfur. The response to chlorine application was appreciable when the level of nitrogen was high.

In general, petiole analysis was a better indicator of the fertility level of the soil than analysis of tops. Critical nitrate nitrogen concentrations of petioles were estimated, and were shown to decrease as the season progressed.

High yields of sugar beets, up to 121 m. ton/ha., were obtained and these were attributed to the favorable soil and climatic conditions prevailing in the area along with suitable cultural practices and adequate fertilization.

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INTRODUCTION

Sugar beets are the dominant source of sugar in areas too cold for growing sugar cane. It is mainly grown in favorable localized regions within a feasible shipping radius of a sugar beet factory. Since 1900 many countries of the Middle East have established sugar factories, and sugar beet production has become an important practice. The Beka'a, Lebanon due to its suitable climate and soil conditions is a favorable place for sugar beet growth. But the yields, as in many sections of the Middle East, are relatively low. The nutrient supply of soil is considered to be one of the most important factors limiting the growth and yield. Poor irrigation practices and lack of adequate disease and insect control also contribute to the low average yields in farmer's fields (25-30 metric tons per hectare).

The necessity of supplying and maintaining an adequate level of nitrogen is generally realized in sugar beet production. However, associated with this upward trend in the use of nitrogen fertilizers and yields has been a decline in quality of beets that lowers the net recovery of sugar for the sugar industry. Moreover, the response to nitrogen is considerably influenced by the level of other elements present in the soil. The response of sugar beets to phosphorus and sulfur is not definite, and is modified by the nutrient supplying power of the soil.

In salt affected areas crop production is limited because of the excess amount of salt in the soil. A high amount of chlorine is toxic to many crops. An excess of sodium directly or indirectly influences the growth of plants. Thus, salt tolerant crops such as sugar beets that can survive and produce economical yields are desired in such areas. Sugar beets have long been known not only to tolerate chlorine but to use chlorine to advantage. Though the exact role of sodium in plant nutrition is not well understood, evidence of a beneficial effect in sugar beet production is conclusive. Moreover, both sodium and chlorine can be supplied to plants cheaply in the form of common salt.

The purpose of the experiment reported here was to study the effect of the five elements, nitrogen, phosphorus, sulfur, sodium and clorine on:

1. the yield of beets and beet sugar as affected by each element individually or by interactions between them;

2. the chemical composition of the sugar beet plants as affected by various combinations of the nutrients studied and to estimate the "critical levels";

3. the optimum rates of fertilizers required for maximum yields.

REVIEW OF LITERATURE

Effect of Nitrogen

Sugar beet yield and quality are greatly affected by the levels of available nitrogen in the soil. A survey which was conducted in California by sugar companies (16) showed that the yield was limited in some fields by deficiency of nitrogen while in other fields a high nitrogen level late in the season appeared to be one of the main factors for low sucrose concentration.

Extensive work has been done by many workers including Ulrich (68), Haddock (25), Tolman (60), Ogden (49), Boawn (8), Adams (3), Loomis (46), Larson (41), Hunter (34), George (21) Magnitski (47) and Hedlin (30) on the effect of nitrogen fertilization on sugar beet plants. All these workers (and others) found that the application of nitrogen increased root and top growth. From study of the top-root ratios Baird (6) concluded that nitrogen favored top growth more than growth of roots. Loomis et al. (46) showed that deficiency of nitrogen reduced the size of top five fold and markedly depressed the growth rate of storage roots. They showed an inverse relationship between size and sucrose concentration of the roots specially in the presence of nitrogen deficiency.

The great increase in the use of nitrogen fertilizers and increase in best tonnages were mostly associated with a decline in quality of beets and increased processing losses. The depressing effect of high nitrogen on sugar beet quality was reported as early as 1912 (58). Later many workers (4, 8, 16, 21, 25, 31, 34, 44, 52, 60) studied this problem and reported that excessive nitrogen applications reduced the sugar percentage of beets and purity of sugar. Nitrogen application increased the non-sugar compounds in the beets (49). Furthermore, the association of total nitrogen and nitrogenous compounds in the root with reduced purity and sugar extraction from the beets was found to be pronounced (52). Low quality beets are not desired for processing because high content of nitrogenous compounds and low juice purity decrease sugar extraction in the factory (4). Haddock et al. (27) showed that the downward trend in sugar percentage of the sugar beets in the United States since 1937 was closely related with a much greater loss of sugar extracted from beets. The loss in extraction was estimated to be more than five times as great as the decrease in sugar percentage.

Round (52) reported that the amino nitrogen constituents and ash made up a large portion of the total non sugars present in the beets. For the purpose of sugar extraction invert sugar and raffinose were classified with non sugar. The concentration of these impurities increased in the beets as the rate of nitrogen application increased Goodban (23) indicated that the purity of diffusion juice and thin juice had an inverse relation to the beet nitrogen content for the field grown sugar beets ($r = -0.97$). In the sugar factory, the sliced beets are carried to diffusion chambers in which the sucrose is extracted with hot water. The assembled juice from the diffusion cells undergoes the process of purification, the object of which is to remove or reduce the amount of the impurities that have been extracted with the sugar. The clarification is affected mainly by heat and added lime, but other chemicals are added as needed to supplement their action. The purified juice before going to evaporators is further heated, and at this stage the juice is known as "thin juice". Round (52) showed that the non-sugar compounds that remained in the juice would enter the crystallization phase of the process, and depressed the crystallization rate of the associated sucrose to the point where it became impossible to further extract sucrose economically by crystallization. At this stage the product was molasses not sugar. A further tentative conclusion was made by Goodban (23) that above a beet nitrogen level of about 0.2% on the fresh basis, there was an appreciable drop in the maximum sedimentation rate during processing of the beets. In one experiment (52) it was shown that the most profitable level of nitrogen fertilization for growers and processors was the medium level (140 lbs./acre) which produced the maximum gross and salable sugar per acre (26.4 tons per acre of beets and 8820 lbs. per acre of sugar). Haddlock (26) found that the yield of sugar beet tops was negatively related to the sucrose and purity percentages, and positively related to the nitrate-nitrogen concentration of the sugar beet petioles.

Ulrich (68) working for many years with the sugar beet crop, suggested that chemical analysis of plant samples should be used as a guide in adjusting the fertilization program for successful beet production. His experiments indicated that only slight increase in yield was found above a certain "critical level" of various nutrients. For nitrogen, the critical level was found to be 1000 ppm. of nitrate - nitrogen (dry basis) in the petioles of "recently matured" leaves in the field and 2000 ppm. under green house conditions. Haddock (25) showed a close relationship between nitrogen fertilization and nitrate nitrogen of petioles. He noticed that when nitrate - N of petioles fell below 1000 ppm. (dry basis) in August the yield tended to be adversely affected, when more than 1000 ppm. was present in October, quality was lowered. The best result was obtained when nitrate - N in petioles dropped below 1000 ppm. by mid-September.

Ulrich (68) stated that the critical value (1000 ppm. of nitrate - N in petioles) was little affected by climate, soil type, management and variety. A favorable nitrogen response could be expected when ever fertilization was timed to keep the nitrate - N in the plant above this level. On the other hand, Magnitski (47) pointed out that the critical level varied in accordance with the phase of development. In order to achieve high yield from fertilization of the crop, all other requirements should be fully satisfied. He showed that the critical levels of nitrate - N content in the petioles of sugar beets, grown under Moscow conditions, was higher (500 ppm. on fresh matter basis) at the beginning of the season than at later stages of growth. The critical values for the July 17, August 7, August 17 and September 7 dates of sampling were 500, 150, 40 and 10 ppm. (fresh matter basis), respectively. The critical values were determined for the yields of roots in the range of 25-45 tons per hectare (with stands not less than 80,000 plants per hectare).

A sugar beet quality survey was conducted in northern California (32) and it was observed that low sugar content and low purity were always associated with high nitrate - N in the petioles at harvest time. However, Boawn (8) found that the decrease in sucrose concentration was related to the amount of nitrogen applied rather than the nitrate - N in the petioles. Though the nitrate - N in the petioles dropped to 210 ppm. (dry basis) as early as August, the sugar percentage in harvested beets decreased from 18.13% to 17.11% as the rate of nitrogen fertilization was increased from 40 lbs. per acre to 160 lbs. per acre.

Hill (31) and Stout (58) suggested that the time of the growing season in which the nitrogen is available to plants had a great bearing on sucrose concentration in the beets. When supplementary nitrogen was added early in the season vegetative growth was stimulated and that, in turn, caused greater sucrose production. Day and night temperatures had great influence on growth of roots and tops and on the production of sugar in beet plants (65, 67). After eight weeks of nitrogen deficiency the sucrose concentration of the beets kept at 17°C. during the night averaged 15.4% and those at 10 and 4°C. averaged 18.3% with individuals as high as 20.0%. The beets high in nitrogen at 17, 10 and 4°C. had sucrose concentrations of 8.8, 11.0 and 12.1%, respectively.

So ripenning or "sugaring up" was induced by low night temperatures and by nitrogen deficiency. Decreasing night temperature greatly reduced the top growth of the high nitrogen plants but had only slight influence on nitrogen deficient plants (66).

Adams (4) studied the effect of three different forms of nitrogen fertilizer for sugar beets. He found that calcium nitrate and urea were as effective as ammonium sulfate at raising sugar yield. Calcium nitrate and to a smaller extent urea produced more top growth than ammonium sulfate. In addition he observed that putting all the nitrogen into the seed bed was as effective as split dressing in raising sugar yield.

Effect of Phosphorus

Baird (6) conducted six fertilizer tests and concluded that the response of sugar beet plants to phosphorus application varried from field to field. Larson (40) reported that phosphorus application was effective in yield on only one of 13 locations that were studied. Adams (3) studied 49 fields in various parts of England and suggested that the optimum dressing rate for sugar beets was 1.0 cwt. nitrogen and 0.5 cwt. per acre P_2O_5. The response to phosphorus, contrary to that of nitrogen, did not have much variation. Hunter et al. (34) reported that only one farm of 15 fertility experiments responded to application of phosphorus. The yields obtained were 13.3 and 19.6 tons per acre with 0 and 80 lbs. per acre P_2O_5, respectively. The farm responsive to phosphorus fertilization tested markedly lower than other soils in both water and CO_2 soluble phosphate.

Thorne (59) conducted field experiments and showed that soils that tested less than 5 ppm. in available P_2O_5 (CO_2 soluble) responded greatly to phosphorus application. Soils containing more than 50 ppm. of avilable P_2O_5 did not respond to addition of phosphorus. Whereas, responses of soils having from 5 to 50 ppm. were not definite. Carlson <u>et al.</u> (11) carried field tests in four locations. They observed no response of sugar beets to phosphorus on three locations where available P_2O_5 (soduim bicarbonate soluble) was 83-89 ppm. Response was observed on one area where the available P_2O_5 was 8.3 ppm. Haddock (26) tentatively supported the use of 25 ppm. of sodium bicarbonate soluble phosphorus as a minimum level of available phosphorus for the proper growth of sugar beets on calcarious soils.

Studying the time of phosphate fertilization Adams (2) found that on the average spring application gave a higher yield of sugar beet tops than plowing down in the fall. Plants on spring fertilized plots mostly grew faster early in the season. Similar results as to the time of phosphorus application were also obtained by Davis <u>et al.</u> (14). But their data indicated that it was not necessary to apply more than 150 lbs. per acre of phosphate at planting time, provided that the phosphorus level in the soil was adequately high. Davis <u>et al</u>. (14) got a slight increase with large application of P_2O_5 (150 lbs. or more per acre) on sugar beets but only smaller applications (50-100 lbs. per acre) produced yield responses which were profitable with the prevailing market prices.

Ogden et al. (49) investigated the effect of phosphorus on quality of storage roots. Though higher rates of phosphorus reduced sugar percentage, phosphorus application did not adversely affect any other of the characteristics studied. Davis (14) and Larson (41) also noted that phosphorus had no significant effect on percentage sugar or apparent purity.

It was suggested that phosphorus affected mainly the root growth with little effect on the above ground portion. Baird (6) studied the root-top ratio and concluded that phosphorus slightly decreased the proportion of tops to roots. Phosphorus had a special effect on the underground storage tissue of the root crops. If phosphorus was applied for beets on a soil deficient in phosphorus, it usually increased the yield of roots more than that of the above ground portion (7).

Phosphorus fertilization showed no effect on the yield except where the nitrogen level was low. When the supply of nitrogen was low, phosphorus application increased phosphorus content in the tissue and sucrose concentration in the roots. Nitrogen application decreased the level of phosphate in the tissue (21). Alexander et al. (5) found that the phosphorus content of the leaf was significantly increased by addition of phosphorus fertilizer. Nitrogen increased the level of phosphorus in the leaf at the first sampling only. Phosphorus concentration of the plant tissue decreased with time, but its decline, in contrast to nitrogen, was more gradual. Samples collected in July (14) indicated that as the amount of phosphorus applied increased the percentage extractable phosphorus in the petioles increased. Similarly, plants sampled in September, showed the same trend. However, the phosphorus content of plants that received phosphorus at planting time only, was lower at the September sampling than at the July sampling. This increase in extractable phosphorus was significant at a low residual fertility level, but was greatly masked if there was sufficient phosphorus in the soil. In another experiment, Davis et al. (15) showed that the phosphorus content of petioles was erratic and varied greatly with time of sampling. When the phosphate fertilizer had been plowed down the percentage extractable phosphorus in the green tissue increased rather than decreased with time. It was shown that the addition of phosphorus resulted in higher phosphorus and lower potassium contents of the beet root (53). Phosphorus had no definite effect on the percentage of Ca or Mg in the tissue, but at the last date of sampling where the highest rates of phosphorus was applied a significant decrease in the calcium content of the tissue was observed (14). In another test it was noticed that calcium was decreased at the first and second date of sampling by phosphorus treatment (5). The proportion of sodium in the leaves was increased by the phosphorus treatment.

Ulrich (63) found that the phosphate values of petioles were much lower than for the corresponding blades. He recommended 750 ppm. of PO_4-P in the petiole (dry basis) as the tentative critical level for phosphorus. Sugar beet fields being at or below this level for a few weeks during the growing season, responded to the application of phosphorus. On the other hand, fields that tested above this level for the entire growing season did not respond to phosphate fertilization, even though the absorption of phosphorus was increased.

Magnitski (47) showed the phosphorus critical level to be 40 ppm. of phosphorus in the petioles (fresh matter basis). As the season advanced this value dropped to 25 ppm. (fresh matter basis) after which the value remained constant. The critical values were chosen for yields of roots in the range of 25-45 tons per hectare (with stand not less than 80,000 plants per hectare) under the conditions of the Moscow region. Haddock (25) pointed out that the phosphorus composition of sugar beet petioles was positively related to the yield of sugar beet roots under all treatments studied.

Effect of Sulfur

Though sulfur is one of the essential elements for plant growth, its importance in relation to sugar beet production has not been studied extensively due to limited evidence of deficiency. The amount added indirectly in superphosphate, ammonium sulfate and mixed fertilizers, together with the amount obtained from irrigation water and from the atmosphere in the form of SO_2, were adequate for successful plant growth in most areas and the amount obtained from mixed fertilizers has decreased with the recent trend toward higher analysis fertilizers, and the need for sulfur application has increased (22). Gilbert (22) reported the work of Power who showed that soils in the Pacific North-west of the United States responded greatly to sulfur application. He pointed out that sulfur deficiency had been localized in several states.

Tolman et al. (61) noticed that during the growing season beets on sulfur treated blocks were noticeably greener than where sulfur was not applied. They found a striking interaction between sulfur and nitrogen, both on plant development and seed production. Sulfur application had no effect on plots where nitrogen was not applied. Also, the response to nitrogen was much greater in the field when sulfur was added.

Kalinevich (39) found that the reduction of sulfate to reduced form, in its biological nature, was very close to the process of reduction of NO_3^- to NH_4^+. Thus, in some processes the sulfur compensated for a deficiency of nitrate, and the nitrate might compensate for sulfur. When the plants were abundantly supplied with nitrate, it was noticed that the reduction of sulfate was retarded. Similarly a high level of sulfate retarded the reduction of nitrate in the plant. Kretschmer et al. (40) found that variation in sulfate content of the substrate had little effect on the plant content of sulfate or on the absorption of other ions by species tested including sugar beets. Corbett et al. (13) reported a highly significant negative correlation between chlorine in the nutrient solution and sulfate uptake in potato tops.

Wood (73) reported that greater top growth was apparent from a NH_4Cl treatment than with $(NH_4)_2SO_4$. However, both treatments produced larger tops than did the checks. A comparison of the root yield revealed no conclusive differences between any of the treated plots or the checks.

Chemical analysis of petioles for SO_4-S indicated a narrow range and did not present the sulfur status of the sugar beet plant readily. For this reason, Ulrich (63) recommended only blade analysis for sulfur as a means of evaluating the sulfur status of sugar beet plants. The critical value for the blade was estimated to be approximately 250 ppm. SO_4-S on the dry basis.

Effect of Sodium

Sodium has been the subject of a large number of field experimentations in attempts to determine its value for improving crop yields (29). Its exact role in plant nutrition had been widely disputed, and its beneficial effects upon certain crops were not well understood. The essentiality of sodium for normal growth of plants has not been proved but several crops have been noticed to be responsive to its application.

Harmer, et al. (29) classified crops into four groups on the basis of their response to sodium: (1) little or no response even with insufficient potassium supply; (2) slight to medium response with sufficient potassium supply; (3) slight to medium response with ample potassium supply; (4) large response with ample potassium supply. Sugar beets were placed in the fourth category. Lehr (43) stated that even though its specific function was not known, sodium was certainly an important element from an agricultural point of view, and that especially for beets it might be as important as potassium.

Data collected by Holt (33) indicated that plants varied in their need and capacity to utilize sodium. However, for some crops sodium might be an essential nutrient for obtaining maximum growth. Sugar beets responded to application of sodium even when 144 pounds per acre of potassium was added. Adams (1) showed that application of salt ($Na\ Cl$) increased the yield of sugar beets. However, plant analysis did not offer any evidence that it acted by replacing potassium in the soil and thereby mobilizing the soil potassium reserve. His data supported the view that sodium was a plant nutrient for sugar beets and not a potassium substitute.

Sayre et al. (54) reported that sodium in the form of nitrate of soda and also in the form of Na Cl when supplemented with nitrogen had great effect on the growth of sugar beet plants. Application of nitrogen without sodium did not significantly increase the yield or enable the beets to recover from abnormal purple spots and maroon color of the foliage. Further, he noticed that the addition of potassium did not affect the beneficial effect of sodium. Magnitski (47) reported that sodium had a specific effect on beets that could not be replaced by high potassium. He, also, observed a probable sodium deficiency of sugar beets which did not differ in symptoms from potassium deficiency.

In pot experiments with red beets, Wybenga and Lehr (75) observed that addition of nitrogen in the form of pure $Na\ NO_3$ or a product containing 10-14% potassium greatly increased fresh weight, dry matter yield and crude protein of the root as compared with an equivalent amount of $Ca\ (NO_3)_2$. Sodium resulted in higher yield even in the presence of high potassium. Woolley (74) concluded that the yield increase in tomato plants with addition of sodium could have been a direct response to added sodium. Truog (62) investigated the response of several crops, including beets (both red and sugar), to the addition of sodium by means of solution cultures and field tests. The yields of beets, rutabagas, carrots and celery were all increased, and generally, vigor and quality of the crops were also improved. These crops responded appreciably even when the level of K was adequate or high. On the other hand, Shepherd (56) reported that the yield response to salt application, on an organic soil, decreased as the level of K application increased. Salt addition at the rate of 500 lbs. per acre to the field receiving 600 lbs. per acre potassium tended to depress the yield. Thus, the salt increased sugar yield with the normal range of potassium fertilization. In the second year of his experiment, though the difference in yield of root was small, higher yield of sugar per acre was produced where salt was applied. It was shown that the greater removal of potassium from soil treated with salt was due to larger yield (1, 56). Based on his studies Larsen (42) concluded that crops (such as beet) that absorbed the most sodium with the least depression in K would respond the most to sodium application.

