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

by

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ABSTRACT

The effects of N, P, S, Cl, Na and B and their interactions on the yield and chemical composition of sugar beets were studied in an irrigated field experiment. A central composite, rotatable, incomplete factorial design including 6 variables, each at 5 levels was used.

The yield of beets was relatively high with an average of 102.3 and a maximum of 147.8 metric tons per hectare indicating that with good management there is a high potential for sugar beet production in the area. In general, N, P and Na had positive effects on the yield of beets with the relative magnitudes in that order. Sugar beet yields could be increased up to the highest applied amount of nitrogen (782 kg. per ha.) especially at high level of P and Na applications due to the positive N-P and N-Na interactions. However, the increase in yield above an application rate of about 300 kg. per ha. of N was associated with a decrease in the processing quality and in the sucrose percentage of the beets. The approximate optimum rate of application for P and Na (for a predicted yield of about 191 metric tons per ha.) were 600 and 300 kg. per ha., respectively. Application of S, Cl or B was detrimental to yields with B and S having the most adverse effects due to their negative first order effects as well as the negative N-S, P-S, S-Na, N-B, P-B and Na-B interactions on the yield of beets and sucrose. These results indicated that these three elements should not be applied under the conditions of this experiment.

Application of N increased the yield of tops, total N percentage in tops and nitrate-N concentration in petioles and decreased the sucrose percentage in roots significantly.

In general, petiole analysis was a good means for assessing the

nutrient status of the growing plants especially for the nitrate-N and phosphate-P concentrations of petioles. The critical levels of nitrate-N were estimated to be 3,400 ppm. at 3 months after planting, 1,800 ppm. at 4 months and 1,100 ppm. at 5 months and later in the season (dry basis). The critical level of phosphate-P concentration in petioles was estimated to be about 1,600 ppm. at four months after planting and later in the season. The critical level for Na percentage in the petioles was 1.73 per cent (dry basis) at four months.

It was concluded that the method of using quadratic regression equations to evaluate the data for 6 variables, each at 5 levels, was efficient and effective.

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INTRODUCTION

The increase in world population requires greater total sugar production. Sugar beets are the major source of sugar in much of the Middle East area where the climate is not suitable for sugar caneproduction. Sugar beet production in the Beqa'a plain of Lebanon is inadequate to supply the only sugar factory to capacity. Average yield in 1963 was only 35 m. tons/ha. although experimental yields of three times this amount have been readily attained in the region. The reason for the low average yield is partly nutritional and partly due to poor irrigation and cultural practices.

In general, it is realized that sugar beet growth and sugar production are dependent upon an adequate supply of N. However, excessive N is usually associated with a decline in sugar processing quality and sucrose concentration. Sugar beet response to P and S applications under the Beqa'a conditions has been irregular and more study is needed. Although Na is not considered an essential element for plant growth, sugar beets have been reported to respond to Na application. Sugar beets require B in adequate amounts and excess B may be toxic. High Cl levels have been reported to be toxic to many crops. However, many workers have found that sugar beet plants can use chlorine to their advantage. Various interaction among nutrients on sugar beet growth have been reported and more work is needed on nutrient balance especially with regard to possible excessive amounts since many arid region soils and irrigation waters contain large amounts of various elements such as Ca, Na, S and Cl.

The purpose of the experiment reported here was to study the interrelationships and direct effects of N, P, S, Cl, Na and B on the yield and composition of sugar beets in the field and to obtain further information regarding the optimum rates of fertilizer application by using a rotatable, central composite, incomplete factorial design. The use of this design with six variables in a field experiment has never been reported.

REVIEW OF LITERATURE

From the 19th century up to the present time, the importance of sugar beet production has increased progressively. Intensive work and investigation have been conducted in Europe and later in the U.S.A. to find the best methods of planting and management of sugar beet fields. As a result, about one third of the present world sugar production is from sugar beets. The following review summarizes some of the nutrition studies including the most recent reported investigations on sugar beet nutrition.

Effect of Nitrogen

Nitrogen is an essential element for the growth of all plants, including sugar beets. Tolman and Johnson (48), Magnitski (37), Boawn et. al. (10), Adams (2), Loomis and Nevins (35), Hedlin and Schreiber (26), Peyer (39), Hussieni (28), Hashimi (25) and others have reported that N applications increased the root and top growth of sugar beets and according to Baird (7) N encouraged top growth more than root growth.

Stout (47) noted that the use of high amounts of N was always associated with both a high root yield and a decline in root processing quality. Hill (27), Ogden et. al. (38), Adams (1), Loomis and Nevins (35), Hussieni (28) and Hashimi (25) pointed out that excessive N applications reduced the sugar percentage of beets and the purity of beet juice. Stout (47) indicated that the reduction in sugar percentage due to high N application was due to increased leaf growth resulting in a high N requirement and the expenditure of stored sugars for the intake and reduction of the nitrate-N. He also noted that the decline in sugar percentage was more often due to the improper timing of nitrate uptake than to total nitrate uptake. Sugar beets receiving heavy N applications late in the season had much lower sugar percentages and were higher in Na, K and amino-N than normally fertilized sugar beets. Dimitrov and Atanasov (17) showed that PK applications decreased the content of harmful nitrogenous impurities in sugar beets.

Adams (1) stated that low quality beets were not desired for processing, because a high content of nitrogenous compounds decreased sugar extraction in the factory. Goodban et. al. (21) suggested that when the N content was higher than 0.20% (fresh basis), the quality of sugar beets was impaired.

Ulrich (52) found that the critical level for N was 1,000 ppm. of nitrate-N in the petioles of recently matured leaves in the field (dry basis). Haddock (23) showed a close relationship between N fertilization and nitrate-N content of petioles. He found that when nitrate-N of petioles fell below 1,000 ppm. (dry basis) in August, the yield tended to be adversely affected. When more than 1,000 ppm. was present in October, root quality was lowered. The best results were obtained when nitrate-N in petioles dropped below 1,000 ppm. by mid-September. Magnitski (37) reported that the critical levels for nitrate-N, under Moscow conditions, was 500 ppm. (fresh basis) early in the season and 10 ppm. (fresh basis) late in the season.

Goodman (22) studied the effect of different soils on the growth and composition of sugar beets and found that soils on limestone had limited P and K availability. He also noted that in most soils N applications limited the availability of P and decreased the P concentration of petioles.

Effect of Phosphorous

The response of sugar beets to phosphorous applications is highly variable. Adams (2) conducted 49 field studies and reported that the response of sugar beets to P was small as compared to the response to N. Carlson and Herring (11) found no response of sugar beets to P on the locations where sodium bicarbonate soluble P_2O_5 was 83-89 ppm. A response to P was obtained in one location where the P_2O_5 was 8.3 ppm.

Davis et al. (16) indicated that the addition of 200-800 lbs. of P_2O_5 per acre to a calcareous loam soil markedly increased the yields and P content of beets and resulted in earlier growth. Haddock (24) used 25 ppm. of sodium bicarbonate soluble P as the minimum level of available P for the proper growth of sugar beets in calcareous soils. Baird (7) and Black (9) noted that P increased the growth of roots more than that of tops. Hussieni (28) and Hashimi (25), under the Beqa'a conditions, reported a slight increase of beet tonnage due to P application. Davis et al. (16) indicated that increased P application increased the gross yield of sugar, but had no significant effect on the percentage of sucrose or the apparent purity of beet juice. Stefan et al. (46) and Dimitrov and Atanasov (17) found that P improved the quality of sugar beets by decreasing the effect of harmful N.

Stefan et al. (46) noted that the P content of leaves decreased and the P content of beet roots increased as the season advanced. George (19) and Alexander et al. (4) indicated that N applications decreased the level of P in the tissues. They also indicated that the decline in P in the plant tissue with time was more gradual in contrast to N. Russel and Dubetz (41) reported that the addition of P resulted in a high P content of the beet roots.

Ulrich (51) recommended 750 ppm. of phosphate-P as the critical level for P in sugar beet petioles. The same report indicated that fields testing above this level for the entire growing season did not respond to P fertilizer while fields testing below this level for a few weeks during the growing season responded to P fertilizer. Davis et al. (16) reported that the highest yield required an extractable P content in petioles not lower than 0.15% (dry basis) throughout the growing season. Magnitski (37) noted that the critical level for petiole-P was 40 ppm. (fresh basis) at the begining of the season, then dropped to 25 ppm. late in the season.

Effect of Sulfur

The sulfur nutrition of sugar beets has not been studied extensively because there are very few cases of obvious S deficiency. This is probably due to the frequent addition of S to the soil from superphosphates ammonium sulfates, mixed fertilizers, irrigation water and atmospheric S compounds in adequate amounts for successful plant growth (15, 20). Jensen (30) pointed out that the quantity of S added by precipitation is uniformly distributed in Denmark with an average of about 13 kg. per ha. annually. Freney et al. (18) indicated that in south-eastern United States the average amount of S added by rain was 5.4 lb. per acre per year.

Tolman and Stoker (49) found a high positive interaction between S and N. They indicated that S applications had no effect on plants when N was not applied and the response to N application was much greater when S was added. Kalinevich (33) suggested that the interaction between N and S could be due to the interchange of sulfate and nitrate in certain plant processes as a result of the similarity between the reduction of sulfate and nitrate.

Freney et al. (18) reported that the rates of N and S mineralization from soil organic matter were nearly alike. They also pointed out that in calcareous soils, sulfate could be found not only as $CaSO_4$ but also in the form of insoluble salts and co-crystallized impurities with calcium carbonate. These insoluble sulfate salts accounted, on the average, for two thirds of the total soil S and decreased the available S for plant use.