Increasing the sodium level in the soil resulted in marked increase in the sodium content of the foliage. In general, application of sodium resulted in reduction in the potassium content of the plant tissue (1, 13). In some cases, sodium application might not have any effect or, even, might slightly increase the uptake of potassium (42). On the average it was shown that salt increased the potassium content of the storage root (1).

Addition of sodium usually depressed the uptake of calcium and magnesium into the plant (13). Adams (1) reported a negative interaction between sodium and potassium on the yield of beets and concluded that it was not economical to apply potassium in the presence of sodium.

Sodium increased the phosphorus content of the roots (14). It was noticed that nitrogen increased the sodium content of the beets (19). Wood (72), and Finkner (19) found a negative relationship between sodium concentration and sucrose content of the storage roots. Leonard (44) noticed that Na^{22} tended to concentrate mainly in the conducting tissue of the plants.

The negative relationship between sodium and potassium had made the estimation of the critical value for potassium in sugar beets somewhat complicated and consequently two critical values for potassium were shown by Ulrich (69) and Magnitski (47). The critical level for sodium had not been determined.

Effect of Chlorine

Chlorine has long been considered as an essential element for the growth and development of many crops including sugar beets, but its essentiality had not been proved. Recently, Broyer et al. (9), as an outgrowth of the intensive work on cobalt, were able to prove the essentiality of chlorine for plant growth. This work served to support many of the past observations suggesting beneficial results from fertilizers containing chlorine. Two of these studies that are of particular interest are the controlled culture experiments of Eaton (17) and Raleigh (50) which showed highly significant increases in yield of many agricultural crops including sugar beets when supplied with chlorine. It also supported the result of Lipman (45) who focussed his attention especially on chlorine as a growth factor for buckwheat and peas. He concluded that if chlorine was not essential for the growth of plants, it was certainly highly beneficial.

The sugar beet crop was among those that could use chlorine to some advantage, and could not tolerate a great deficiency of chlorine (37). A number of the studies reported have shown definite response of sugar beets to chlorine application.

Raleigh (50) in a culture solution experiment noticed that the addition of chloride in general gave a much more consistent increase in the growth of table beets than sodium. A similar result was reported by Buchner (10) in Germany. In water culture and in field experiments it was shown that sodium and chlorine salts were beneficial to the sugar beet crop. However, chlorine increased yield more than sodium. In a comparison of chloride and sulfate salts of Na, K and NH_4 as fertilizers for sugar beets, greater top growth was obtained from NH_4Cl application than with $(NH_4)_2SO_4$ application (73). Sirochenk (57) in a study with sugar beets used K Cl, K_2SO_4 and a salt of K Mg as different sources of potassium. He noticed that all potassium salts increased leaf and root growth, but the effect was greatest with K Cl.

Ulrich et al. (70) found that chlorine was necessary for growth of tops and roots of the sugar beet plant and was associated with sugar formation. The storage roots of the plants deficient in both chlorine and potassium were higher in sucrose concentration then non-deficient plants, but the deficiency of either element alone resulted in a decreased sucrose concentration. He also noticed that increasing rates of chlorine application had a depressing effect on sucrose concentration, while the size of the roots was not decreased.

In a sand culture study conducted in the green house Meyer et al. (48) noticed that chlorine, as compared with sulfate, depressed the radioactive phosphorus absorption by tomato plants. Plants grown with chlorine, contained less nitrogen than those grown with sulfate, but little difference per plant was noted because of the greater growth of the plants grown with chlorine.

Kretschner et al. (40) noticed that increasing chloride concentration of the substrate resulted in a linear increase in chlorine content of all plant species tested including sugar beets. Nitrogen content of the plants decreased as the level of chlorine was increased. Radioactive chlorine when applied to plant leaves was translocated both upward and downward. Conductive tissue contained the highest concentration of Cl^{36} (40).

Ulrich (69) estimated 0.4% of chlorine in the petioles of sugar beets to be the critical level. He reported that the chlorine content of the petioles ranged from 0.01 to 8.5% (dry basis).

MATERIALS AND METHODS

In the study reported here five different elements —nitrogen, phosphorus, sulfer, sodium, and chlorine-- were varied at the same time. In order to study the interrelationships between these elements a field experiment was conducted at the American University Farm, Northern Beka'a, Lebanon. A central composite, rotatable, incomplete factorial design was utilized (28) and each element was varied at five different rates that were coded as -2, -1, 0, +1, and +2. The coded 0 rate was set to approximate a substantial addition to the soil supply of the nutrient. The coded -2 level was considered to be a possible deficiency level and the +2 rate a possible excess level of the element added. The rates of each element were varied according to the natural log scale in order to cover this wide range of application (table 1). There were a total of 27 treatments with one treatment repeated six times in order to estimate the experimental error (Table 4 shows the treatment combinations).

Table 1. Rates of application of N, P, S, Na, Cl for sugar beets

Level	Coded rate.	lb. per acre.	Kg. per ha.
1	-2	10.0	11.35
2	-1	27.2	30.87
3	0	73.8	83.76
4	+1	200.0	227.0
5	+2	544.0	617.44

Statistical analysis was done according to the method described by Cochran and Cox (12). Regression equations of the quadratic form for yields and concentration of elements analysed were computed from the data collected. The form of equation used was: $Y = b_o + b_1 x_1 + b_2x_2 + b_3x_3 + b_4x_4 + b_5x_5 + b_{11}x_1^2 + b_{22}x_2^2 + b_{33}x_3^2 + b_{44}x_4^2 + b_{55}x_5^2 + b_{12}x_1x_2 + b_{13}x_1x_3 + b_{14}x_1x_4 + b_{15}x_1x_5 + b_{23}x_2x_3 + b_{24}x_2x_4 + b_{25}x_2x_5 + b_{34}x_3x_4 + b_{35}x_3x_5 + b_{45}x_4x_5$.

Where b = regression coefficient for treatment effect

x_1 = coded level of N

x_2 = coded level of P

x_3 = coded level of S

x_4 = coded level of Na

x_5 = coded level of Cl

The significance of the magnitude of each individual regression coefficient was evaluated by determining the probability of a true effect using the "t" test. The nature of the response surface for the interactions that had high probability was found by the use of the regression equations. Analysis of variance of the data collected was calculated and the critical "F" test was used to find the significance of linear, quadratic, and lack of fit terms. The percentage of the total treatment sum of squares accounted for by the linear and quadratic terms was computed and used to show how well the quadratic regression equation fitted the actual data collected.

On March 23, 1962, 32 plots were established, with each plot composed of 4 rows, 0.50 meters apart and 8 meters long. The fertilizers for each row were distributed by hand in a furrow after which the ridges were split thus covering the fertilizers with about 10 cm. of soil. After packing the ridges with a packer seeds of the Khun R. variety of sugar beets were planted with a planet, Jr, seeder on top of the ridges at a depth of about 3 cm. thus placing the seed directly above the fertilizers.

Nitrogen was added in the form of NH_4NO_3 and $NaNO_3$; phosphorus in the form of $Ca(H_2PO_4)_2$ and NaH_2PO_4; sulfur in the form of $CaSO_4 \cdot 2H_2O$ and $Na_2SO_4 \cdot 10H_2O$; sodium in the form of $NaNO_3$, $NaSO_4 \cdot 10H_2O$, NaCl and NaH_2PO_4; and chlorine in the form of $CaCl_2 \cdot 6H_2O$ and NaCl. The carriers used were varied in order to supply the required combination for each treatment (Table 4). Amounts of all elements were controlled with the exception of calcium. However the soil contained about 30% calcium carbonate and therefore additional calcium would not be expected to have much effect. The fertilizer carriers were analyzed to determine the amount of element present.

On May 1, the small beets were thinned to a distance of approximately 20 cm. between blocks. The second thinning, to one plant per hill, was done on May 11. The final stand was counted to leave a total of 40 plants per 8 meters in order to insure uniformity. Irrigation was done every week using sprinklers for the first six weeks and the furrow method later on. The field was sprayed against cut-worms, leaf hoppers, aphids and powdery mildew any time an attack was observed.

Leaf samples were collected on four dates during the growing season from the two middle rows of each plot. The dates were June 4, July 8, August 8 and September 12. Ten "recently mature" leaves (69) were taken at random from 10 different plants. The petiole was immediately detached from the blade. Samples were rinsed in tap water and then in distilled water to remove dust contamination. They were dried in an oven at 65-70°C. for 48 hours. The dry weight of the 10 leaves (petioles plus blades) was determined. Petioles and blades were ground separately in a Wiley mill using a 40 mesh screen and stored in plastic envelopes prior to chemical analyses.

On October 25, a six meter length from the center of the two middle rows of each plot was harvested. Values for fresh weight of tops, fresh weight of roots, and number of roots were recorded. Samples of tops and roots were collected for chemical analyses and moisture determination.

Analysis of Petioles

Nitrate-nitrogen. The nitrate-nitrogen concentration of water extracts of petioles was determined by the phenol-disulphonic acid method. Excess chloride was precipitated by silver sulfate solution (38).

Phosphorus-acid soluble. Two percent acetic acid soluble phosphate was determined by developing the blue phosphomolybdate color, using stannous chloride solution as the reducing reagent (38).

Sulfur-acid soluble. Two percent acetic acid soluble sulfate was determined by the turbidimetric method (36). The solution was digested with hydrogen peroxide to remove discoloration.

Cations-acid soluble. Sodium, potassium, calcium and magnesium were determined in the acetic acid solution, using a Beckman DU emission spectrophotometer (36).

Analysis of tops and roots

Wet oxidation. Plant tissue was predigested in HNO_3 prior to addition of $HClO_4$. The digestion was carried at an elevated temperature according to the procedure described by Jackson (36).

Total phosphorus: The determination of the phosphorus was made by the molybdenum blue method using amidol as the reducing agent (38).

Total sulfur. Sulfate determination was made by the turbidimetric method (36).

Total cations. Sodium, potassium, calcium, and magnesium were determined on the nitric-perchloric digests using a flame emission spectrophotometer (36).

Chloride by the Mohr method (38). Chloride in petioles, tops and roots was determined by titration with silver nitrate, using potassium chromate as an indicator. Activated carbon was used to decolorize the solution.

Total nitrogen. Nitrogen was determined by the Kjeldahl method as described by Jackson (35).

Sugar Analysis. Sucrose concentration in roots was determined according to the procedure described in A.O.A.C. (Methods of Analysis of the Association of Official Agriculture Chemists, 7th Ed. A.O.A.C. Washington, D.C. 1960).

EXPERIMENTAL RESULTS AND DISCUSSION

The experiment reported here was designed to study the interrelationships between nitrogen, phosphorus, sulfur, sodium, and chlorine on the growth of sugar beet leaves, yield of tops, yield of roots, sucrose concentration in roots, yield of sucrose, and chemical composition of roots, tops and petioles. A central composite, rotatable, incomplete, factorial design was used. This design allows the computation of a quadratic regression equation for the response to the varied nutrients. A positive sign for the regression coefficient of a linear term indicates that the general overall effect of the element was increasing, while a negative sign denotes an overall depressing effect of the element. The sign of the regression coefficient for the squared terms indicates whether the response is curvilinear (concave upward, positive, or concave downward, negative). The relative magnitude indicates the degree of curvature. The magnitude of the regression coefficient for the interaction between two elements denotes the degree of interaction involved. A negative sign for the coefficient shows that an increase in the level of one element decreases the requirement for the other. This type of relationship is referred to as a complementary effect. A positive sign for the interaction coefficient indicates that an increase in the level of one element increases the requirement for the other and this type of relationship is called an antagonistic effect. These relationships are illustrated in Fig.2 where the overall linear effect of nitrogen is positive but the effect changes as the level of sulfur changes. Similarly, the linear effect of sulfur changes as the nitrogen level changes but the overall linear effect tends to be small because of cancelling out. The magnitude and direction of these changes is a result of the size and sign of the N-S interaction term which is negative in this case. The N^2 term is positive and this is shown by the upward curvature of the response lines. The S^2 term is negative so the response lines have a downward curvature.

Results of Soil and Water Analysis

The pH of the soil was 8.1 and the calcium carbonate content was 11.50% (Table 2). The total nitrogen content was found to be 0.075% indicating a relatively low supply of nitrogen. The bicarbonate soluble phosphorus as determined by the Olsen method was found to be 18.0 ppm. According to Thorne (59) the response of sugar beets to phosphorus

Table 2. Results of chemical analysis of the surface soil for the experimental plots and of the irrigation water.

Soil Analysis			Water Analysis	
P H		8.1	Sodium	0.282 m.e./liter
Calcium carbonate, %		11.50	Calcium	0.705 "
Organic matter, %		1.50	Magnesium	0.833 "
Total nitrogen, %		0.075	Potassium	0.056 "
Phosphorus, ppm. (bicarbonate soluble)		18.0	Sulfur	0.125 "
			Chlorine	0.318 "
Ammonium	K	2.24		
Acetate	Ca	41.00		
Soluble, m.e/100g.	Na	0.58	Electrical conductivity	0.155 m.mho/cm

application on this soil might not be definite. But Haddock (27), on the basis of results obtained, tentatively considered 25 ppm. of sodium bicarbonate soluble phosphorus as a minimum level for the proper growth of sugar beets on calcarious soil. The ammonium acetate extractable calcium, potassium and sodium were 41.00, 2.24 and 0.58 m.e/100 grams of soil, respectively.

The water is considered to be of good quality (Table 2). It was estimated that approximately 65 Kg. of sodium, 141 Kg. of calcium, 100 Kg. of magnesium, 22 Kg. of potassium, 20 Kg. of sulfur and 113 Kg. of Cl per ha. were added through the irrigation water considering an estimated one meter depth applied during the season.

Effect of Nitrogen on Plant Growth and Sugar Accumulation

Yield of roots: The analysis of variance (Table 3) indicated that the proportion of the total treatment sum of squares accounted for by the quadratic regression equation (equation sufficiency) was 94.6%, which indicated a close fit of the regression equation to the actual yield data.

The yield of roots (Table 4) varied from 74.2 to 121.0 m. tons/hectare. The regression coefficient (Table 5) for the linear effect of nitrogen on the yield of roots was highly significant ($p = 0.99$) and positive indicating high response to nitrogen application. Among quadratic terms, the NP($p=0.52$) and N-Cl ($p=0.91$) interactions were antagonistic. Tolman (60) and Alexander (5) also found a positive interaction between phosphorus and nitrogen on the yield of sugar beets.

Table 3. Analysis of variance for yield of roots (fresh basis), yield of sucrose, weight of 10 leaves (dry basis, average for the season), and yield of tops (dry basis), as affected by various combinations of levels of N, P, S, Na and Cl.

Source	Total	Linear	Quadratic	Lack of fit	Error	C.V. %	Equation suffi- ciency, %[1]
d.f.	31	5	15	6	5		
Roots							
m.tons/ha.							
S.S.	3795.8	2542.7	765.6	204.8	284.8	8.14	94.6
M.S.		508.5**	51.0	34.1	57.0		
Sucrose							
m.tons/ha.							
S.S.	127.6	73.7	405.3	5.50	7.84	7.33	95.7
M.S.		14.8**	2.70	0.93	1.57		
Leaves							
Grams							
S.S.	464.1	358.4	77.69	18.00	9.99	8.99	97.8
		71.67**	5.18	3.00	2.00		
Tops							
m.tons/ha.							
S.S.	15.26	5.33	7.73	0.55	1.65	13.60	96.4
		1.07	0.52	0.09	0.33		

** Statistically significant at the 1% level.

1 Percentage of total treatment sum of squares accounted for by the quadratic regression equation.

Table 4 - Observed yield of roots (fresh basis), yield of sucrose, weight of 10 leaves (dry basis, average for the four stages during season), and yield of tops (dry basis) as affected by various combinations of levels of N,P,S,Na and Cl.

Treatment levels N	P	S	Na	Cl	Roots m.tons/ha.	Sucrose m.tons/ha.	Leaves grams	Tops m.tons/ha.
2	2	2	2	4	74.2	15.1	9.9	2.9
4	2	2	2	2	96.9	16.9	19.5	3.6
2	4	2	2	2	85.9	17.3	16.3	2.8
4	4	2	2	4	121.1	20.2	19.7	5.3
2	2	4	2	2	87.0	16.0	12.4	3.2
4	2	4	2	4	107.9	19.8	21.2	3.6
2	4	4	2	4	92.3	17.7	13.0	3.3
4	4	4	2	2	110.1	21.5	23.0	3.9
2	2	2	4	2	93.5	19.0	15.3	3.4
4	2	2	4	4	108.2	22.4	17.1	3.8
2	4	2	4	4	83.6	17.1	13.4	2.6
4	4	2	4	2	103.3	20.4	18.6	4.3
2	2	4	4	4	84.8	16.5	11.4	3.1
4	2	4	4	2	87.6	19.4	20.5	3.2
2	4	4	4	2	91.2	17.3	13.1	2.7
4	4	4	4	4	111.6	21.5	21.3	3.1
5	3	3	3	3	116.5	21.7	28.3	5.0
1	3	3	3	3	79.5	16.0	11.6	2.9
3	5	3	3	3	88.2	18.4	17.9	3.8
3	1	3	3	3	96.9	17.3	13.7	3.3
3	3	5	3	3	91.2	17.3	16.1	3.6
3	3	1	3	3	85.9	15.4	14.2	2.5
3	3	3	5	3	102.9	19.2	13.1	4.8
3	3	3	1	3	97.6	17.0	15.6	4.9
3	3	3	3	5	102.2	17.1	16.2	3.4
3	3	3	3	1	86.6	15.4	12.9	3.3
3	3	3	3	3	82.9	16.3	17.4	3.4
3	3	3	3	3	85.5	17.2	14.7	2.3
3	3	3	3	3	96.1	15.5	14.6	2.9
3	3	3	3	3	101.0	18.3	17.0	3.7
3	3	3	3	3	99.9	16.5	14.1	3.7
3	3	3	3	3	90.8	18.8	16.5	2.7

Table 5 - Regression coefficients (b) and the probability of a true effect (p) for yield of roots (fresh basis), yield of sucrose, weight of 10 leaves (dry basis, average for the season), and yield of tops (dry basis) as affected by various combinations of levels of N, P, S, Na and Cl.