Ulrich (51) recommended the determination of S in leaf blades rather than petioles as a means of evaluating the S status of sugar beet plants and as a reflection of the S status of the soil. He estimated the critical level for sulfate-S concentration of leaf blades to be 250 ppm. (dry basis)

Effect of Chlorine

According to Johnson et al. (31) sugar beets can use Cl to some advantage and cannot tolerate a great deficiency of Cl. Wood and Nelson (55) showed that NH_4Cl increased the top growth of sugar beets more than NH_4SO_4 and Sirochenk (44) found that KCl increased leaf and root growth more than K_2SO_4. Under the conditions of the Beqa'a plain, Hashimi (25) obtained an appreciable increase in beet yields due to Cl application and a slight depressing effect on sucrose percentage. Ulrich and Okhi (54) indicated that Cl was necessary for top and root growth in sugar beets but only up to a certain rate. High rates of Cl application had a depressing effect on sucrose concentration while the size of roots was not affected. Kretschmer et al. (34) noticed that increasing Cl concentration of the substrate resulted in a linear increase in the Cl content of sugar beets and a decrease in the N content of the plant.

Ulrich et al. (53) reported that the Cl content of the petioles ranged from 0.01 to 8.5 per cent (dry basis) and estimated the critical level of Cl in the petioles of sugar beet plants to be 0.4 per cent (dry basis).

Effect of Sodium

Sodium is an important element for sugar beets. Applications of NaCl or $NaNO_3$ have increased the yield of sugar beets (3, 28, 42, 43 and 50).

Adams (3) used plant composition data to show that Na did not replace K in the soil but had a specific effect in increasing the yield and Na content of the foliage. Sayre and Shaffer (42) and Magnitski (37) reached a similar conclusion after finding that the specific effect of Na could not be replaced by K. Adams (3) reported a negative interaction between Na and K on the yield of sugar beets. He obtained greater yields from Na than from K applications and indicated that Na increased the effect of N application. On the basis of his findings he concluded that, for sugar beets, Na is the most important element after N and that in many cases it is not economical to apply K in the presence of Na. Sayre and Shaffer (42) pointed out sodium increased the yield of sugar per acre, particularly when soil K was within the normal range.

Effect of Boron

Plants vary greatly in their B needs and in their sensitivity to high B concentration. Sugar beets require relatively large amounts of B (13).

Powers (40) reported that the B contents of the surface 8 inches of soils ranged between 1.5 ppm. in peats to 9 ppm. in silty clay loams.

Water analysis indicated B contents ranging from very low to high enough to prevent B deficiency in many crops. Berger (8) found that sugar beets did not respond to B fertilizers when the soil contained more than 2 lb. per acre of available B.

Heart rot of sugar beet is the main symptom of B deficiency. Cook and Miller (13) reported that there was no correlation between the appearance of heart rot and the B content of the surface soil but there was correlation between the appearance of heart rot and the active calcium content of the soil. They also found that calcium and magnesium carbonates were very effective (while sodium carbonate had no effect) in preventing toxicity of borax by fixation into unavailable forms. Amberger (5) pointed out that both deficiency and excess of B led to an increase in the respiration rate while an optimum B supply resulted in an increased production of sugar and lower content of amino acids in sugar beets.

Cook and Miller (14) stated that borax applied at the rate of 20 lb. per acre as a side dressing on a Wisner silt loam soil reduced the number of beets showing heart rot symptoms from 96.8 to 11.36 per cent and increased yields from 7.16 to 14.30 tons per acre. Furthermore, the borax applications increased sucrose contents from 14.11 to 18.02 per cent, and purity from 80.92 to 84.91 per cent. Borax applications also increased the B content, and reduced the nitrogen content of the sugar beet roots. Similar results were obtained when borax application rates were doubled.

Yang (56) indicated that leaf analysis can be used as a guide for borax applications and reported that leaves containing 20 ppm. showed B deficiency symptoms while leaves containing 40-65 ppm. were normal.

MATERIALS AND METHODS

Five macronutrient elements, N, P, S, Cl and Na and one micronutrient element, B, were varied at five different levels in an experiment on an irrigated calcareous soil at the Agricultural Research and Education Center (AREC) of the American University of Beirut located in the Beqa'a Plain, Lebanon. A central composite, rotatable, incomplete factorial design (Plan 8A.7 with 54 plots in three blocks, Cochran and Cox, reference 12) was chosen to study the main effects and the interactions of the various elements on the yield, growth and composition of sugar beets. The rates of each element were varied according to the logarithmic scale to base 2 in order to cover a wide range of application and to straighten the response curves (table 1). The rates were coded as -2.366, -1, 0, +1 and +2.366 to simplify the calculation of the regression equations. The coded 0 level was set to supply a medium quantity of each element. The coded -2.366 level was assumed to be a possible deficiency

Table 1. Rate of applications of the macro-elements (N, P, S, Cl, Na) and the micro-element (B).

Level of application	Coded levels	Rate of application, kg/ha.	
		Macro-elements	Micro-element
1	-2.366	29	7
2	-1	75	18
3	0	150	36
4	+1	300	71
5	+2.366	782	185

rate and +2.366 a possible excess rate. There were 45 treatments with one of them repeated ten times and distributed at random in order to estimate the experimental error (appendix, table 6).

The carriers used were commercial grades of $NaNO_3$ and NH_4NO_3 for N; $Ca(H_2PO_4)_2$ for P; $CaSO_4$ and $Ca(H_2PO_4)_2$ (2% S impurity) for S; NaCl and $CaCl_2$ for Cl; $NaNO_3$, $NaHCO_3$ and $Na_2B_4O_7 \cdot 10\,H_2O$ for Na; H_3BO_3 and $Na_2B_4O_7 \cdot 10H_2O$ for B. All these carriers were analyzed and their amounts were varied in order to supply the required amount of each element. It was not possible to hold the level of Ca constant but the experimental area contained about 15 per cent $CaCO_3$ and so it was expected that the effect of any additional Ca present in the carriers would be negligible.

On March 24, 1963, 54 plots were established. Each plot consisted of 3 rows, 8 m. long and 0.5 m. apart. The fertilizers were spread by hand in furrows. The ridges were split and packed to cover the fertilizers with about 10 cm. of soil. Seeds of the Kleinwanzleben variety were planted with a Planet Jr. seeder on the top of the ridges above the fertilizer at a depth of about 3 cm.

The experimental area was irrigated weekly using sprinklers during the first month and by furrow irrigation later on.

Leaf-hoppers, aphids and powdery mildew were controlled throughout the season by spraying as needed.

Thinning was started on April 26, 1963 and was completed on May 17, 1963, leaving an average of 5 plants per meter.

Petiole samples of 15 recently matured leaves, picked at random from the middle row of each plot, were taken at the following dates: June 26, August 10, September 21 and November 2, 1963. Petioles were washed with tap water followed by distilled water to remove soil and dust contamination. Samples were then dried at 65-70°C for 48 hours, ground in a Wiley mill using a 40 mesh screen and stored in plastic bags prior to chemical analysis.

On November 14, 1963, beets from seven m. of the middle row of each plot were harvested and values for fresh weights of tops and roots and number of beets were recorded. Samples of tops and roots were taken for chemical analysis and moisture determinations.

Petiole Analysis

1. Nitrate-nitrogen: The nitrate-N concentration of water extracts of petioles was determined by the phenol-disulphonic acid method (32).

2. Phosphorus, acid soluble: 2 per cent acetic acid soluble phosphate was determined with the chlorostanous - reduced molybdophosphoric blue color method (32).

3. Sulfur, acid soluble: 2 percent acetic acid soluble sulfate was determined by the turbidimetric method (29). The extract was digested with hydrogen peroxide to remove coloration.

4. Chlorine, water soluble: The chlorine concentration of water extract of petioles was determined by the Mohr method (32). Activated carbon was used to decolorize the solution.

5. Sodium: Na was determined in the nitric-perchloric extracts using a Beckman D.U. emission spectrophotometer (29).

6. Boron: B was determined in the petiole after dry ashing at 550°C using the Curcumin method of Dible *et al.* (32).

Analysis of Tops and Roots

1. Total nitrogen: Total N was determined in both roots and tops

by the Kjeldahl method (29).

2. Sugar analysis: Sucrose concentrations in roots were determined by the A.O.A.C. method (6).

Statistical Analysis:

The statistical analysis was done according to the method described by Cochran and Cox (12). Regression equations of the quadratic form for yields and element concentrations were computed from the collected data. The following equation was used: $Y = b_0 + b_1x_1 + b_2x_2 + b_3x_3 + b_4x_4 + b_5x_5 + b_6x_6 + b_{11}x_1^2 + b_{22}x_2^2 + b_{33}x_3^2 + b_{44}x_4^2 + b_{55}x_5^2 + b_{66}x_6^2 + b_{12}x_1x_2 + b_{13}x_1x_3 + b_{14}x_1x_4 + b_{15}x_1x_5 + b_{16}x_1x_6 + b_{23}x_2x_3 + b_{24}x_2x_4 + b_{25}x_2x_5 + b_{26}x_2x_6 + b_{34}x_3x_4 + b_{35}x_3x_5 + b_{36}x_3x_6 + b_{45}x_4x_5 + b_{46}x_4x_6 + b_{56}x_5x_6$.

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 Cl

x_5 = coded level of Na

x_6 = coded level of B

Analysis of variance of the collected data was performed and the "F" test was used to find the significance of linear, quadratic and lack of fit terms. The percentage of equation sufficiency and the coefficient of variance were calculated. The "t" test was used to evaluate the significance of the individual regression coefficients. An IBM 1401 computer was used for the computations.