	Roots		Sucrose		Leaves		Tops	
	m.tons/ha.		m.tons/ha.		grams		m.tons/ha.	
Coefficient	b	p	b	p	b	p	b	p
Mean	92.41		16.91		15.61		3.18	
N	+9.931	.99	+1.570	.99	+3.729	.99	+0.448	.98
P	+1.323	.57	+0.420	.89	+0.813	.96	+0.094	.54
S	+1.109	.50	+0.220	.57	+0.413	.79	-0.005	.02
Na	+0.378	.18	+0.570	.92	-0.388	.76	-0.098	.55
Cl	+2.044	.76	+0.240	.60	-0.213	.51	+0.051	.32
NN	+1.610	.70	+0.630	.96	+1.165	.99	+0.115	.67
PP	+0.238	.13	+0.390	.85	+0.127	.37	+0.016	.11
SS	-0.755	.40	+0.001	0	-0.035	.10	-0.104	.55
NaNa	+2.178	.82	+0.450	.89	-0.235	.60	+0.348	.98
ClCl	+0.710	.38	-0.020	.06	-0.185	.49	-0.029	.20
NP	+1.374	.52	+0.140	.34	-0.156	.33	+0.255	.87
NS	-1.274	.48	+0.200	.45	+1.006	.96	-0.218	.81
NNa	-1.799	.61	+0.090	.22	-0.469	.75	-0.090	.44
NCl	+3.975	.91	+0.550	.86	+0.444	.73	+0.071	.37
PS	+0.428	.17	+0.300	.62	-0.081	.17	-0.099	.48
PNa	-2.368	.73	-0.630	.90	-0.431	.72	-0.184	.74
PCl	+1.139	.43	-0.160	.38	+0.281	.54	+0.010	.06
SNa	-1.420	.52	-0.600	.89	-0.144	.30	-0.106	.48
SCl	+0.191	.08	+0.010	.03	+0.469	.75	-0.025	.13
NaCl	-0.806	.32	+0.002	.01	+0.194	.40	-0.185	.74

The response to chlorine and nitrogen application was considerably influenced by the positive N-Cl interaction (p=0.91) (Fig. 1). At a low level of chlorine, nitrogen fertilization only slightly increased the yield of roots. As the level of chlorine application increased, the response of beets to nitrogen greatly increased. When nitrogen was at a low level, increasing chlorine resulted in a general reduction in root yield. However, a considerable positive response to chlorine was indicated when nitrogen was at the higher levels. The N-Na (p=0.61) and N-S (p=0.48) interactions were complementary, thus, the response to nitrogen fertilization tended to be slightly greater if sodium and sulfur were low (Table 5).

A highly significant response to nitrogen was also observed in two other sugar beet experiments (20, 35) which were conducted on the University Farm. In these two fertilizer tests the N-P interaction was also shown to be positive. However, contrary to the experiment reported here, the N-Na interaction was positive in both experiments.

<u>Sucrose concentration.</u> The data for sucrose percentage (table 6) indicated a range of 16.1 to 20.9%. The regression coefficient for the overall linear effect of nitrogen (Table 7) was negative (p=0.60) indicating that nitrogen fertilization tended to have a depressing effect on the concentration of sucrose in the roots as has been found by many other workers (4, 46, 49). Under conditions of this experiment the depressing effect of nitrogen fertilization was relatively small. Hussieni (35) reported a depressing effect of nitrogen of nearly the same

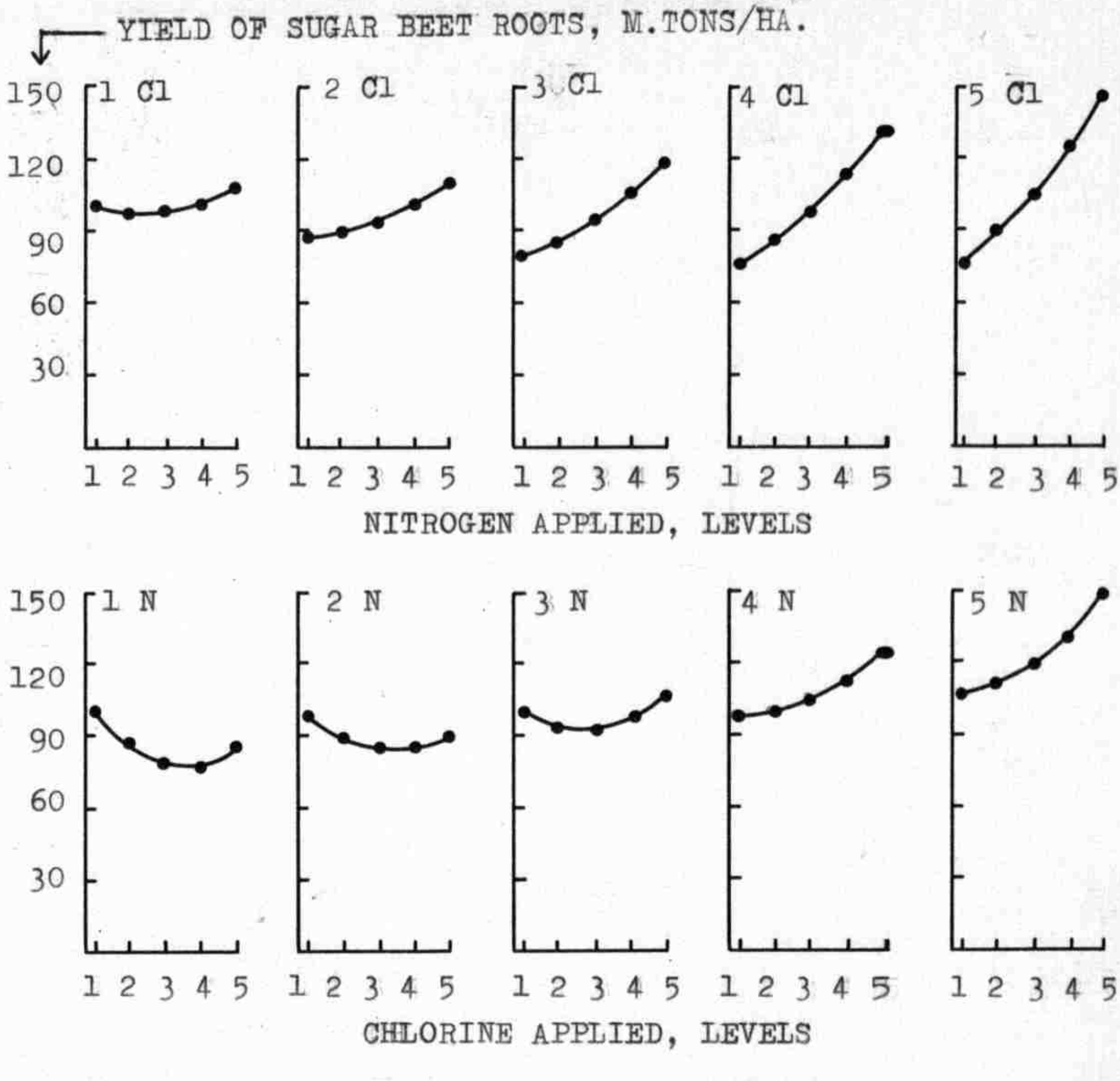

Fig. 1, Yield of sugar beet roots as affected by levels of applied N at constant levels of applied Cl (above) and by levels of applied Cl at constant levels of applied N (below). Levels of P,S and Na were held constant at the middle level (3) of five levels of application.

Table 6 - Observed sucrose concentration of roots (fresh basis), nitrogen concentration of roots (fresh basis), mean seasonal nitrate - nitrogen concentration of petioles (dry basis), and nitrogen concentration of tops (dry basis) as affect by various combinations of levels of N, P, S, Na and Cl.

Treatment levels					Sucrose	N-Root	NO_3-N	N-Tops
N	P	S	Na	Cl	%	%	ppm.	%
2	2	2	2	4	20.3	0.161	280	2.41
4	2	2	2	2	17.4	0.120	4058	2.61
2	4	2	2	2	20.1	0.129	727	2.98
4	4	2	2	4	16.7	0.150	2215	3.20
2	2	4	2	2	18.4	0.122	610	2.04
4	2	4	2	4	18.3	0.127	2772	2.29
2	4	4	2	4	19.1	0.118	548	2.35
4	4	4	2	2	19.6	0.127	3083	2.33
2	2	2	4	2	20.3	0.098	324	2.10
4	2	2	4	4	20.7	0.148	1745	2.49
2	4	2	4	4	20.4	0.092	499	2.24
4	4	2	4	2	19.8	0.121	3298	2.07
2	2	4	4	4	19.5	0.117	460	2.23
4	2	4	4	2	19.9	0.146	2300	3.06
2	4	4	4	2	19.3	0.113	368	2.85
4	4	4	4	4	19.3	0.121	768	2.61
5	3	3	3	3	18.7	0.225	7061	2.74
1	3	3	3	3	20.1	0.122	100	2.58
3	5	3	3	3	20.9	0.142	176	1.99
3	1	3	3	3	17.9	0.128	385	2.50
3	3	5	3	3	18.9	0.108	290	2.23
3	3	1	3	3	17.9	0.112	192	2.67
3	3	3	5	3	18.7	0.163	3254	2.46
3	3	3	1	3	17.4	0.114	696	1.69
3	3	3	3	5	16.8	0.120	336	2.47
3	3	3	3	1	17.8	0.154	153	2.32
3	3	3	3	3	19.7	0.129	896	1.45
3	3	3	3	3	20.1	0.172	414	2.35
3	3	3	3	3	16.1	0.086	352	2.14
3	3	3	3	3	18.1	0.116	300	2.36
3	3	3	3	3	16.5	0.091	376	1.75
3	3	3	3	3	20.7	0.132	561	2.44

Table 7 - Regression coefficients (b) and the probability of a true effect (P) for sucrose concentration of roots (fresh basis), nitrogen concentration of roots (fresh basis), mean seasonal nitrate nitrogen concentration of petioles (dry basis), and nitrogen concentration of tops (dry basis).

	Sugar, %		N-Roots, %		NO_3-N, log ppm.		N-Tops, %	
Coefficient	b	p	b	p	b	p	b	p
Mean	18.37		0.124		2.621		2.07	
N	-0.368	.60	+0.013	.91	+0.388	.99	+0.073	.59
P	+0.226	.42	-0.002	.20	-0.026	.52	+0.016	.16
S	-0.010	.02	-0.002	.20	+0.002	.05	-0.050	.44
Na	+0.490	.73	0	0	+0.003	.06	+0.040	.37
Cl	-0.103	.20	0	0	-0.023	.43	+0.004	.04
NN	+0.362	.64	+0.010	.85	+0.134	.99	+0.155	.91
PP	+0.372	.65	0	0	+0.008	.19	+0.051	.50
SS	+0.123	.26	-0.006	.64	-0.005	.12	+0.102	.79
NaNa	+0.032	.08	+0.001	.16	+0.198	.99	+0.008	.08
ClCl	-0.167	.36	+0.001	.16	-0.009	.20	+0.088	.72
NP	-0.104	.28	+0.002	.30	-0.054	.74	-0.118	.71
NS	+0.456	.61	-0.001	.04	-0.049	.70	+0.011	.08
NNa	+0.373	.52	+0.008	.64	-0.030	.48	+0.011	.08
NCl	-0.186	.30	0	0	-0.055	.75	+0.076	.53
PS	+0.191	.30	0	0	+0.074	.86	-0.022	.16
PNa	-0.170	.29	-0.004	.37	-0.015	.26	-0.100	.64
PCl	-0.379	.54	-0.005	.44	-0.018	.32	+0.034	.26
SNa	-0.255	.39	+0.007	.55	-0.043	.64	-0.253	.95
SCl	-0.081	.13	-0.007	.55	+0.018	.32	-0.089	.54
NaCl	+0.093	.15	-0.004	.37	+0.019	.33	-0.049	.37

magnitude. Among the interaction terms, N-P and N-Cl were complementary and N-S and N-Na were antagonistic with regard to sucrose percentage. The probability of a true effect for all of these terms was relatively small (Table 7).

Yield of sucrose. As with the yield of roots, nitrogen fertilization has a significant increasing effect on the yield of sucrose (Table 5). However, the increase was modified to some extent by the decreased percentage of sucrose.

The N-P, N-S, N-Na and N-Cl interactions were all antagonistic (Table 5), with N-Cl having the highest probability of a true effect (p=0.86) and N-Na the lowest (p=0.22). Increasing nitrogen tended to increase the requirement for the other nutrients studied. The N-S and N-Na interactions were negative for yield of roots but for sugar yield they were positive due to the positive effect of the two interactions on sucrose percentage (Table 7).

Yield of tops: The yields of the harvested beet tops (Table 4) ranged from about 2.5 to 5.0 m.tons per hectare (dry basis). The linear effect of nitrogen on the yield of tops was positive (p=0.98) (Table 5). Hussieni (35) and Fuehring (20) also found that nitrogen gave the highest increase in yield of beet tops. Studying the interaction of nitrogen with other elements, it was found that the N-P (p=0.87) and N-Cl (p=0.37) interactions were antagonistic. The N-S (p=0.81) and N-Na (p=0.44) interactions were complementary as with the yield of roots. Examination of the negative N-S relationship (Fig.2)

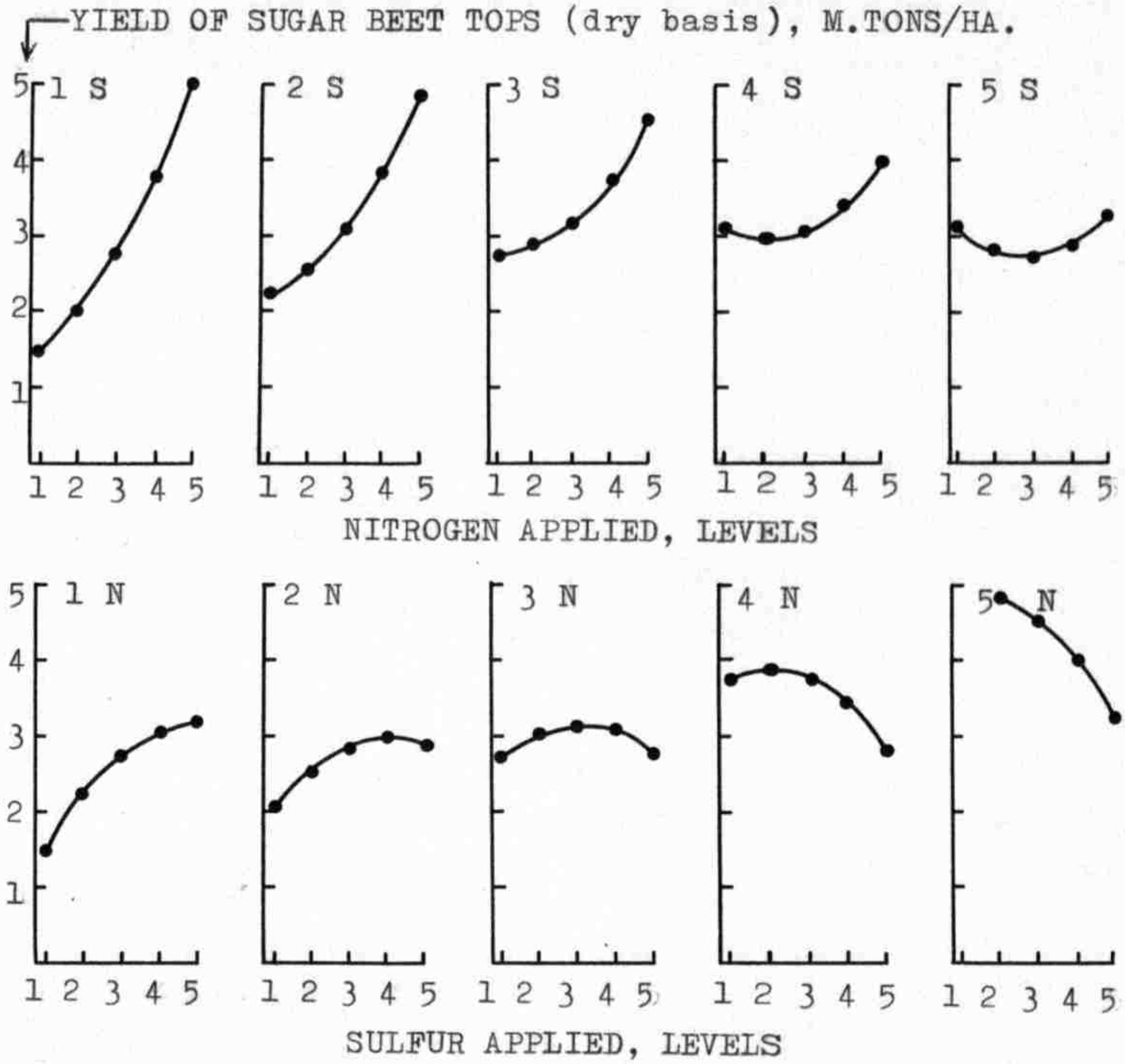

Fig. 2. Yield of beet tops as affected by levels of applied N at constant levels of applied S (above) and by levels of applied S at constant levels of applied N (below). Levels of P, Na and Cl were held constant at the middle level (3) of five levels of application.

indicated that at a low level of sulfur increasing nitrogen application resulted in an appreciable increase in yield of tops. At higher levels of sulfur, response to nitrogen application was considerably reduced. At low nitrogen levels, applied sulfur gave an appreciable increase in yield while at the higher levels of nitrogen application of sulfur reduced the yield of tops.

Size of leaves during growing season: The increase in the size of leaves (recently matured) collected at the four sampling dates (Fig.3) was rapid at the beginning of the growing season. After July the size of new leaves was reduced and probably the development of the storage roots had begun at a faster rate. This supported the view of Schultz (55) who indicated that there were two stages of growth of sugar beet plants, one mainly leaf growth and the other mostly root growth. Stout (58) also pointed out that the roots of sugar beet plants were slow to enlarge until a fairly large canopy of leaves had developed so that leaves could make more sucrose than was needed for new leaf growth and other metabolic processes. The greatest leaf size was obtained with the highest level of nitrogen fertilization (Fig.3) and as the rate of nitrogen application decreased the leaf size was reduced. Also, high leaf size occurred further along in the season at the higher nitrogen rates. The overall linear effect of nitrogen (Table 5) on the mean seasonal weight of 10 recently matured leaves indicated a significant positive response to nitrogen application. Among quadratic terms, the N-P ($\bar{p}=0.33$) and N-Na ($\bar{p}=0.75$) interactions were complementary for the size of leaves, while

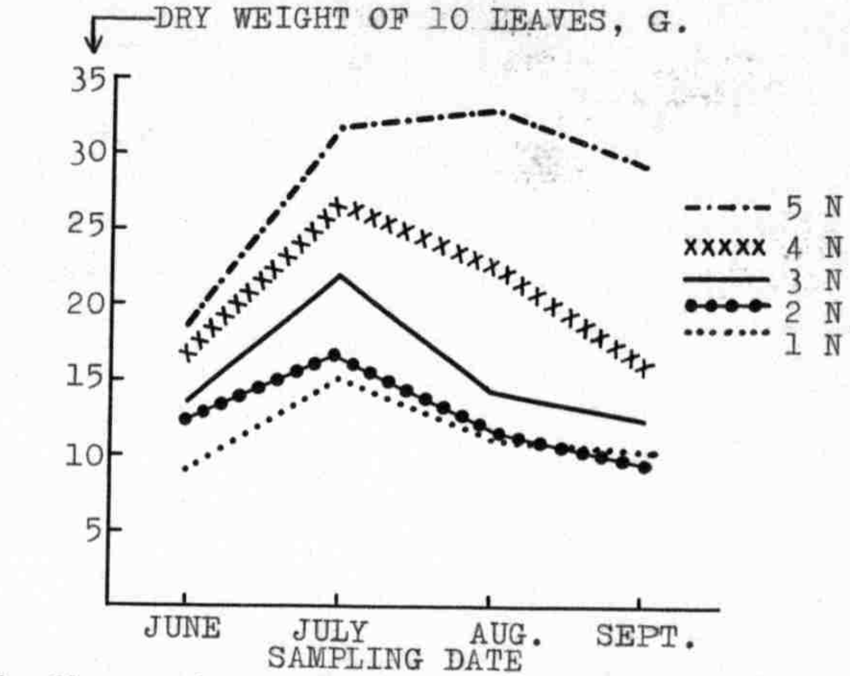

Fig. 3. Observed seasonal weight of 10 leaves (recently matured, dry basis, grams).

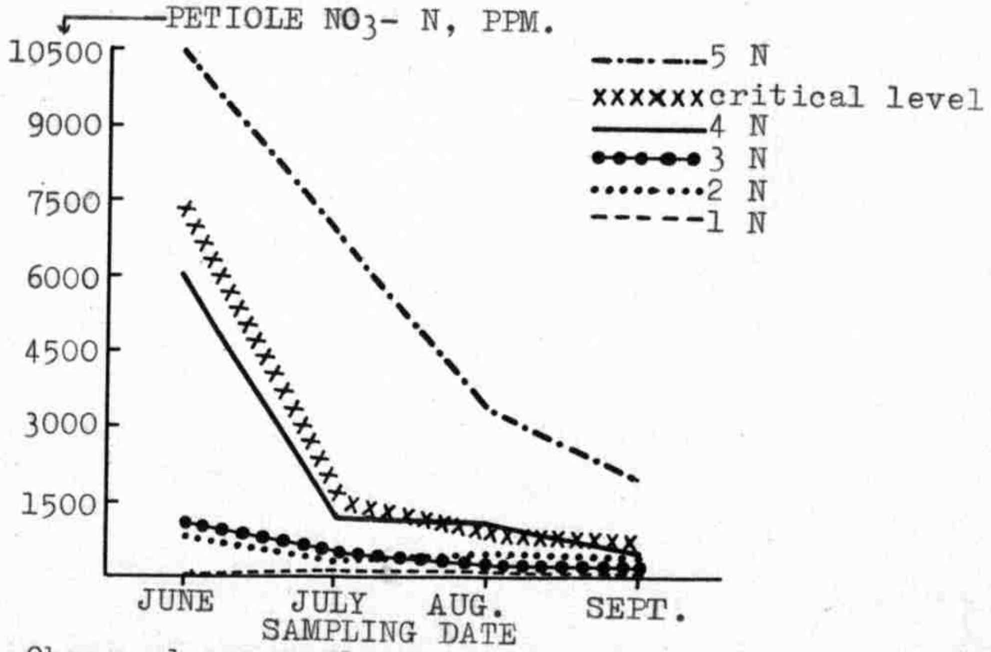

Fig. 4. Observed seasonal change in average nitrate nitrogen concentration of petioles (recently mature, ppm., dry basis).

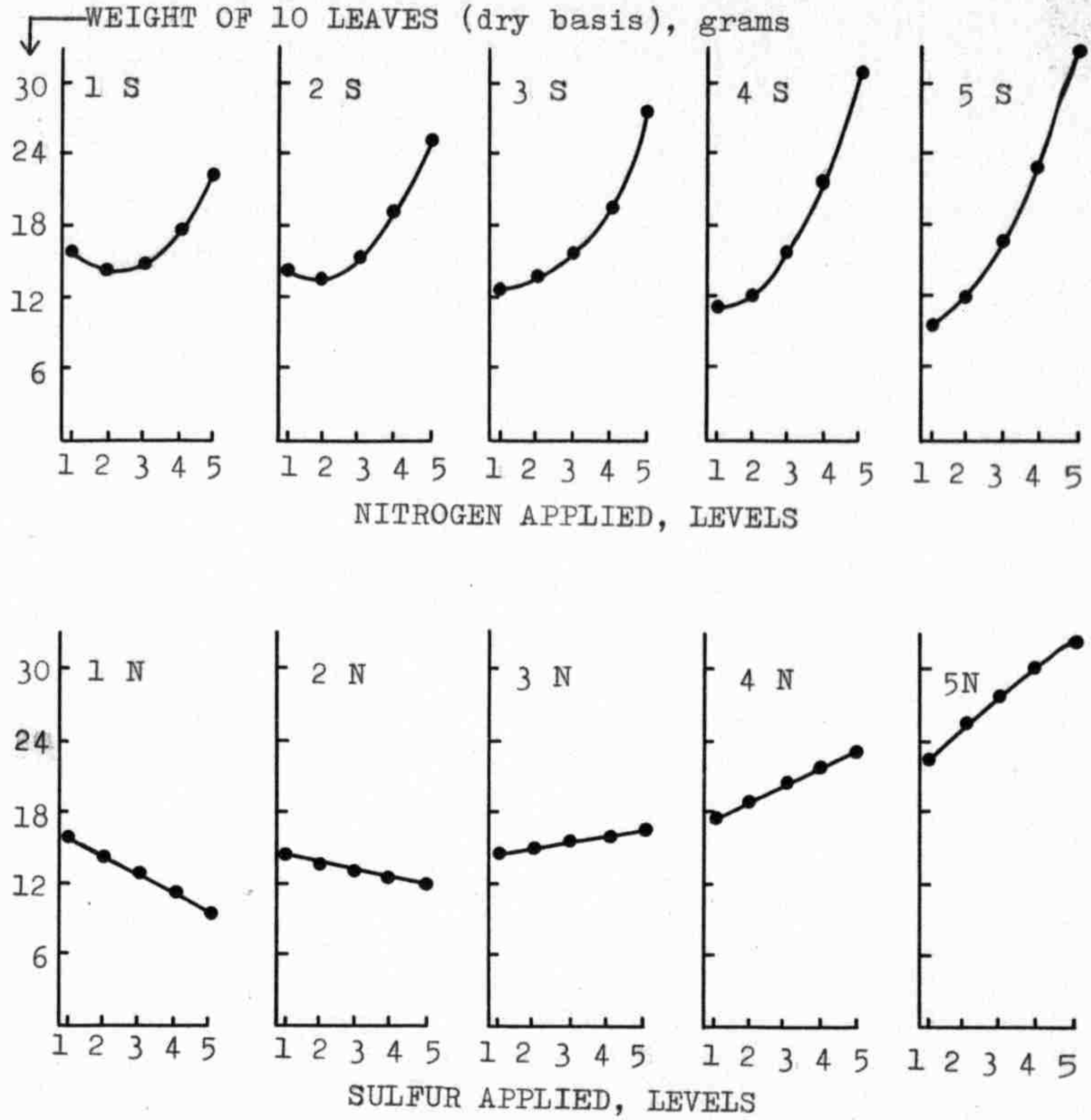

Fig. 5. Weight of 10 leaves (recently matured) as affected by levels of applied N at constant levels of applied S (above) and by levels of applied S at constant levels of applied N (below). Levels of P, Na and Cl were held constant at the middle level (3) of five levels of application.

concentrations of tops was negligible. Among the interaction terms on nitrogen concentration of tops N-P ($\dot{p}$ = 0.71) was complementary and N-Cl ($\dot{p}$=0.53) was antagonistic (Table 7). Hussieni (35) and Fuehring (20) found that the N-P interaction on the nitrogen concentration of tops was positive.

The data for the nitrogen percentage of roots (fresh basis) indicated a range of 0.086 to 0.225% (Table 6). The application of nitrogen at high levels, as was shown by many workers (52, 58), greatly increased the nitrogen content of the roots of sugar beets. This high nitrogen concentration of the roots has a considerable adverse effect on the purity of the juice which will be discussed further in later sections. Nitrogen application increased the sodium and magnesium concentrations of roots. Examination of the interaction terms (Table 7) indicated that N-Na, as was shown by Fuehring (20), tended to be positive.

The nitrate-nitrogen concentration of petioles (Fig.4) was positively related to nitrogen application rates at all four sampling times during the season. The concentration of nitrate-nitrogen was greatest at the first sampling date (June) and decreased as the season advanced. Low levels of nitrogen application resulted in reduced nitrate-nitrogen concentration of petioles with a similar seasonal trend. The positive regression coefficient (Table 7) for the effect of nitrogen on the nitrate nitrogen concentration[1] of the petioles supported further the above finding, that increasing levels of nitrogen application increased the nitrate content of petioles. Magnitski (47) and Ulrich (68) found similar results with regard to the effect of nitrogen on the nitrate concentration of the petioles. The data obtained under the conditions of this experiment suggested that the nitrate — nitrogen content of the petioles was a better indicator of the level of available nitrogen in the soil than the total nitrogen concentration of tops. Furthermore, analysis of variance for the nitrate - nitrogen concentration of petioles indicated that the linear treatment effect was highly significant (Table 9). The significance of the linear term was due to the overall linear effect of nitrogen application.

The linear effect of nitrogen was negative on the potassium ($p=0.99$), phosphate ($p=0.98$), sulfate ($p=0.89$) and chlorine ($p=0.92$) concentrations of petioles (Table 10). The sodium concentration of petioles was significantly increased by nitrogen application. The effect of nitrogen on the calcium and magnesium concentrations of petioles was negligible. All the interactions between nitrogen and the other

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[1]Statistical analysis for nitrate concentration of petioles required a conversion of the concentration values in ppm. to logarithms because of the great range in values. Without conversion to logarithms the effect of a few extremely high values would be to overshadow the effect of all other values. Also values less than 100 were converted to the logarithm, 2.0. Since the method of nitrate determination is not sensitive enough to measure accurately the nitrate concentrations below 100 ppm. Also, values of less than the logarithm, 2.0, would introduce abnormally great effects into the calculations.

Table 8. Regression coefficients (b) and the probability of a true effect (p) for phosphorus sulfur, sodium, chlorine, potassium, calcium and magnesium concentrations of tops (dry basis) as affected by various combinations of levels of N, P, S, Na and Cl.

Coefficient	P, ppm.		S, %		Na, %		Cl, %		K, %		Ca, %		Mg, %	
	b	p	b	p	b	p	b	p	b	p	b	p	b	p
Mean	1376		0.580		3.360		4.180		4.850		1.700		1.910	
N	-14	.02	+0.046	.88	+0.090	.42	-0.351	.92	0	0	+0.013	.16	+0.031	.46
P	+185	.92	-0.001	.02	+0.005	.02	-0.092	.42	-0.189	.54	-0.072	.84	-0.001	.02
S	-49	.41	+0.081	.98	+0.112	.50	+0.083	.38	+0.381	.84	+0.068	.67	+0.074	.83
Na	+38	.30	-0.022	.58	+0.077	.37	-0.159	.64	+0.061	.20	-0.093	.80	-0.024	.37
Cl	-12	.02	-0.000	0	-0.003	.01	+0.465	.97	+0.326	.78	-0.051	.55	-0.046	.62
NN	+155	.89	-0.008	.28	+0.004	.01	-0.020	.10	-0.071	.26	-0.086	.81	-0.041	.60
PP	+85	.68	+0.017	.50	-0.070	.37	+0.011	.07	+0.037	.12	-0.037	.46	-0.131	.97
SS	+110	.79	+0.019	.57	-0.207	.80	+0.041	.20	+0.172	.54	-0.026	.34	-0.098	.92
NaNa	+47	.44	+0.003	.09	-0.019	.08	-0.078	.43	-0.166	.54	-0.066	.70	-0.090	.90
ClCl	+134	.86	-0.022	.64	-0.305	.92	-0.028	.15	+0.165	.54	-0.068	.70	-0.165	.98
Np	-33	.24	-0.017	.41	-0.076	.50	-0.121	.44	-0.446	.82	+0.001	0.01	-0.004	.06
NS	+136	.75	+0.024	.54	+0.014	.05	-0.088	.34	+0.371	.75	-0.031	.30	-0.092	.82
NNa	-41	.25	-0.002	.03	-0.063	.26	+0.166	.56	-0.245	.58	+0.019	.18	-0.034	.42
NCl	+98	.61	-0.002	.03	-0.020	.07	+0.377	.89	+0.140	.36	+0.049	.44	+0.027	.34
PS	-59	.41	-0.069	.75	0	0	-0.014	.07	+0.033	.10	-0.025	.22	-0.038	.46
PNa	-75	.50	+0.014	.36	+0.019	.07	+0.022	.08	-0.040	.10	+0.110	.74	+0.084	.79
PCl	-39	.30	+0.042	.79	+0.229	.72	+0.021	.07	-0.334	.70	-0.008	.08	+0.058	.63
SNa	+166	.83	+0.013	.33	-0.129	.48	-0.116	.43	-0.055	.14	-0.055	.50	-0.021	.27
SCl	-92	.59	+0.020	.46	-0.191	.64	+0.031	.12	+0.241	.57	-0.018	.18	-0.001	.01
NaCl	-49	.36	+0.009	.22	-0.038	.16	-0.136	.48	-0.289	.64	+0.010	.10	+0.023	.27

Table 9 - Analysis of variance for sucrose concentration of roots (fresh basis), nitrogen concentration of roots, (fresh basis), nitrate — nitrogen concentration of petioles (average for the season, log ppm, dry basis), and nitrogen concentration of tops (dry basis).

Source	Total	linear	quadratic	Lack of fit	error	c.v. %	equation sufficiency, %[1]
Sucrose %							
d.f.	31	5	15	6	5		
S.S.	56.70	10.49	19.69	7.93	18.59	10.42	86.0
M.S.		2.10	1.31	1.32	3.72		
N-Roots, %							
d.f.	31	5	15	6	5		
S.S.	0.023	0.0043	0.0073	0.0063	0.0049	25.95	73.0
M.S.		0.0009	0.0005	0.0010	0.0010		
NO_3-N, log ppm.							
d.f.	31	5	15	6	5		
S.S.	6.853	3.645	1.970	1.096	0.147	6.45	84.0
M.S.		0.729**	0.131	0.183	0.029		
N-tops, %							
d.f.	31	5	15	6	5		
S.S.	4.440	0.237	2.798	0.620	0.790	19.08	86.0
M.S.		0.047	0.187	0.103	0.158		

** Statistically significant at the 1% level.

1. Percentage of total treatment sum of squares accounted for by the quadratic regression equation.

Table 10. Regression coefficients (b) and the probability of a true effect (p) for mean seasonal phosphorus, sulfur, sodium, chlorine, potassium, calcium and magnesium concentrations of petioles (dry basis) as affected by various combinations of levels of N, P, S, Na and Cl.

Coefficient	PO_4-P, ppm.		SO_4-S, %		Na, %		Cl, %		K, %		Ca, %		Mg, %	
	b	p	b	p	b	p	b	p	b	p	b	p	b	p
Mean	1439		0.400		2.840		3.870		5.470		0.226		1.322	
N	-120	.98	-0.040	.89	+0.654	.99	-0.231	.92	-0.177	.99	-0.011	.17	0	0
P	+256	.99	-0.004	.04	+0.221	.96	+0.097	.60	-0.064	.80	-0.003	.04	+0.034	.82
S	+102	.96	+0.044	.91	-0.107	.76	+0.023	.18	+0.055	.74	-0.009	.08	+0.033	.80
Na	-1	.02	+0.016	.53	+0.243	.97	-0.156	.79	-0.293	.99	-0.014	.97	-0.006	.20
Cl	+3	.06	-0.038	.87	+0.053	.48	+0.892	.99	+0.380	.99	+0.036	.99	-0.007	.21
NN	-39	.71	-0.005	.19	+0.018	.18	-0.099	.64	+0.030	.52	+0.003	.46	-0.113	.99
PP	+38	.70	+0.041	.92	-0.045	.44	+0.020	.18	+0.025	.45	-0.002	.35	-0.073	.98
NaNa	-69	.91	-0.012	.44	+0.280	.99	+0.115	.70	-0.110	.96	-0.010	.93	-0.027	.77
ClCl	-32	.62	-0.037	.90	+0.048	.48	+0.457	.99	+0.280	.99	+0.012	.96	-0.056	.96
NP	-170	.98	+0.022	.57	+0.267	.96	+0.168	.74	-0.099	.88	-0.003	.32	-0.017	.44
NS	-50	.72	+0.008	.22	+0.038	.30	-0.023	.15	-0.045	.58	0	0	+0.073	.94
NNu	-69	.82	+0.013	.37	-0.057	.43	-0.026	.18	+0.060	.70	+0.001	.16	-0.017	.44
NCl	-62	.78	+0.069	.96	+0.194	.90	+0.238	.87	+0.131	.94	0	0	+0.056	.94
PS	+79	.87	-0.002	.04	-0.044	.34	-0.110	.56	+0.316	.99	+0.011	.89	+0.068	.95
PNa	+49	.72	-0.054	.91	-0.019	.18	+0.069	.38	-0.021	.30	-0.008	.74	-0.026	.62
PCl	-31	.50	+0.037	.72	+0.277	.56	+0.010	.06	+0.005	.08	-0.014	.94	+0.054	.90
SNa	-11	.20	+0.072	.96	+0.111	.70	+0.059	.30	+0.170	.98	-0.003	.32	+0.077	.93
SCl	-70	.83	+0.021	.56	+0.077	.54	+0.025	.17	+0.146	.96	+0.001	.16	-0.008	.22
NaCl	-42	.61	-0.017	.46	-0.198	.90	-0.069	.38	-0.101	.89	+0.008	.74	+0.038	.78

varied elements on the nitrate nitrogen concentration of petioles tended to be complementary in nature (Table 7).

The nitrate nitrogen concentration of petioles increased with chlorine application at the lower levels of nitrogen (Fig. 6). This increase in nitrate concentration was accompanied by a decrease in the yield of sucrose. At the higher levels of nitrogen, however, the addition of chlorine decreased the nitrate concentration and appreciably increased the yield of sucrose. The higher rates of nitrogen application, irrespective of the chlorine level, increased the nitrate -- nitrogen concentration, with the greatest increase at the lower levels of chlorine. Nitrogen fertilization, at the higher chlorine levels, increased the yield of sucrose appreciably along with increasing nitrate -- nitrogen concentration. This relationship indicated a close relationship between nitrogen and chlorine in sugar beet plants.

Examination of the relationship between the yield of sucrose and nitrate concentration of petioles as influenced by the P-S interaction (Fig.7) suggested that high nitrate concentration and yield of sucrose resulted when both sulfur and phosphorus were high, or both were low. In general, the yield of sucrose was positively related with the nitrate -- nitrogen concentration of the petioles.

The relationship between the yield of sucrose and the nitrate concentration of petioles as influenced by the S-Na interaction (Fig.8) indicated that at low levels of sulfur, only high levels of sodium resulted in greater yield of sucrose and nitrate concentration.