RESULTS AND DISCUSSION

Interrelationships of applied N, P, S, Cl, Na and B on the yield of roots, tops and sucrose, N and sucrose percentages of roots and the chemical composition of tops and petioles of sugar beet plants were studied in a field experiment on an irrigated calcareous soil. A central composite, rotatable, incomplete factorial design was used because it permits the calculation of regression equations in the quadratic form. A positive sign of the regression coefficient of the first order term for an element indicates an increasing effect of that element on the property studied, while a negative sign indicates a depressing effect of that element. The magnitude of the regression coefficient of a squared quadratic term indicates the degree of curvature of the response to that variable and the sign shows whether this curvature is concave upward, positive, or concave downward, negative. A positive sign for the interaction quadratic term of two elements indicates that the positive response of the property under study to one of the varied elements increases as the second element is increased, while a negative sign denotes a decreasing positive response to the varied element as the second element is increased. In evaluating the regression coefficients the "t" test was used. In this manuscript, the term "significant" will be used to indicate at least the five per cent level of statistical significance while "highly significant" will indicate at least the one per cent level.

Results of Soil and Water Analysis

The results of soil analysis (table 2) as found by Soltanpour (45) indicated that the total N supply of the soil was low and the level of available P was medium while the results of irrigation water analysis showed that the water used was of very good quality.

Table 2. Results of chemical analysis of the surface soil for the experimental area and of the irrigation water. Soltanpour (45).

Soil Analysis		Water Analysis	
pH (1:2.5 soil-water ratio)	8.1	Na	0.282 me./1.
Calcium carbonate, %	15.0	Ca	0.705 "
Organic matter (wet oxidation), %	1.22	Mg	0.833 "
Total N, %	0.061	K	0.056 "
P (bicarbonate-soluble)	18 ppm.	S	0.125 "
Ammonium	(K 1.95	Cl	0.318 "
Acetate	(Ca 40.00	Electrical conductivity 0.155 m.mho/cm. at 25°C.	
Soluble me./100 g.	(Na 0.58		

Effect of Fertilizer Treatments on Root Yield

Root yields ranged between 59.6 and 147.8 with an average of 102.3 metric tons per ha. (appendix table 6). Study of the regression coefficients (b) and their standard errors (s_b) (table 3) indicated that N was the only applied element showing a significant positive first order effect on root yields indicating that increasing the rate of N application increased the yield of roots. These results are in agreement with those obtained by Hussieni (28) and Hashimi (25) under similar experimental conditions and with many other workers (2, 10, 26, 35, 37, 39, 48). The positive signs of the first order regression coefficients of P, Na and Cl indicated that there was a tendency for these elements to increase the yield of roots with P having the greatest effect. Davis et al. (16) indicated that the addition of 200-800 lbs. of P_2O_5 per acre to a calcareous soil markedly increased the yield of beets. Application of S tended to decrease root yields and B had a significant negative first order effect on root yields indicating that application of B under the conditions of this experiment was detrimental.

Among the squared terms NN and NaNa tended to have negative effects on the yield of roots indicating that at high rates of application, N and Na had less tendency to increase the yield of roots than at lower application rates. The PP term was positive indicating a tendency for the positive response to P to become greater as the application rate increased.

Although none of the regression coefficients of the interaction terms were of sufficient magnitude to be statistically significant, the N-P and N-Na terms were of considerable magnitude and positive indicating a tendency for higher yield response to N as the P or Na levels were increased (figure 1-2). Similar findings were obtained by Hussieni (28) but Hashimi (25) found that the N-Na interaction had a small negative effect of root yields. The negative N-S interaction indicated that the yield response to N decreased when the S levels were increased (figure 3). A similar result was obtained by Hashimi (25). The negative S-Na and Cl-Na interactions indicated a tendency for the positive yield response to Na to become less as the S or Cl levels were increased (figure 4-5). However, there is a suggestion that at low Na levels Cl application could increase beet yields (figure 5).