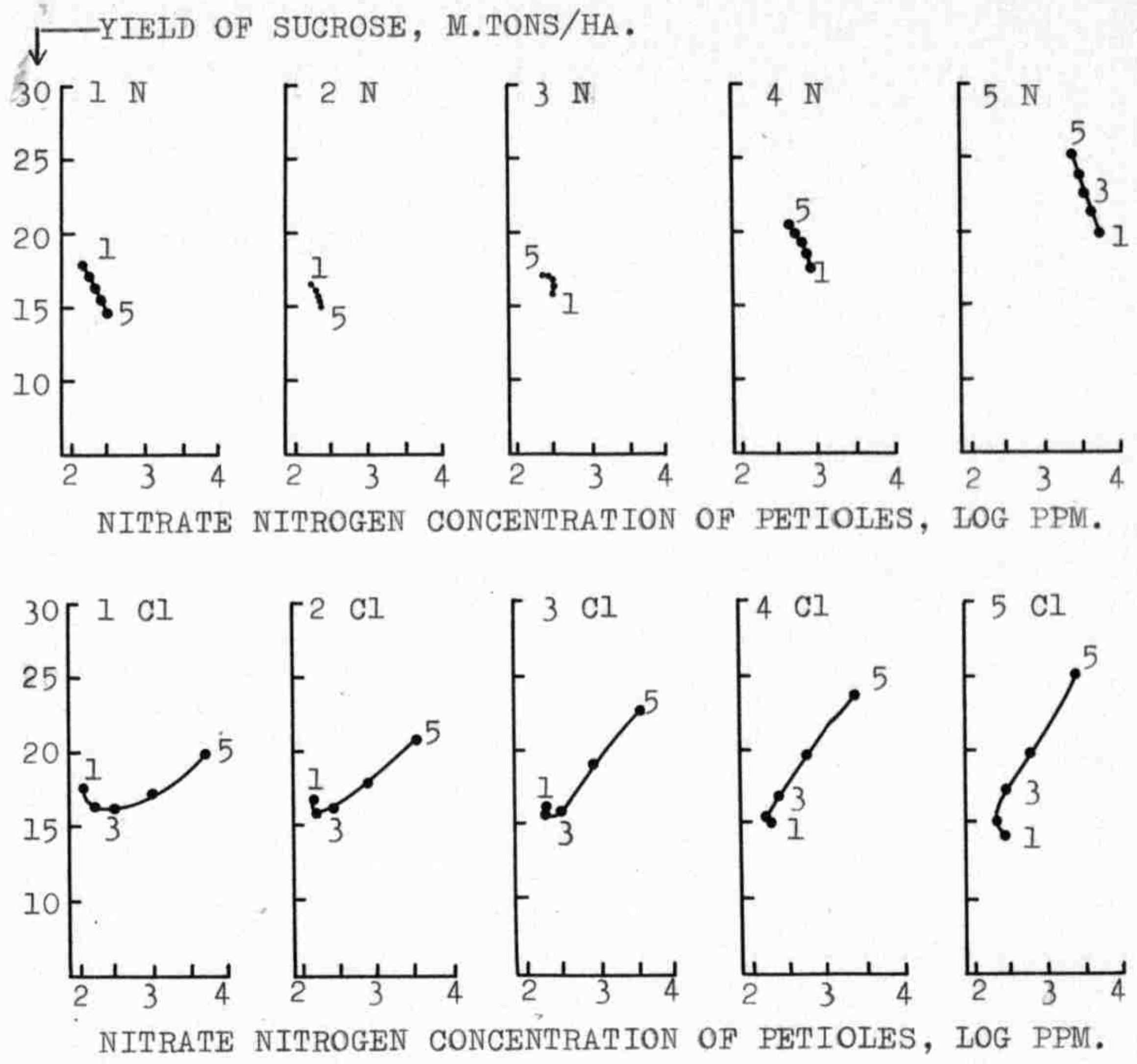

Fig. 6. Relationship between yield of sucrose, m.tons/ ha., and nitrate nitrogen of petioles of recently mature leaves (dry basis) as affected by addition of different levels of N and Cl with P, S and Na held at the middle level (3) of five levels of application. Numbers at points refer to the levels of Cl (above) and N (below) added.

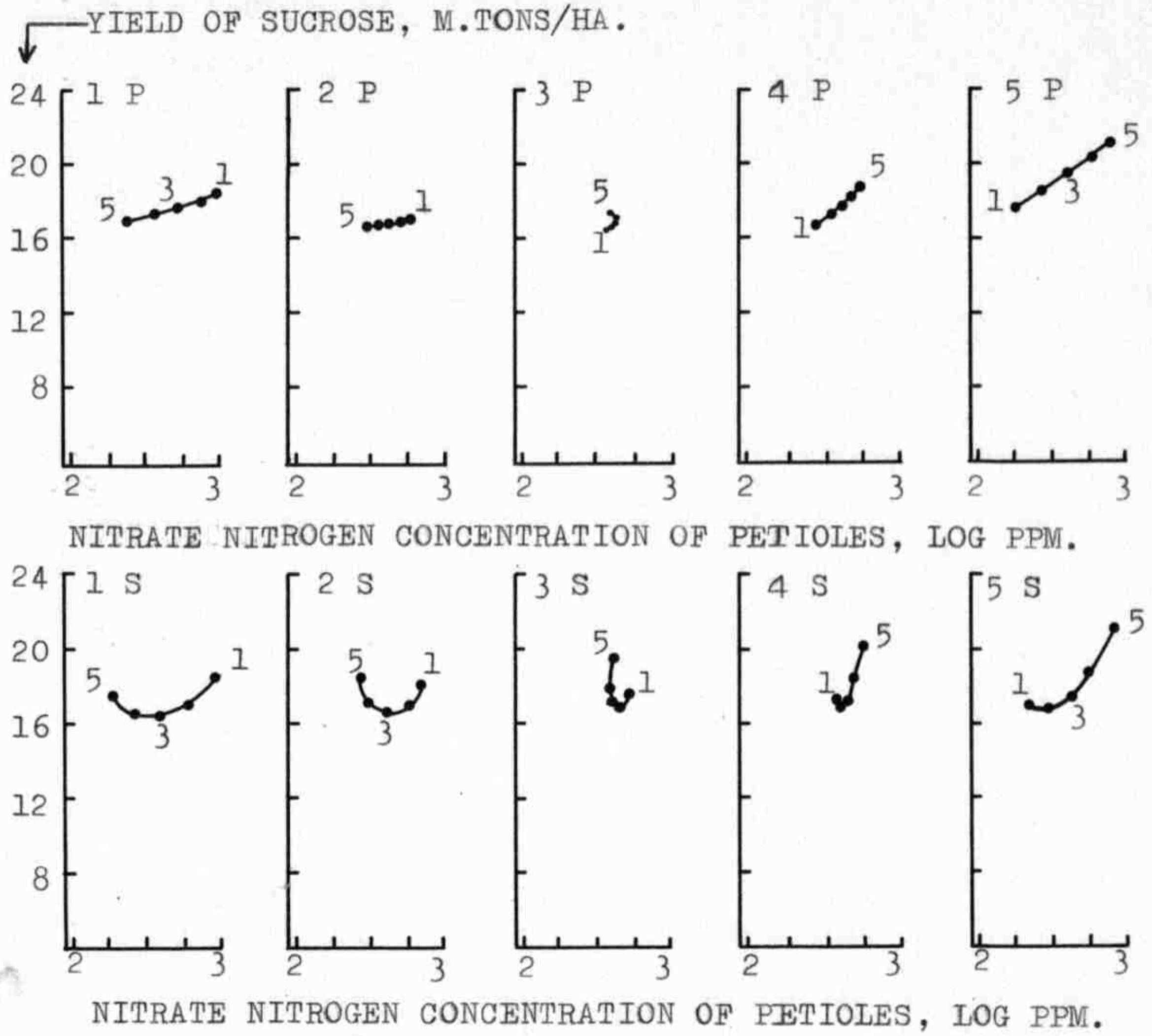

Fig. 7. Relationship between yield of sucrose, m.tons/ ha., and nitrate nitrogen of petioles of recently mature leaves (dry basis) as affected by addition of different levels of P and S with N, Na and Cl held at the middle level (3) of five levels of application. Numbers at points refer to the levels of S (above) and P (below) added.

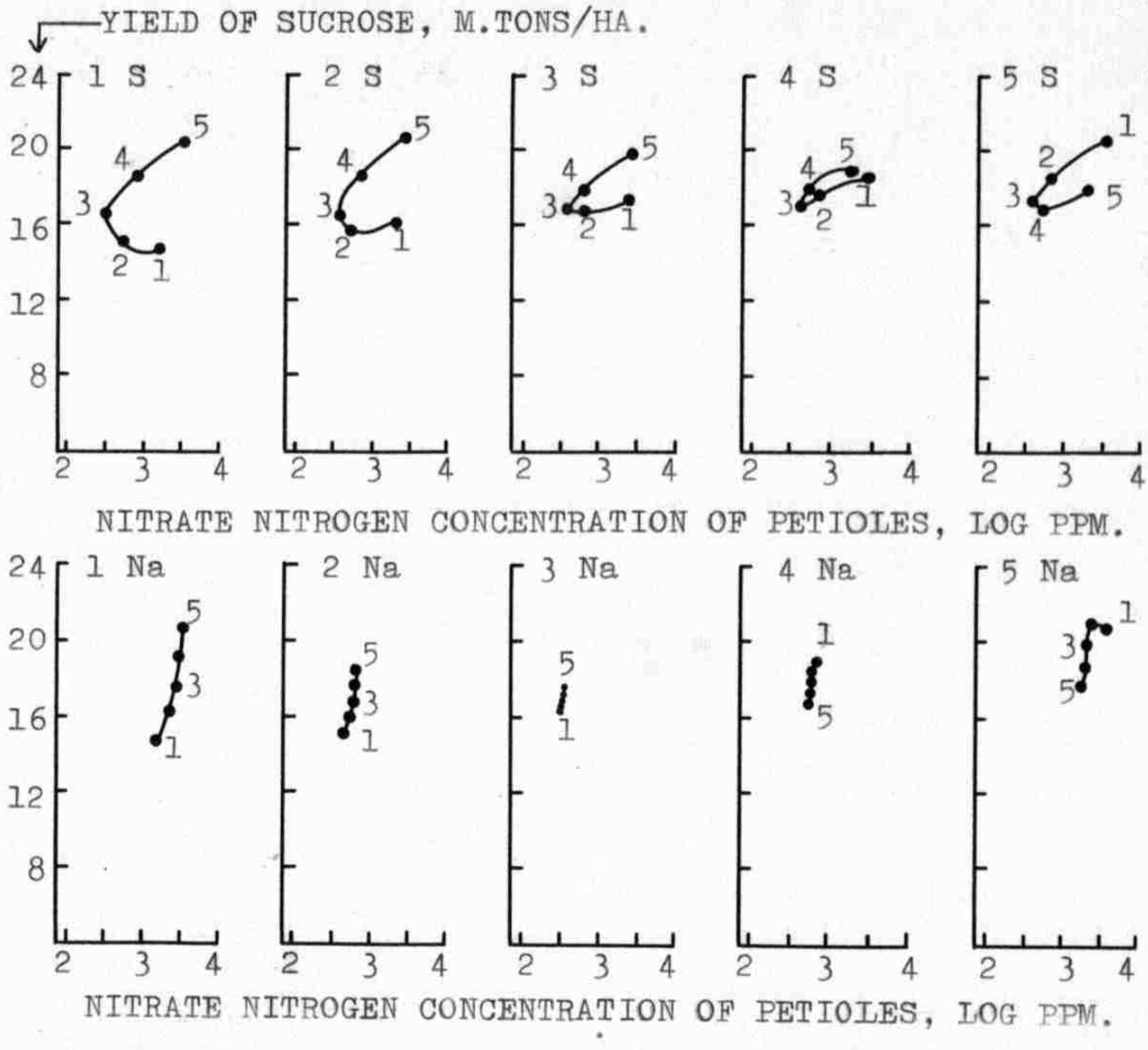

Fig. 8. Relationship between yield of sucrose, m.tons/ha., and nitrate nitrogen of petioles of recently mature leaves (dry basis) as affected by addition of different levels of S and Na with N, P and Cl held at the middle level (3) of five levels of application. Numbers at points refer to the levels of Na (above) and S (below) added.

However, at higher levels of sulfur, the lowest level of sodium application resulted in highest yield of sucrose and nitrate concentration of petioles. On the other hand, at the low level of sodium, application of sulfur resulted in a considerable increase in yield of sucrose along with slight increasing of the nitrate - nitrogen concentration of petioles. At the higher levels of sodium, addition of sulfur decreased the yield of sucrose as well as the nitrate concentration. In this case the yield of sucrose was not always positively correlated to the nitrate concentration of petioles. This relationship also suggested that a high yield of sucrose was obtained when either sulfur or sodium application was high but not both together.

The data reported herein clearly showed that the concentration of nitrate in petioles during the growing season was directly related to the rates of nitrogen applied (Fig.4). A tentative critical nitrate-nitrogen concentration (for the yield of roots of nearly 136 tons/ha.) was calculated under the conditions of the experiment. The estimated critical contration for nitrate-nitrogen of petioles on the dry basis was 7420 ppm. for June 8, 1660 ppm. for July 4, 915 ppm. for August 8, and 750 ppm. for the September 12 sampling (Fig.4). These values agree fairly closely with Ulrich's 1000 ppm. (63) for most of the season. Magnitski (47) indicated also that the critical concentration of nitrate of petioles changes according to phase of the growth of the plant, but his critical levels were considerable lower than Ulrich's, probably due to the lower yields obtained. The correlation between the yield of roots and the mean seasonal nitrate concentration of petioles was found to be fairly high(r=+0.681). Under the conditions of this experiment a slightly larger correlation was calculated between the yield of roots and the mean seasonal weight of 10 leaves (r=+0.736). Since a close positive correlation existed between nitrogen fertilization and the size of new leaves (Fig.3), it would be desirable to supply the plant with an abundant supply of nitrogen early in the season to produce a rapid early growth of leaves. Stout (58) stated that an early development of a full canopy of foliage lengthened the time for the effective use of leaves for the manufacturing of sucrose, and subsequently, increasing sugar yield. As to the importance of leaf coverage Schultz (55) concluded that the factor determining dry matter production was the mean leaf area per unit area of ground over the entire growth season.

Effect of Phosphorus on Plant Growth and Sugar Accumulation

Yield of roots: The direct effect of phosphorus application was a slight increase in the yield of the sugar beet roots (Table 5). Similar results on sugar beets in the Beka'a were reported by Hussieni (35) but Fuehring (20) showed a slight decrease due to addition of phosphorus. The slight response of sugar beets to phosphorus fertilization could be attributed to the medium level of available phosphorus in the soil (18 ppm. sodium bicarbonate soluble) (Table 2). These data showed that the phosphorus fertility of the soil determined, for a large part, the lack of appreciable yield response obtained from fertilizer application. Among the interaction terms Na-P ($p = 0.73$) was completementary (Table 5). Similar results for the Na-P interaction were shown by Hussieni (35) and Fuehring (20).

Sucrose concentration: Phosphorus, as was shown by Hussieni (35) and Fuehring (20), had a slight increasing effect on the sucrose percentage in roots (Table 7). The interactions between phosphorus and other varied elements were very small.

Yield of sucrose: The linear effect of phosphorus on the yield of sucrose was positive ($p=0.89$) (Table 5). Hussieni (85) also showed a positive effect, but results obtained by Fuehring (20) indicated that the direct effect of phosphorus on the yield of sucrose was negative.

The response of the yield of sucrose phosphorus application was considerably influenced by the P-Na interaction ($p=0.90$). At the low levels of phosphorus (Fig.9) the response to sodium was great, whereas at the high phosphorus levels, application of sodium decreased the yield of sucrose. Also, at a high level of sodium, phosphorus application considerably depressed the yield. Therefore, the application of phosphorus gave no beneficial response when chlorine (the P-Cl interaction was also negative) and Na levels were high. Similarly high application of phosphorus reduced the need for sodium and chlorine.

Yield of tops: As was found by Hussieni (35), phosphorus application increased the yield of tops (table 5). Among the interaction terms N-P was antagonistic and P-Na was complementary. An antagonistic effect for the N-P interaction was also shown by Fuehring (20) and Hussieni (35), whereas for the P-Na interaction the latter found a positive effect. The positive N-P interaction indicated that the response to nitrogen application was great when phosphorus was applied at higher rates.

<u>Size of leaves during the growing season</u>: The regression coefficient for the direct effect of phosphorus on the size of 10 leaves was greater than the effect on total yield of tops (Table 5). It has been shown by many workers (2, 14) that early application of phosphorus favored leaf growth in sugar beet plants. The Na-P ($\dot{p}$=0.72) interaction on the size of leaves was complementary (Table 5).

Effect of Phosphorus on the Chemical Composition of Sugar Beets

The mean seasonal phosphate-phosphorus concentration of petioles of recently mature leaves ranged from 1168 to 2732 ppm. on the dry basis (Table 11). These values were much above the critical phosphate phosphorus (750 ppm.) suggested by Ulrich (63). Because plants did not appreciably respond to phosphorus application, it could be assumed that the soil had sufficient supply of phosphorus available to support the normal growth of plants and resulted in high phosphate concentration of petioles even with the lowest treatment of phosphorus. The available phosphorus (sodium bicarbonate soluble) as determined by the Olsen method was found to be 18 ppm. (Table 2). Thus, from the limited data reported herein, it could be concluded that sugar beet plants, if supplied with high sodium and chlorine, would not appreciably respond to phosphorus fertilization when the level of available phosphorus in the soil is 18 ppm.

Analysis of variance (Table 12) for phosphorus concentration of

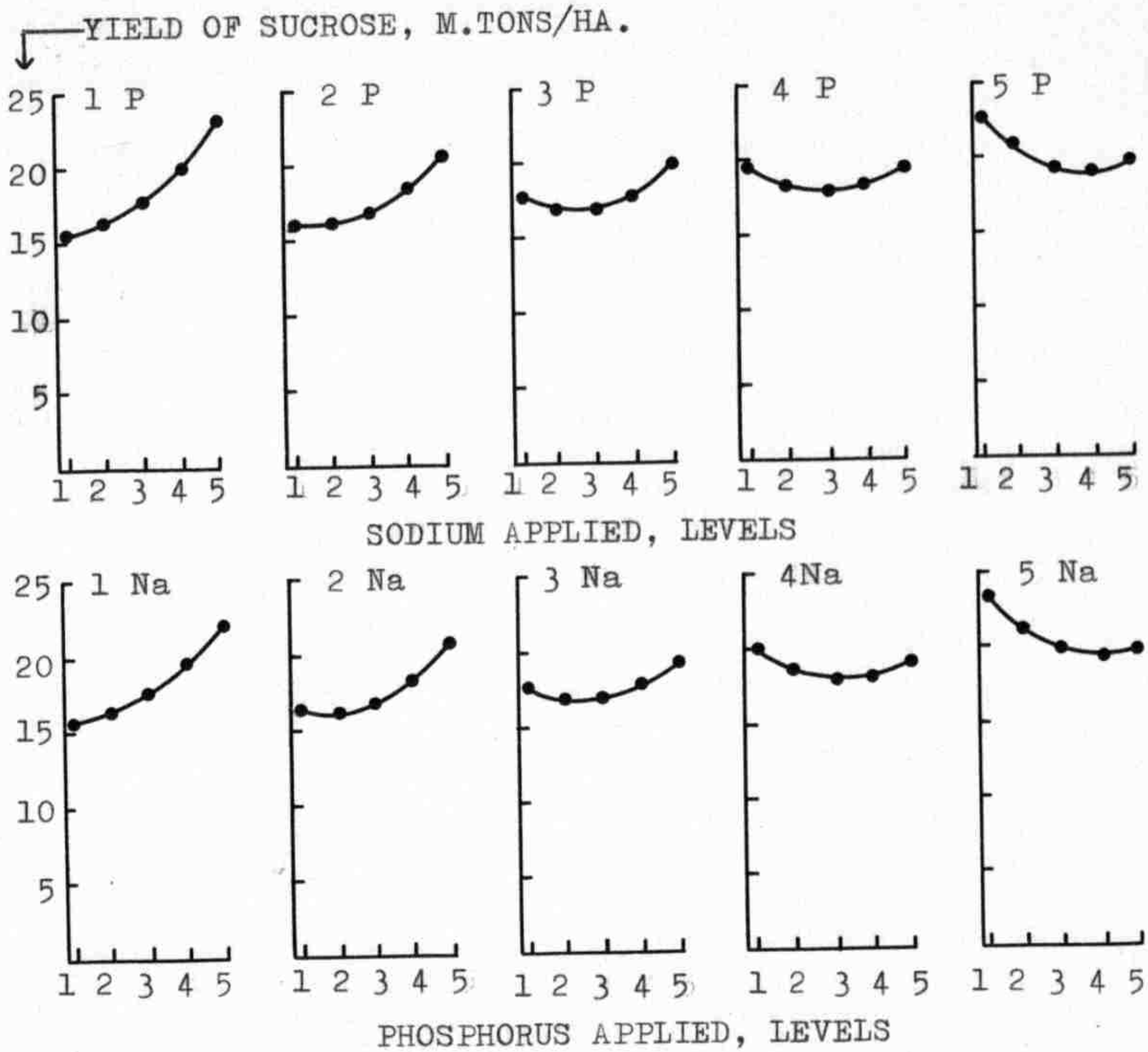

Fig. 9. Yield of sucrose as affected by levels of applied Na at constant levels of applied P (above) and by levels of applied P at constant levels of applied Na (below). Levels of N,S and Cl were held constant at the middle level (3) of five levels of application.