Considering the above effects of the elements on the yields of

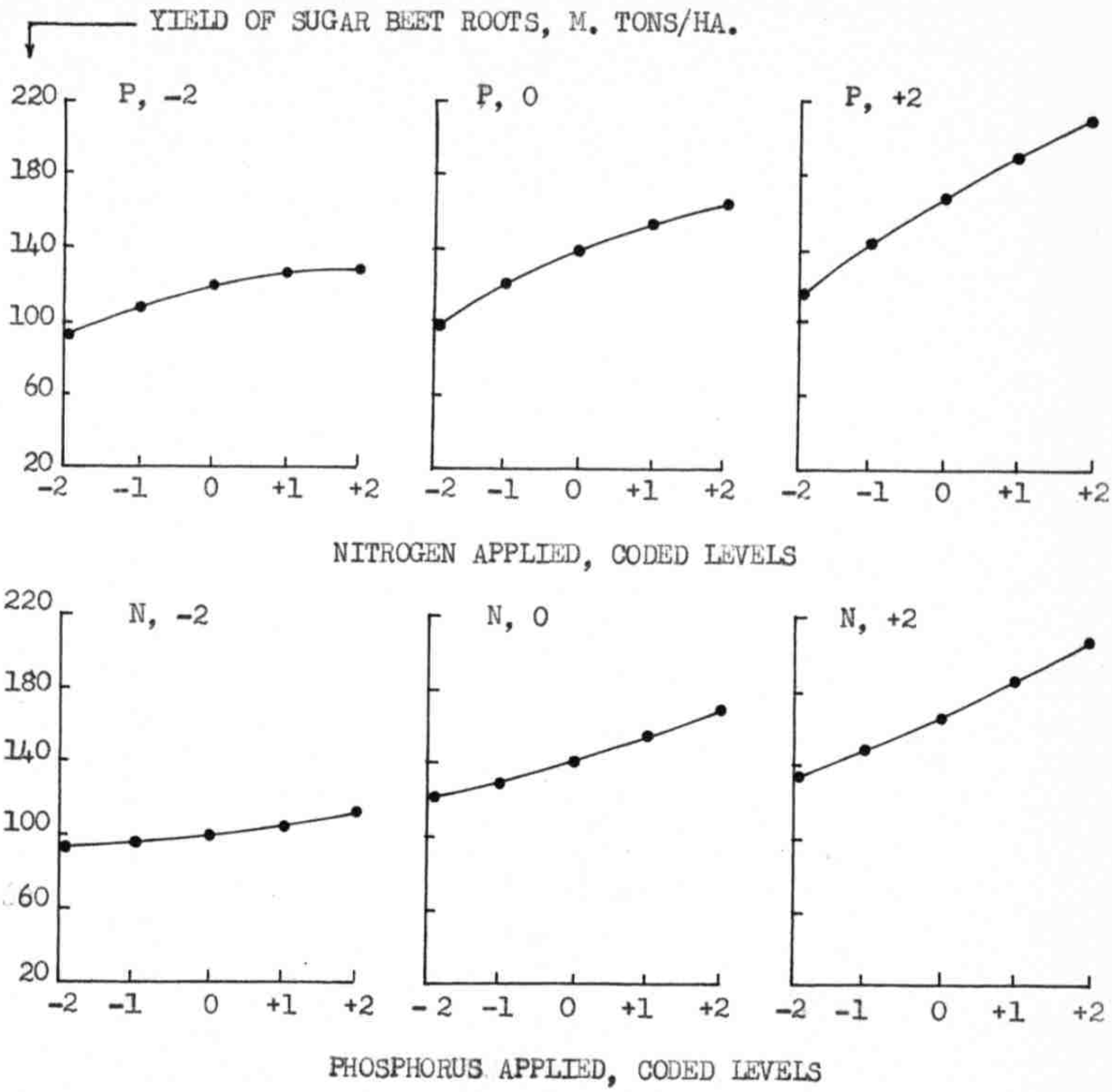

Fig. 1. Yield of sugar beet roots as affected by levels of applied N at constant levels of applied P (above) and by levels of applied P at constant levels of applied N (below). S, Cl, Na and B were held at the -2, -2, +1, and -2 levels of application, respectively.

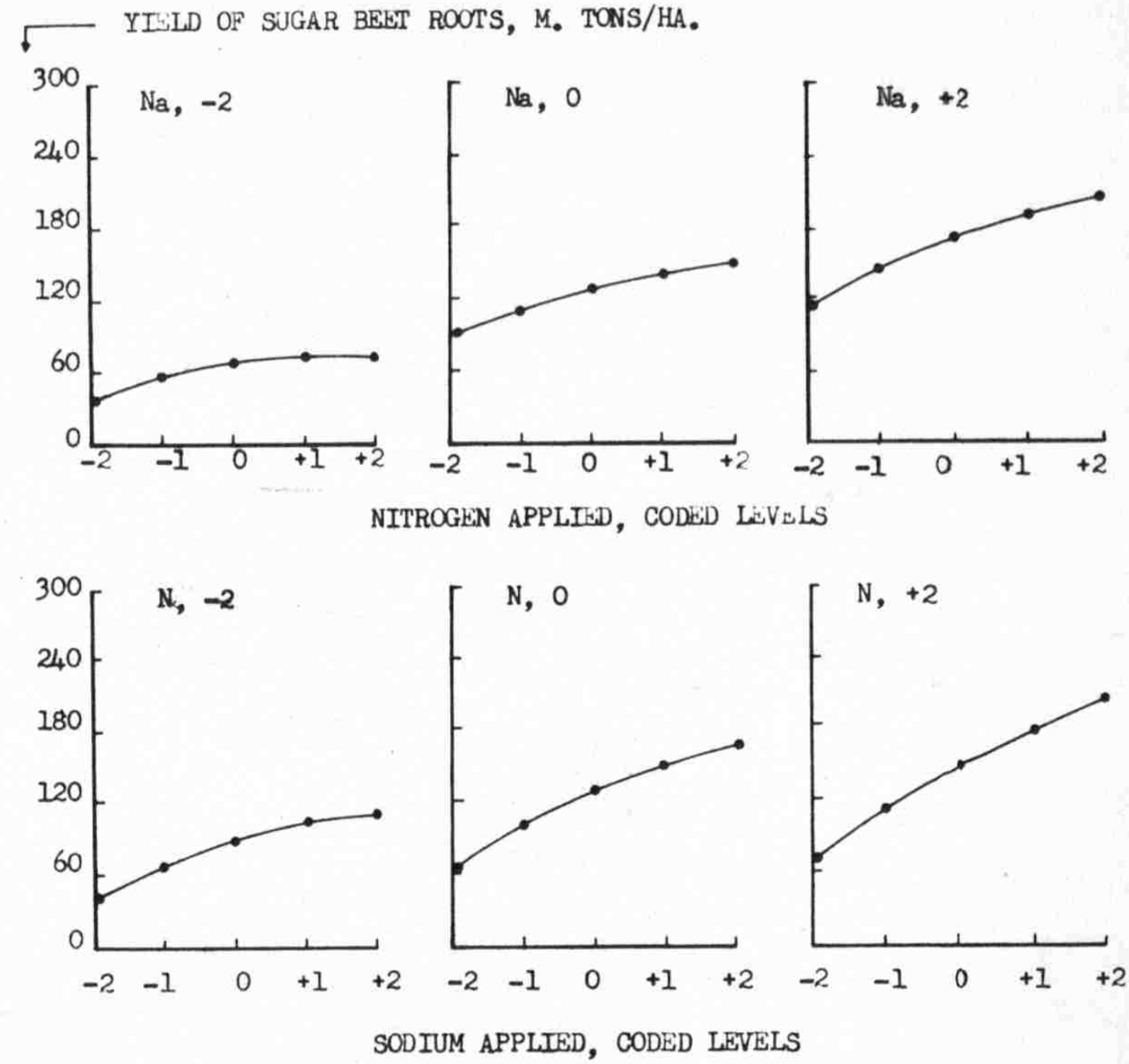

Fig. 2. Yield of sugar beet roots as affected by levels of applied N at constant levels of applied Na (above) and by levels of applied Na at constant levels of applied N (below). Levels of P, S, Cl and B were held constant at the +1, -2, -2, -2 levels of application, respectively.