Table 11. Observed mean seasonal phosphorus, sulfur, sodium, chlorine, potassium, magnesium and calcium concentrations of petioles (dry basis) as affected by various combinations of levels of N, P, S, Na and Cl.

Treatment Levels					PO_4-P	SO_4-S	Na	Cl	K	Mg	Ca
N	P	S	Na	Cl	ppm.	%	%	%	%	%	%
2	2	2	2	4	1629	0.30	2.11	4.78	6.44	0.87	0.28
4	2	2	2	2	1443	0.31	3.32	2.79	5.85	0.87	0.20
2	4	2	2	2	1804	0.62	2.35	3.72	5.96	0.92	0.27
4	4	2	2	4	1766	0.57	5.29	5.67	6.09	0.94	0.24
2	2	4	2	2	1359	0.44	2.01	3.85	5.04	0.81	0124
4	2	4	2	4	1648	0.27	3.24	5.10	5.95	0.93	0.28
2	4	4	2	4	2648	0.41	2.27	4.77	7.00	0.96	0.25
4	4	4	2	2	1987	0.31	3.28	3.22	5.23	1.00	0.21
2	2	2	4	2	1168	0.58	3.44	3.64	5.53	0.93	0.19
4	2	2	4	4	1493	0.28	3.19	4.50	5.87	0.88	0.26
2	4	2	4	4	2439	0.19	2.70	4.90	5.15	0.89	0.24
4	4	2	4	2	1586	0.26	4.43	3.71	4.79	0.39	0.18
2	2	4	4	4	1609	0.45	2.08	5.05	5.56	0.94	0.29
4	2	4	4	2	1393	0.53	3.70	3.04	4.85	1.04	0.18
2	4	4	4	2	2732	0.53	2.55	4.00	6.08	1.04	0.17
4	4	4	4	4	1769	0.58	4.93	5.58	6.45	1.40	0.18
5	3	3	3	3	1603	0.23	3.74	2.49	4.98	0.95	0.23
1	3	3	3	3	1895	0.50	1.83	4.71	6.26	1.00	0.26
3	5	3	3	3	2342	0.45	2.68	3.95	5.30	1.27	0.25
3	1	3	3	3	1767	0.65	2.38	4.20	5.90	1.00	0.20
3	3	5	3	3	1762	0.64	2.69	3.81	5.94	0.97	0.21
3	3	1	3	3	1444	0.32	2.59	3.99	5.52	1.29	0.29
3	3	3	5	3	1641	0.39	4.35	3.39	4.12	1.23	0.18
3	3	3	1	3	1610	0.28	3.01	5.52	6.00	1.41	0.21
3	3	3	3	5	1410	0.14	3.04	8.08	7.61	0.96	0.40
3	3	3	3	1	2142	0.33	2.77	3.57	5.64	1.45	0.16
3	3	3	3	3	1707	0.59	3.68	4.62	5.26	1.44	0.18
3	3	3	3	3	1763	0.44	3.00	4.30	5.60	1.34	0.22
3	3	3	3	3	2053	0.33	2.64	3.79	5.56	1.35	0.24
3	3	3	3	3	2082	0.40	2.73	3.40	5.75	1.21	0.22
3	3	3	3	3	2135	0.35	2.81	3.53	5.40	1.16	0.24
3	3	3	3	3	1964	0.30	2.70	3.30	5.21	1.21	0.24

petioles indicated that the effects of linear and quadratic treatment terms were highly significant. The regression coefficient (table 10) showed that the direct effect of increasing the phosphorus level in the soil resulted in a highly significant increase in extractable phosphate concentration of petioles. Phosphorus application tended to decrease nitrate-nitrogen (table 7) and potassium (table 10) concentration of the petioles. However, the direct effect of phosphorus on the sodium, chlorine and magnesium concentrations of petioles was shown to be positive. Under the conditions of this experiment, the direct effect of phosphorus on sulfate, and calcium concentrations of petioles was negligible (Table 10). Examination of the interaction terms for phosphate concentration of petioles (Table 10) indicated that, at the higher levels of phosphorus, low levels of nitrogen and chlorine, and high levels of sulfur and sodium resulted in higher phosphate concentration of petioles. At the lower phosphate levels the opposite would be true.

As with the extractable phosphate concentration of petioles, the application of phosphorus considerably increased the total phosphorus concentration of tops (Table 8). The direct effect of phosphorus was negligible for magnesium, nitrogen, sulfur and sodium concentrations of tops. The regression coefficients for the overall linear effect of phosphorus indicated that phosphorus tended to decrease the chlorine ($p=0.42$), potassium ($p=0.54$) and calcium ($p=0.84$) concentrations of tops (Table 8). The phosphorus concentration of tops ranged from 870 to 2671 ppm. on the dry basis (Table 13).

Table 12. Analysis of variance for mean seasonal phosphorus, sulfur, sodium, chlorine, potassium, calcium and magnesium concentration of petioles (dry basis) as affected by various combinations of levels of N, P, S, Na and Cl.

Source	Total	Linear	Quadra-tic	Lack of fit	error	C.V. %	Equation suffi-ciency, %[1]
d.f.	31	5	15	6	5		
PO_4-P, ppm.							
S.S.	4241845	2168515	1305180	611680	156470	9.1%	75.6
M.S.		433703**	87012**	101947	31298		
SO_4-S,%							
S.S.	0.610	0.125	0.378	0.052	0.055	26.0	91.5
M.S.		0.025	0.251	0.009	0.0110		
Na,%							
S.S.	21.10	13.19	6.48	0.670	0.759	13.3	96.8
M.S.		2.64**	0.43	0.112	0.152		
Cl,%							
S.S.	35.61	21.19	8.93	4.04	1.40	13.9	88.5
M.S.		4.24**	0.60	0.68	0.28		
K,%							
S.S.	13.74	6.45	6.06	1.02	0.22	3.6	92.6
M.S.		1.29**	0.40*	0.17	0.04		
Ca,%							
S.S.	0.072	0.041	0.015	0.013	0.003		
M.S.		0.008**	0.001	0.002	0.001	10.4	82.0
Mg,%							
S.S.	1.635	0.056	1.003	0.518	0.058	8.4	68.0
M.S.		0.011	0.067	0.086*	0.011		

* Statistically significant at the 5% level.
** Statistically significant at the 1% level.

1. Percentage of total treatment sum of squares accounted for by the quadratic regression equation.

Table 13. Observed phosphorus, sulfur, sodium, chlorine, potassium, calcium and magnesium concentrations of tops (dry basis) as affected by various combinations of levels of N, P, S, Na and Cl.

Treatment levels					P	S	Na	Cl	K	Ca	Mg
N	P	S	Na	Cl	ppm.	%	%	%	%	%	%
2	2	2	2	4	1879	0.38	2.19	4.23	4.37	1.39	0.96
4	2	2	2	2	1381	0.67	2.87	2.97	4.06	1.59	1.59
2	4	2	2	2	2671	0.51	1.80	4.38	4.63	1.16	1.09
4	4	2	2	4	2633	0.61	2.93	4.48	3.79	1.20	1.32
2	2	4	2	2	1322	0.71	2.93	4.60	3.30	1.95	1.86
4	2	4	2	4	1749	0.88	2.74	4.87	8.03	1.82	1.51
2	4	4	2	4	1711	0.52	2.61	5.15	5.35	1.19	1.35
4	4	4	2	2	2154	0.59	2.89	2.85	5.11	1.37	1.36
2	2	2	4	2	1643	0.43	3.03	4.14	4.74	1.29	1.23
4	2	2	4	4	1533	0.46	3.15	4.76	4.86	1.47	1.20
2	4	2	4	4	2141	0.54	3.40	4.17	4.38	1.18	1.30
4	4	2	4	2	1702	0.54	2.76	3.55	3.77	1.45	1.45
2	2	4	4	4	1544	0.65	2.26	3.88	5.29	1.27	1.42
4	2	4	4	2	1994	0.90	3.66	3.35	5.65	1.45	1.45
2	4	4	4	2	2369	0.43	2.86	4.48	5.71	1.41	1.64
4	4	4	4	4	2147	0.74	2.88	4.47	5.16	1.37	1.46
5	3	3	3	3	1901	0.53	3.12	2.85	4.10	1.22	1.80
1	3	3	3	3	2077	0.58	3.44	5.20	5.43	1.50	1.67
3	5	3	3	3	1702	0.80	3.19	3.42	4.66	1.60	1.43
3	1	3	3	3	1719	0.51	2.78	4.89	5.73	1.51	1.32
3	3	5	3	3	1667	0.87	2.93	4.53	5.77	1.73	1.50
3	3	1	3	3	1958	0.54	1.98	4.02	5.70	1.47	1.51
3	3	3	5	3	1896	0.51	2.89	3.03	4.52	1.08	1.37
3	3	3	1	3	1222	0.69	3.49	4.57	4.25	1.80	1.71
3	3	3	3	5	1809	0.50	2.22	5.37	6.60	1.32	1.25
3	3	3	3	1	2002	0.50	1.87	2.63	4.82	1.54	1.23
3	3	3	3	3	1102	0.46	3.47	3.71	2.55	1.91	1.83
3	3	3	3	3	1699	0.64	3.61	4.69	4.78	2.02	2.06
3	3	3	3	3	1670	0.76	3.86	4.89	4.99	1.89	2.09
3	3	3	3	3	870	0.48	3.24	3.56	5.67	1.48	2.16
3	3	3	3	3	1063	0.65	4.17	5.13	5.31	1.64	1.53
3	3	3	3	3	1862	0.49	2.00	3.27	5.41	1.22	1.80

Effect of Sulfur on Plant Growth and Sugar Accumulation

Yield of roots. The regression coefficient indicated that the direct response to sulfur application was small (Table 5). This small response might be accounted for by the level of available sulfur in the soil which was sufficient for the apparently normal growth of the plants. The interactions between sulfur and other varied elements, under the conditions of the experiment, were small (Table 5).

Sucrose concentration. Sulfur had very little direct effect on the sucrose percentage in roots (Table 7). Here again, the interaction between sulfur and other elements studied in this experiment was small.

Yield of sucrose. Among elements varied in this experiment sulfur had the least direct effect (positive) on the yield of sucrose (Table 5). The response in the yield of sucrose to sulfur addition was considerably affected by sodium application (Fig. 10). When the level of sulfur was low, sodium application increased the yield of sucrose. Sodium tended to depress the yield at higher levels of sulfur. Also, at high levels of sodium, addition of sulfur resulted in reduction of the yield of sucrose. Therefore, sulfur was needed less when the level of sodium was high.

Yield of tops. Though sulfur application resulted in greater size of the individual recently mature leaves, the direct effect of sulfur on the yield of harvested tops (Table 5) was negligible. The interactions of sulfur, phosphorus and chlorine with sodium were small. The N-S interaction on the yield of tops was illustrated in a previous section (Fig.2).

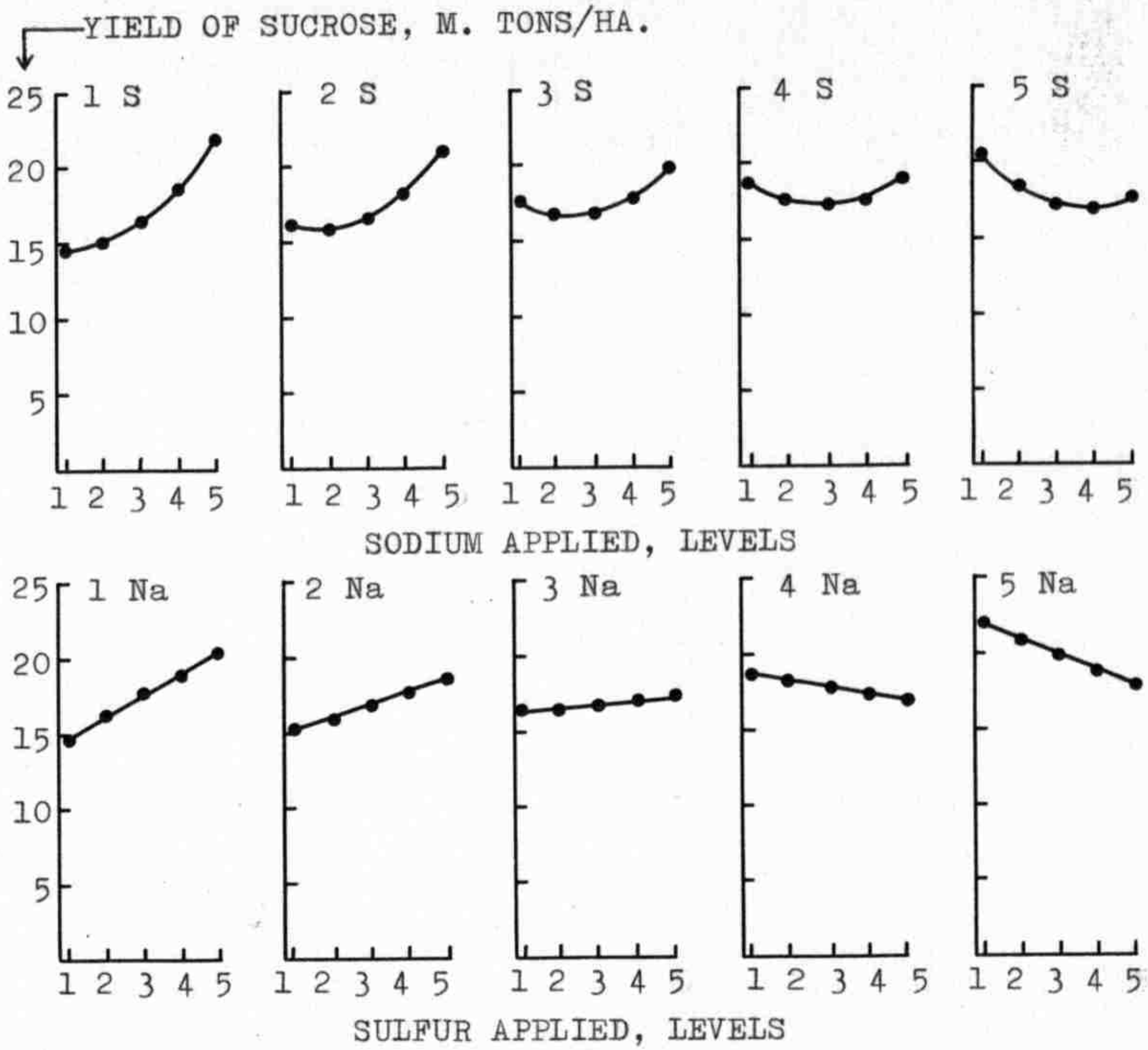

Fig. 10. Yield of sucrose as affected by levels of applied Na at constant levels of applied S (above) and by levels of applied S at constant levels of applied Na (below). Levels of N, P and Cl were held constant at the middle level (3) of five levels of application.

Size of leaves during growing season. The regression coefficients for the weight of leaves indicated that sulfur alone, or in combination with nitrogen resulted in greater size of individual recently mature leaves (Table 5).

Effect of Sulfur on the Chemical Composition of Sugar Beets.

The data for the seasonal mean extractable sulfate sulfur concentration of petioles indicated a range of 0.19 - 0.65% on the dry basis (Table 11). These values are much above the critical level reported by Ulrich (69) for sulfate-- sulfur (250 ppm.). The high level of extractable sulfur in the petioles, even at a low level of sulfur application, suggested that the sulfur supply of the soil was adequate for the normal growth of plants.

The regression coefficient (Table 10) indicated that the extractable sulfate concentration of petioles was considerably increased by increasing levels of applied sulfur. Sulfur application significantly increased the phosphate, and to a lesser extent potassium and magnesium concentrations of the petioles (Table 10). Increasing the level of sulfur decreased the sodium concentration of petioles. The direct effect of sulfur on nitrate-- nitrogen and chlorine concentrations of petioles was very slight. Examination of the interaction between sulfur and sodium ($\bar{p}$=0.96) (Table 10) for sulfate concentration of petioles indicated that, at high levels of sulfur, increasing level of sodium increased the sulfate concentration of petioles. At low sulfur levels, application of sodium, however, reduced the sulfate concentration of petioles.

As with extractable sulfur in the petioles, the addition of sulfur increased the sulfur concentration of tops (Table 8). The direct effect of sulfur tended to be negative for phosphorus ($p=0.41$) and nitrogen ($p=0.44$), and positive for potassium ($p=0.84$), magnesium ($p=0.83$), calcium ($p=0.67$) sodium ($p=0.50$) and chlorine ($p=0.38$) concentrations of tops (Table 8). The P-S interaction for the sulfur concentration of tops indicated that, at high levels of sulfur, increasing phosphorus tended to decrease the sulfur concentration of tops (Table 8).

The N-S interaction for phosphate concentration of tops (Table 8) suggested that for the higher phosphorus concentration of tops sulfur and nitrogen should be both high or both low. Sulfur application did not have any effect on the sulfate concentration of sugar beet roots (Table 14).

The overall response to sulfur as summarized from the results discussed in this section indicated that the need for sulfur fertilization in the experiment reported herein was low. Furthermore, the response of the yield of roots and total sucrose to sulfur was considerably decreased when nitrogen, sodium and chlorine were applied individually at higher rates.

Effect of Sodium on Plant Growth and Sugar Accumulation

Yield of roots. The sugar beet had the least overall linear response, among elements studied, to sodium application ($p=0.18$) (Table 5). Fuehring (20) showed similar results for the direct effect of sodium, but Hussieni (35) reported a significant positive response

Table 14. Regression coefficients (b) and the probability of a true effect (p) for potassium calcium, magnesium, sulfur, sodium and phosphorus concentrations of roots (dry basis) as affected by various combinations of levels of N, P, S, Na and Cl.

	K, %		Ca, %		Mg, %		S, %		Na, %		P, ppm.	
	b	p	b	p	b	p	b	p	b	p	b	p
Mean	0.637		0.206		0.256		0.055		0.093		542	
N	0	0	-0.002	.26	+0.012	.92	+0.001	.50	+0.011	.90	+22.21	.54
P	-0.035	.86	-0.010	.82	-0.003	.36	-0.006	.98	-0.001	.15	+64.96	.93
S	+0.026	.64	-0.012	.90	+0.008	.78	0	0	-0.016	.97	+ 0.96	.03
Na	+0.053	.96	0	0	+0.013	.92	+0.001	.30	+0.022	.99	+2.13	.05
Cl	+0.056	.96	-0.005	.58	-0.002	.23	-0.007	.98	-0.007	.75	+2.88	.06
NN	-0.042	.94	-0.004	.46	+0.027	.99	-0.008	.99	+0.014	.96	-9.52	.29
PP	+0.014	.53	+0.001	.16	+0.005	.60	-0.001	.54	-0.001	.08	-25.52	.64
SS	-0.056	.98	-0.001	.16	+0.020	.99	+0.001	.59	-0.001	.08	-12.02	.38
NaNa	-0.067	.98	+0.003	.34	+0.010	.90	-0.006	.98	+0.014	.96	-30.64	.73
ClCl	+0.066	.98	+0.011	.70	-0.003	.38	-0.004	.97	-0.001	.08	+48.98	.89
NP	-0.004	.12	-0.014	.88	-0.003	.28	-0.005	.93	-0.006	.55	+12.56	.27
NS	-0.078	.98	-0.011	.78	-0.018	.96	-0.003	.75	-0.006	.55	+25.56	.52
NNa	-0.008	.24	+0.011	.78	-0.004	.42	0	0	-0.016	.94	+59.44	.86
NCl	-0.014	.40	-0.003	.30	-0.011	.86	+0.007	.98	+0.003	.35	-14.81	.30
PS	-0.013	.40	+0.006	.52	-0.004	.42	+0.004	.85	+0.018	.96	-33.94	.64
PNa	+0.044	.86	+0.007	.60	+0.010	.85	+0.006	.94	+0.008	.71	+52.19	.82
PCl	-0.029	.70	-0.007	.60	+0.015	.92	-0.003	.72	+0.012	.92	-44.06	.76
SNa	-0.038	.81	-0.001	.06	-0.008	.69	+0.002	.54	-0.012	.92	+45.44	.77
SCl	-0.018	.41	-0.018	.94	-0.005	.52	0	0	-0.003	.30	+13.81	.30
NaCl	-0.037	.80	+0.006	.60	+0.026	.99	-0.003	.78	+0.019	.96	-23.81	.50

to sodium application. The response of sugar beets to sodium application was influenced by the P-Na interaction (Fig.11). At high levels of phosphorus, application of sodium decreased the yield while at low phosphorus levels sodium application increased the yield. Similarly, phosphorus application gave the highest response when the level of sodium was low. However, at high levels of sodium, phosphorus decreased the yield. Thus, either sodium or phosphorus but not both needed to be high for high yield of sugar beet roots.

Sucrose concentration. Though sodium had slight positive direct effect on the yield of roots, it increased the sucrose concentration in roots (p=0.73) (Table 7). Data obtained by Hussieni (35) and Fuehring (20) indicated a depressing effect on sugar concentration due to addition of sodium. The positive sign for the N-Na interaction suggested that increasing nitrogen supply tended to intensify the increasing effect of sodium on percentage of sucrose.

Yield of sucrose. Sodium, as was shown by Hussieni (35), significantly increased the yield of sucrose (Table 5). Data by Fuehring (20) indicated a depressing effect. The N-Cl interaction proved to have an antagonistic relationship whereas, Na-P and Na-S were complementary. The response to sodium was appreciably affected by the sulfur and phosphorus supplies (Fig.9 and 10). These relationships indicated that sodium depressed the yield of sucrose when the sulfur or phosphorus levels were high.

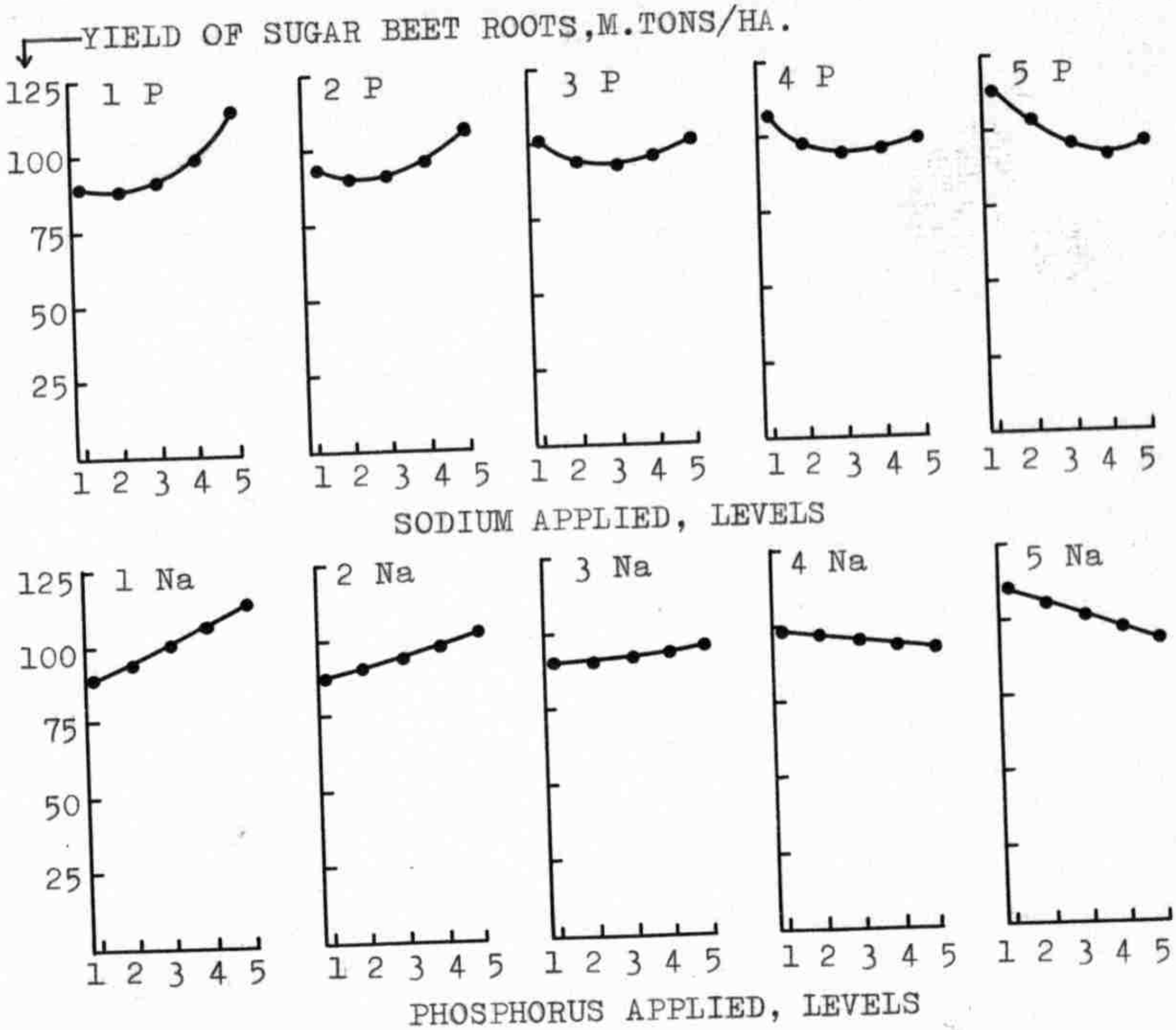

Fig. 11. Yield of sugar beet roots as affected by levels of applied Na at constant levels of applied P (above) and by levels of applied P at constant levels of applied Na (below). Levels of N,S and Cl were held constant at the middle level (3) of five levels of application.

Yield of tops. The negative sign for the regression coefficient indicated that sodium tended to depress the yield of tops (Table 5). All the interactions between sodium and other varied elements, as was found in the yield of roots, proved to have complementary relationships. The signs of the Na-S and Na-P interactions were negative for the yield of roots, yield of sucrose, yield of tops and sucrose percentage. This indicated that the higher application of sodium, under the conditions of this experiment, appreciably reduced the need for sulfur and phosphorus.

Size of leaves during growing season. The effect of sodium on the weight of 10 leaves (recently mature) was similar to its effect on the yield of tops (Table 5). The N-Na and P-Na interactions were shown to be complementary. The magnitudes of the Na-Cl and S-Na interactions on the size of leaves were found to be small (Table 5).

Effect of Sodium on the Chemical Composition of Sugar Beets

The mean seasonal sodium concentration of petioles (Table 11) showed a range of 1.83 to 5.29% on the dry basis. The sodium concentration of petioles was significantly increased by increasing levels of applied sodium (Table 10). Addition of sodium seemed to have a significant effect in depressing the potassium content of petioles (Table 10). However the decrease of potassium concentration in this experiment did not have a negative effect. This was suggested by the fact that addition of sodium had no depressing effect upon the yield of sugar (Table 5), but, on the contrary, resulted in an increase in yield of sugar. Also the complementary Na-P and Na-S interactions for the yield of sugar emphasized the beneficial effect of sodium, particularly at low phosphorus and sulfur levels. It should be noted that the potassium concentration of petioles (Table 11) was much above the critical level for potassium reported by Ulrich (68) and Magnitski (47). Thus, the data presented in this paper indicated that sodium had a specific influence on the yield of sucrose independent of the potassium content. The direct effect of sodium on the nitrate, magnesium, and phosphate concentrations of petioles was negligible. However, sodium tended to decrease the chlorine and to increase the sulfate concentration of petioles (Table 10). High levels of sodium caused a decrease in the calcium concentration of petioles. The Na-Cl interaction for the sodium concentration of petioles was complementary, whereas S-Na was antagonistic (Table 10).

The analysis of variance (Table 15) indicated that the proportion of the total treatment sum of squares accounted for by the quadratic regression equation was 86.3%, which indicated a close fit of the regression equation to the actual data. The sodium concentration of tops increased with the application of sodium, but the magnitude of the effect was not as great as in the case of sodium concentration of petioles (Table 8). Thus, in this experiment the sodium concentration of petioles appeared to be better indicator of the sodium status of the soil than that of tops. The total potassium concentration of tops was not appreciably affected by the increasing levels of sodium in the soil. Sodium tended to increase nitrogen and phosphate, and to decrease sulfate, chlorine, calcium and magnesium concentration of tops (Table 8).

Table 15. Analysis of variance for phosphorus, sulfur, sodium, chlorine, potassium, calcium and magnesium concentrations of tops (dry basis) as affected by various combinations of levels of N, P, S, Na and Cl.

Source	Total	Linear	Quadra-tic	Lack of fit	Error	C.V.	Equation suffi-ciency, %[1]
d.f.	31	5	15	6	5		
P, ppm.							
S.S.	5203568	925807	2743442	678293	856026	30.0	87.0
M.S.		185161	182896	113049	171205		
S, %							
S.S.	0.596	0.221	0.049	0.253	0.073	20.9	58.0
M.S.		0.044	0.003	0.042	0.015		
Na, %							
S.S.	10.68	0.633	5.741	1.468	2.839	22.2	86.3
M.Ss		0.127	0.383	0.245	0.568		
Cl, %							
S.S.	18.992	9.127	3.976	2.794	3.095	18.7	85.3
M.S.		1.825	0.265	0.466	0.617		
K, %							
S.S.	30.91	6.979	13.832	3.615	6.482	23.8	88.3
M.S.		1.396	0.922	0.603	1.296		
Ca, %							
S.S.	1.998	0.507	0.877	0.141	0.465	18.0	92.9
M.S.		0.101	0.059	0.025	0.093		
Mg, %							
S.S.	2.551	0.237	1.900	0.133	0.281	12.4	94.7
		0.047	0.127	0.022	0.056		

1. Percentage of total treatment sum of squares accounted for by the quadratic regression equation.

In general, the interactions between sodium and other varied elements for the sodium concentration of tops were small (Table 8).

The analysis of variance for the sodium concentration of the roots (Table 16) indicated that the linear effect was significant due to effect of sodium application. Though the direct effect of nitrogen and sodium on the sodium concentration of roots was positive, the N-Na relationship for the sodium content of roots (negative) indicated that, at high levels of sodium, the sodium concentration decreased with nitrogen application (Table 14). The sodium concentration of roots ranged from 0.05 to 0.23% on the dry basis (Table 17).

To summarize the overall effect of sodium from the results discussed above, it could be concluded that sodium tended to counter-balance the depressing effect of nitrogen on the sucrose percentage. Sodium application had a direct increasing effect on the yield of sucrose. Furthermore, as the sodium supply increased, the sulfur and phosphorus applications were less beneficial for the yield of sucrose.

Effect of Chlorine on Plant Growth and Sugar Accumulation.

Yield of roots. The regression coefficient (p=0.76) for the linear effect of chlorine indicated that chlorine tended to increase the yield of roots to an extent that was exceeded only by nitrogen (Table 5). The effect of chlorine was in agreement with the results obtained by other workers (10, 70). Buchner (10) showed that sodium and chloride were beneficial to sugar beet plants. However, chlorine increased the yield more than sodium. This suggested that sugar beet

Table 16 - Analysis of variance for potassium, calcium, magnesium, sulfur, sodium and phosphorus concentrations of roots (dry basis) as affected by various combinations of levels of N, P, S, Na and Cl.

Source	Total	Linear	Quadra-tic	Lack of fit	Error	C.V.	Equation suffi-ciency, %[1]
d.f.	31	5	15	6	5		
K, %							
S.S.	1.033	0.183	0.642	0.159	0.049	15.8	84.6
M.S.		0.037*	0.043	0.027	0.010		
Ca, %							
S.S.	0.0361	0.0065	0.0084	0.0165	0.0047	14.5	54.3
M.S.		0.0013	0.0006	0.0027	0.0009		
Mg, %							
S.S.	0.1124	0.0091	0.0406	0.0591	0.0036	10.8	47.4
M.S.		0.0018	0.0027	0.0099**	0.0007		
S, %							
S.S.	0.0078	0.0020	0.0047	0.0019	0.0004	15.9	89.8
M.S.		0.0004	0.0003	0.0003	0.0008		
Na, %							
S.S.	0.071	0.0224	0.0335	0.0117	0.0037	31.4	83.6
M.S.		0.0045*	0.0022	0.0020	0.0007		
P, ppm.							
S,S.	624471	110433	357183	66326	90529	25.0	89.5
M.S.		22087	23812	11054	18106		

* Statistically significant at the 5% level.

** Statistically significant at the 1% level.

1. Percentage of total treatment sum of squares accounted for by the quadratic regression equation.

Table 17. Observed potassium, calcium, magnesium, sulfur, sodium and phosphorus concentrations of roots (dry basis) as affected by various combinations of levels of N, P, S, Na and Cl.

Treatment levels					K	Ca	Mg	S	Na	P
N	P	S	Na	Cl	%	%	%	%	%	ppm.
2	2	2	2	4	0.47	0.27	0.24	0.040	0.06	658
4	2	2	2	2	0.54	0.26	0.40	0.047	0.19	320
2	4	2	2	2	0.35	0.22	0.24	0.035	0.07	709
4	4	2	2	4	0.47	0.20	0.25	0.031	0.08	538
2	2	4	2	2	0.53	0.25	0.38	0.038	0.10	439
4	2	4	2	4	0.40	0.20	0.25	0.052	0.05	441
2	4	4	2	4	0.41	0.21	0.25	0.027	0.06	450
4	4	4	2	2	0.34	0.20	0.29	0.014	0.11	496
2	2	2	4	2	0.31	0.16	0.30	0.035	0.18	219
4	2	2	4	4	0.68	0.29	0.35	0.049	0.18	317
2	4	2	4	4	0.64	0.22	0.35	0.020	0.19	535
4	4	2	4	2	0.63	0.20	0.32	0.030	0.11	756
2	2	4	4	4	0.84	0.18	0.34	0.017	0.08	359
4	2	4	4	2	0.49	0.22	0.33	0.026	0.06	511
2	4	4	4	2	0.77	0.23	0.28	0.063	0.13	633
4	4	4	4	4	0.62	0.16	0.29	0.033	0.12	652
5	3	3	3	3	0.55	0.18	0.44	0.032	0.23	652
1	3	3	3	3	0.47	0.20	0.35	0.020	0.11	399
3	5	3	3	3	0.53	0.20	0.38	0.032	0.11	465
3	1	3	3	3	0.94	0.22	0.25	0.075	0.11	450
3	3	5	3	3	0.50	0.17	0.42	0.068	0.10	539
3	3	1	3	3	0.41	0.23	0.31	0.061	0.12	492
3	3	3	5	3	0.36	0.25	0.34	0.044	0.22	471
3	3	3	1	3	0.40	0.18	0.31	0.029	0.12	411
3	3	3	3	5	1.14	0.22	0.32	0.030	0.10	810
3	3	3	3	1	0.75	0.28	0.23	0.054	0.12	709
3	3	3	3	3	0.51	0.25	0.26	0.050	0.10	597
3	3	3	3	3	0.74	0.24	0.28	0.047	0.08	651
3	3	3	3	3	0.61	0.20	0.27	0.041	0.09	406
3	3	3	3	3	0.55	0.18	0.22	0.063	0.07	587
3	3	3	3	3	0.66	0.19	0.23	0.060	0.13	329
3	3	3	3	3	0.67	0.18	0.23	0.059	0.05	642

plants are not only tolerant to chlorine, but perform better when chlorine is present. The sodium and chlorine requirement of sugar beets may explain partly the ability of the crop to grow fairly well in salt affected soils. The sign of the N-Cl interaction was positive (Table 5) indicating that the response to chlorine was great only at a high level of nitrogen. At low nitrogen levels chlorine reduced the yield (Fig.1). This relationship suggested that when the level of chlorine is high, nitrogen should be applied in relatively large amount.

Sucrose concentration. As in the case of nitrogen, application of chlorine tended to have a slight depressing effect on the sucrose percentage ($p=0.20$) (Table 7). The interaction terms between chlorine and other varied elements in this experiment were small. Here again, the positive N-Cl interaction for the yield of sucrose indicated that at high levels of chlorine the supply of nitrogen should be high.

Yield of tops. The overall linear effect of chlorine fertilization was a small tendency to increase the yield of tops ($p=0.32$) (Table 5).

Size of leaves during growing season. Though the linear effect of chlorine on the size of recently matured leaves tended to be negative ($p=0.51$), all the interaction relationships of chlorine with the elements studied tended to be positive (Table 5). This indicated a possible high requirement of chlorine for size of leaves when the supply of other elements was individually high.

Effect of Chlorine on the Chemical Composition of Sugar Beets

The mean chlorine concentrations of petioles were in the range of

2.79 to 8.08% on the dry basis (Table 11). These values are much higher than the critical chlorine concentration suggested by Ulrich (69), 0.4% on the dry basis. The data reported herein indicated that under the conditions of the experiment the critical level was considerably higher than 0.4% since the root yield was increased (p=0.76) by chlorine application. The chlorine concentration of petioles was significantly increased by chlorine fertilization (Table 10). This result is in agreement with many workers (40, 70). The overall linear effect of chlorine and the negative N-Cl interaction for the nitrate nitrogen concentration of petioles (Table 7) indicated that high levels of chlorine, at the higher levels of nitrogen, tended to depress the nitrate concentration of petioles. However, the overall effect of chlorine application was not depressing on the total nitrogen concentration of tops (Table 7), which showed that the decrease in nitrate concentration of petioles might have been due to greater assimilation of nitrate rather than to reducing the uptake of nitrogen from the soil. This view is further supported by the positive interaction relationship between chlorine and nitrogen for the yield of roots and tops. (Table 5). Furthermore, though the direct effect of nitrogen on chlorine concentration was negative, the positive N-Cl interaction for the chlorine concentration of plant tissue (petioles and tops) indicated that at high levels of chlorine increasing nitrogen resulted in an increase in chlorine concentration (Tables 8 and 10). And since, the increase in chlorine concentration in plant tissue was associated with an increase in yields (the antagonistic relationship between chlorine and nitrogen for yields of roots and tops) (Table 5 and Fig.1), it would be concluded that the beneficial effects of chlorine were better manifested at the higher levels of nitrogen.

The overall linear effect of chlorine was positive for calcium ($p=0.99$), potassium($p=0.99$) and sodium ($p=0.48$) concentrations of petioles (Table 10). The linear effect of chlorine on sulfate was negative, but the positive N-Cl interaction for sulfate concentration of petioles (Table 10) indicated that when nitrogen was at high levels, application of chlorine increased sulfate concentration of petioles. The phosphate and magnesium concentrations of petioles were little affected by chlorine.

Chlorine application tended to increase the potassium and reduce the calcium and magnesium concentrations of sugar beet tops (Table 8). The effect of chlorine was negligible on the phosphate, sulfate and sodium concentration of tops.

The overall response to chlorine as summarized from the data presented to this point, indicated that the sugar beet plant responded considerably to chlorine application particularly at high levels of nitrogen. When the supply of chlorine is high, nitrogen should be applied at high rates. This point may be of great practical importance on salt-affected soils.

CONCLUSIONS

The data presented up to this point indicated that the application of nitrogen markedly increased the yield of sugar beet roots, but tended to decrease the sugar percentage (Fig.12). In addition, associated with this great increase in yield of roots, the nitrogen concentration (on fresh basis) in the roots also increased (Fig.12). Round (52) reported a close relationship between the total nitrogen and reduced purity of sugar and a lower extraction of sugar from the sugar beet roots. Similarly, Goodban (23) showed that the purity of juice had an inverse relation to the nitrogen content of the beets. Therefore, the nitrogen application should be high enough to approach the maximum yield of sugar without any serious effect on the quality of the roots. In the sugar industry, producing good quality beets is nearly as important as the yield. The question arises, then, of how much nitrogen should be supplied to meet this requirement.

Before assaying the above question, it is preferable to estimate the best levels of the other varied elements. Then the amount of nitrogen required could be conveniently computed at the best levels of these elements studied.

Though the direct effect of phosphorus was positive, studying the interaction relationships indicated that the application of sodium and chlorine reduced the need for phosphorus (Table 5) (Fig.9 and 11).

Likewise, it was shown that at high levels of sodium and chlorine, the sulfur requirement was low (Table 5). Sodium had a positive effect on the sucrose percentage (Table 7), and the interaction relationships suggest that it counterbalanced the depressing effect of nitrogen on sugar percentage. Furthermore, it could be cheaply supplied in the form of salt (NaCl). The sugar beet plants responded appreciably to chlorine fertilization (Table 5). Also, the positive N-Cl interaction for yield of roots (Table 5) (Fig. 1) indicated that the response to nitrogen was greater at the higher levels of chlorine. By the trial and error method of placing various selected combinations of varied elements into the regression equation the possible combination for the best yield of sucrose was computed. The trial was limited to the range of fertilizers tested under the conditions of the experiment. Therefore, under the condition of the experiment the best combination of fertilizers would be:

-2 P or 11.35 Kg./ha.

-2 S or 11.35 Kg./ha.

+2 Cl or 617.0 Kg./ha.

+2 Na or 617.0 Kg./ha.

The chlorine, 617 Kg./ha., and part of the sodium, 400.0 Kg/ha., (in the ratio similar to that of common salt) required could be applied in the form of sodium chloride. The rest of the sodium, 217.0 Kg/ha., needed was calculated as sodium nitrate to make sodium up to the coded +2 level. Calculation indicated that the application of the additional sodium in the form of $NaNO_3$ resulted in an increase in yield of roots that would justify its application.

The fact that the P-Na and S-Na interactions on the yield of sucrose (Table 4) were complementary indicated that another possible combination might also be obtained if both sulfur and phosphorus were kept high, and sodium was low. The combination containing high phosphorus and sulfur was found to result in a slight increase in yield of sucrose (about 3%) over the combination containing high sodium. However, application of high sodium was justified, on the basis that it could be supplied more cheaply (as NaCl) than phosphorus.

Solving the regression equation for the combination of -2P, -2S, +2Na and +2Cl at different levels of nitrogen gave various yields of roots, which were plotted against the amount of nitrogen applied (Fig.12). The return above the cost of fertilizers, considering the value of tops and roots, was also presented in Fig. 12. The estimated local market price of tops and roots was reduced 10% to allow for the increased costs of digging, loading and transporting to the factory. The low levels of nitrogen resulted in the lowest yield of roots. The highest nitrogen level (617.44 Kg. of N/ha.) gave the largest yield of roots and return over fertilizers cost. Considering the quality of beets, the accompanying increase in nitrogen content of the roots (Fig.12) at the higher level of nitrogen probably reduced the quality, which might affect the net extraction of sugar. Goodban (23) stated that a beet nitrogen concentration above about 0.2% (fresh basis) appreciably dropped the maximum sedimentation rate that can be reached.

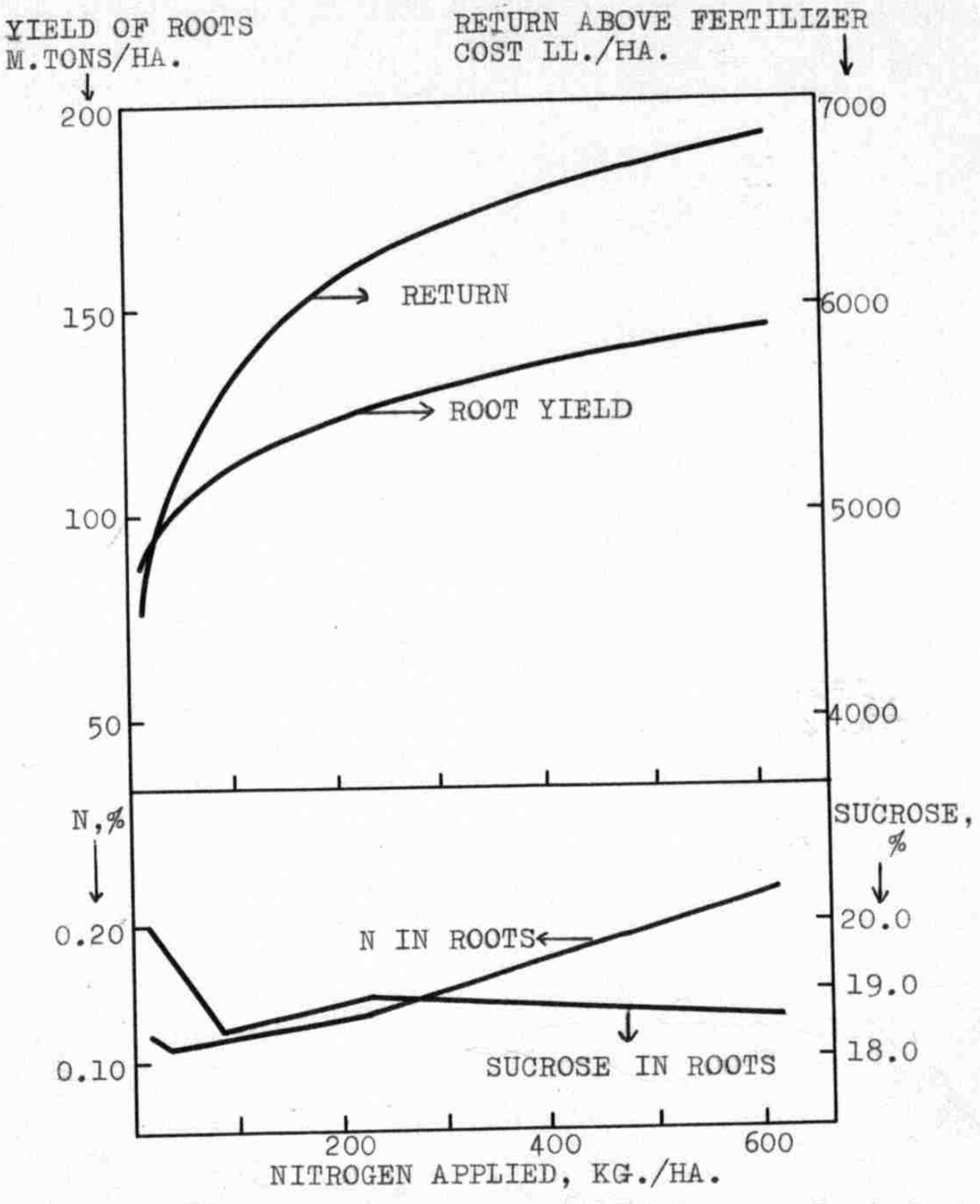

Fig. 12. Effect of nitrogen on yield of sugar beet roots and return above fertilizer cost. Data were calculated from the regression equation. Levels of P and S were held at the first level (1) and Na and Cl at the fifth level (5) of five levels of application. Prices used were beets at 49.50 LL./ton, tops at 90LL./ton (dry basis), N at 1 LL./kg., P at 1.45LL./kg., S at 0.45LL/kg. and NaCl at 0.15LL./kg. (upper graph). Nitrogen in roots and sucrose in roots,%, fresh basis, calculated from actual data (lower graph).

In clarification of sugar the combined action of heat and chemicals is to coagulate and precipitate part of the impurities of the juice. It is desirable that this process be accomplished at a certain maximum rate and this rate is decreased by a high nitrogen level in the beets.

In view of the above discussion, the most profitable rate of nitrogen application, under the conditions of the experiment, for grower and processor was estimated to be at the coded + 1.6 level (450 Kg. N/ha.) which resulted in the estimated yield of roots of nearly 136 tons/ha. with a nitrogen content of less than 0.2%. Also at this point the producer would get about two Lebanese pounds per pound spent for fertilizer, providing a margin of safety.

Considering 450 Kg./ha. the recommended rate of nitrogen application (for the yield of roots in the neighbourhood of 136 tons/ha.), a tentative critical level for nitrate-- nitrogen of petioles on the dry basis (Fig.4) for the growing season was calculated from the regression equations for nitrate levels (Appendix Table 20). The estimated critical value was 7420 ppm. for June 8, 1660 ppm. for July 4, 915 ppm. for August 8, and 750 ppm. for the September 12 sampling. The critical level estimated in this experiment compares fairly closely with Ulrich's 1000 ppm. (63) for most of the season.

Though the recommended rate of nitrogen was relatively high, it should be noted that the yields under the conditions of the experiment were much higher than commonly obtained. The suitable climatic condition of the Beka'a, Lebanon resulted in very high potential yield resulting in a higher than ordinary nitrogen requirement. Fife (18) indicated that if sugar beets, in fertile soils with an abundance of nitrogen, were grown under high light intensity no toxic nitrogenous compounds were formed. Whereas, under low light intensity "tip burn" was observed. Tolman (60) indicated that in long season areas the nitrogen requirement of sugar beets was higher than for short season areas. Furthermore, under the conditions of this experiment, the nitrogen content of plants near the harvest time dropped down to low levels (Fig.4) which did not adversely affect the quality of the roots (Fig. 12). Magnitski (47) showed also that the critical level of nitrogen changed according to the phase of the growth of the plants. In the experiment reported herein, when the calculated rate of nitrogen application was 450 Kg./ha., the sugar beet plants removed an estimated 367 Kg./ha. of nitrogen from the soil in tops and roots. This suggested a high utilization of nitrogen (81.5%) from the soil, which further justified the high nitrogen fertilization of sugar beets.

Magnitski (47) showed yields of roots in the range of 25-45 tons/ha. under Moscow conditions. Ulrich in California (68) reported yields of 29.0 tons per acre with an initial nitrogen application of 80 lbs. per acre and 160 lbs. as a side - dressing. Tolman (60) and Round (52) reported similar results. The higher root yields of this experiment were more than 50% greater than the reported California yields and about triple the Russian results. The data for sucrose concentration in the roots (Table 5) also indicated a relatively high sucrose concentration, even at the higher levels of nitrogen (16.1 to 20.7%). These high yields of roots and high sucrose concentration, aside from proper cultural practices, could be attributed to the favorable climatic conditions prevailing in the Beka'a, Lebanon. Ulrich (64, 65, 66) indicated that sugar beet plants subjected to low temperature for several weeks increased in sucrose concentration even though supplied with a high nitrogen level. Similarly, long days were also proved to be conducive to an increase in sucrose concentration, but the increase in sucrose concentration was not as great as the effect on the size of roots. Went (71) suggested that successful sugar beet production should involve early nutrient feeding at warm summer temperature for maximum growth followed by low nitrate in the sunny fall weather, with night temperatures dropping to near freezing. The thermal and light condition for sugar beet production were very favorable in the Beka'a (Table 18). July and August have warm sunny days and cool nights and October has very cool nights. Therefore, with proper cultural practices and adequate fertilization high yields of sugar beets would be expected.

Table 18 . American University Farm Air Temperatures (1962).

Temperature, Degree C.	July	Aug.	Sept.	Oct.
Average day time max.	32.5	34.0	31.4	24.5
Average night time min.	13.2	15.1	11.8	9.7
Max. for the month.	35.0	37.4	34.8	32.0
Min. for the month.	8.5	10.5	8.7	6.8
Mean sun hours	12:38	12:20	12:00	10:45

SUMMARY

Five elements nitrogen, phosphorus, sulfur, sodium and chlorine were applied to a calcareous soil in various combinations to determine the effect of each element individually and in combination with others on the yield and chemical composition of sugar beet plants. An economic analysis of the yield data was made to estimate the optimum combination of applied fertilizers at current local market values of beet roots, beet tops and fertilizers.

Nitrogen fertilization had a large positive effect on the yield, nitrate concentration of petioles and nitrogen content of roots. It has been established and reported by numerous investigators that sugar recovery in the factory is influenced adversely by a high nitrogen level in sugar beet roots (0.2% on the fresh basis was reported as about the highest permissible level by Goodban, 23). On the basis of 0.2% nitrogen in the roots, the maximum allowable level of nitrogen application was estimated to be 450 Kg./ha. for the yield of roots of about 136 m. tons/ha. Sulfur and phosphorus were held at the lowest and chlorine and sodium at the highest levels of application. It was estimated that sugar beet yields could be profitably increased up to the highest applied amounts of nitrogen, 617 Kg./ha. but the increase was small and the adverse effect on quality and sugar concentration of roots made such high application rates unwarrented. On the basis of 450 Kg./ha. of nitrogen application, the critical nitrate nitrogen concentration of

beet leaf petioles was estimated to be 7,420 ppm. for June 8, 1,660 ppm. for July 4, 915 ppm. for August 8, and 750 ppm. for the September 12 sampling. These values agree with the 1,000 ppm. nitrate nitrogen level established by Ulrich (63). The overall effect of nitrogen was shown to be depressing on the chlorine concentration of tops and petioles and on the potassium and phosphorus concentrations of petioles. The sodium concentration of petioles was shown to decrease with increasing levels of nitrogen.

Sodium tended to increase yields, especially at low levels of phosphorus and sulfur. Yield response to phosphorus and sulfur, particularly at higher levels of sodium, were found to be small. Thus high levels of sodium, rather than high levels of sulfur and phosphorus, were recommended because sodium could be more cheaply supplied. Chemical analysis of petioles revealed that the concentrations of extractable phosphate and sulfate were much above the critical levels established for these elements by Ulrich (68) which indicated that the levels of available phosphorus and sulfur in the soil were probably sufficient for the normal growth of plants. Phosphorus application had a positive effect on the extractable phosphate of petioles and total phosphorus concentration of tops. Increasing levels of phosphorus increased the sodium and decreased the potassium concentration of petioles. Sulfur application was shown to have an increasing effect on the sulfate concentration of petioles and total sulfur concentration of tops. The phosphate and potassium concentrations of petioles were also increased by sulfur application. An inverse relationship between the sodium and potassium concentrations of petioles was indicated in that high levels of sodium reduced the potassium concentration. However, the potassium concentration of petioles was considerably above the critical level reported by Ulrich. The calcium concentration of petioles was also reduced by sodium application.

Chlorine application resulted in increased sugar beet yield particularly at the higher levels of nitrogen application. Application of chlorine significantly increased the chlorine concentration of the plant. Also chlorine had a direct positive effect on the potassium content of petioles.

The very high yield of sugar beets obtained under the condition of this experiment, aside from adequate cultural practices, were attributed to the suitable soil and climatic conditions prevailing in the Beka'a, Lebanon. The high requirement for nutrients found in the study was due to the high yield level attained.

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APPENDICES

Table 19. Observed nitrate nitrogen concentration of petioles of recently mature leaves for four sampling dates (dry basis, ppm.) as affect by various combinations of levels of N, P, S, Na and Cl.

Treatment levels					Sampling dates			
N	P	S	Na	Cl	June	July	Aug.	Sept.
2	2	2	2	4	375	180	296	220
4	2	2	2	2	8160	2778	1237	1000
2	4	2	2	2	876	235	1070	650
4	4	2	2	4	3100	850	2695	1202
2	2	4	2	2	1000	483	347	415
4	2	4	2	4	7142	300	874	507
2	4	4	2	4	780	100	764	400
4	4	4	2	2	7788	1080	383	531
2	2	2	4	2	423	180	307	190
4	2	2	4	4	4608	250	378	295
2	4	2	4	4	1134	155	210	150
4	4	2	4	2	8750	455	691	470
2	2	4	4	4	475	430	476	300
4	2	4	4	2	6000	800	100	352
2	4	4	4	2	675	100	329	195
4	4	4	4	4	1825	150	328	239
5	3	3	3	3	10525	7180	3479	1998
1	3	3	3	3	100	100	100	100
3	5	3	3	3	230	200	100	150
3	1	3	3	3	954	100	100	100
3	3	5	3	3	100	100	100	100
3	3	1	3	3	100	100	100	100
3	3	3	5	3	6458	3000	304	495
3	3	3	1	3	1000	400	688	498
3	3	3	3	5	408	500	100	100
3	3	3	3	1	110	250	100	160
3	3	3	3	3	1900	240	548	250
3	3	3	3	3	822	200	219	210
3	3	3	3	3	611	250	194	185
3	3	3	3	3	560	240	100	160
3	3	3	3	3	877	250	100	168
3	3	3	3	3	1206	375	100	100

Table 20. Regression coefficients (b) and the probability of a true effect (p) for the nitrate nitrogen concentration of petioles of recently mature leaves for four sampling dates (dry basis, log ppm.) as affected by various combinations of levels of N, P, S, Na and Cl.

Coefficient	June		July		August		September	
	b	p	b	p	b	p	b	p
Mean	2.864		2.412		2.159		2.192	
N	+.468	.99	+.306	.99	+.172	.96	+.188	.99
P	-.043	.65	-.045	.94	+.055	.60	+.024	.58
S	+.021	.38	-.025	.78	-.066	.68	-.023	.54
Na	+.038	.61	-.009	.38	-.155	.95	-.112	.99
Cl	-.014	.27	-.070	.98	+.030	.38	-.050	.86
NN	+.102	.96	+.124	.99	+.205	.98	+.148	.99
PP	+.017	.35	-.071	.99	+.012	.16	+.008	.24
SS	+.026	.48	-.108	.99	+.012	.16	-.015	.42
NaNa	+.201	.99	+.152	.99	+.177	.98	+.159	.99
ClCl	-.078	.91	+.029	.86	+.012	.16	+.010	.30
NP	-.091	.86	+.053	.92	+.012	.12	-.006	.14
NS	-.028	.40	-.067	.98	-.138	.88	-.083	.94
NNa	-.019	.30	-.094	.99	-.077	.65	-.024	.49
NCl	-.065	.73	-.113	.99	+.137	.88	0	0
PS	-.069	.78	-.079	.98	-.041	.40	-.068	.92
PNa	+.026	.38	-.039	.83	-.027	.26	-.056	.84
PCl	-.021	.30	+.047	.91	-.023	.22	+.008	.18
SNa	-.091	.86	+.063	.96	+.036	.36	+.038	.66
SCl	-.010	.16	-.023	.64	+.127	.83	+.039	.66
NaCl	+.057	.70	+.089	.99	-.014	.16	+.005	.11

Table 21. Analysis of variance for nitrate nitrogen concentration of petioles of recently mature leaves for four sampling dates (dry basis, log ppm.) as affected by various combinations of levels of N, P, S, Na and Cl.

Source	Total	Linear	Quadra-tic	Lack of fit	Error	C.V %	Equation Sufficiency, %[1]
d.f.	31	5	15	6	5		
June							
S.S.	9.988	5.354	1.504	2.434	0.195	6.7	74.3
M.S.		1.071**	0.100	0.409*	0.039		
July							
S.S.	6.428	2.432	2.683	1.273	0.039	3.7	80.2
M.S.		0.486**	0.179**	0.211**	0.008		
Aug.							
S.S.	6.080	1.489	2.990	1.169	0.435	13.2	80.8
M.S.		0.300	0.199	0.195	0.087		
Sept.							
S.S.	3.578	1.233	1.625	0.628	0.092	6.1	82.5
M.S.		0.247**	0.108 *	0.105 **	0.018		

* Statistically significant at the 5% level.

** Statistically significant at the 1% level.

1 Percentage of total treatment sum of squares accounted for by the quadratic regression equation.