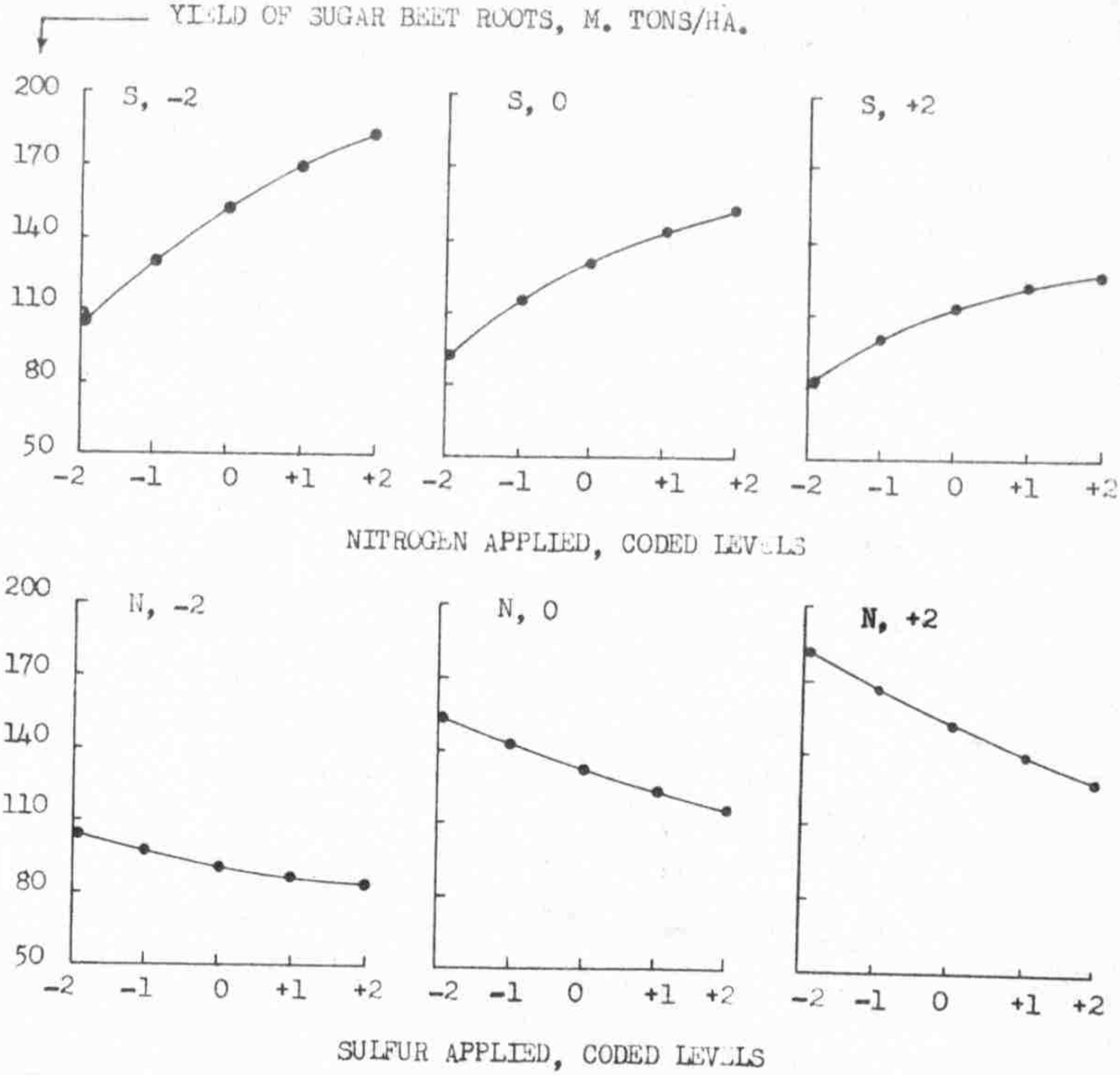

Figure 3. Yield of sugar beet roots as affected by levels of applied N at constant levels of applied S (above) and by levels of applied S at constant levels of applied N (below). P, Cl, Na and B were held at the +1, -2, +1 and -2 levels of application, respectively.

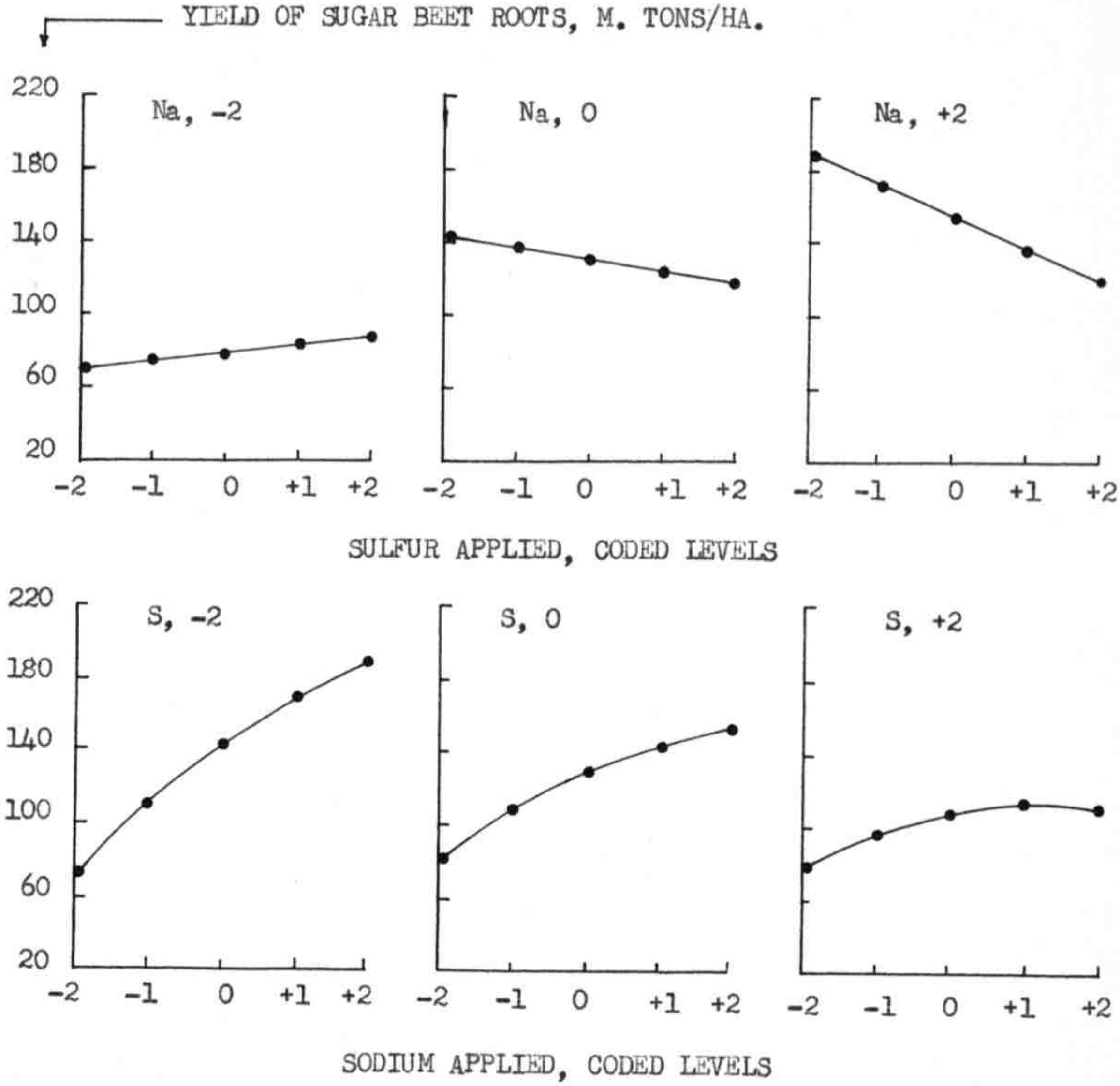

Figure 4. Yield of sugar beet roots as affected by levels of applied S at constant levels of applied Na (above) and by levels of applied Na at constant levels of applied S (below). N, P, Cl, and B were held at the +1, +1, -2, -2 levels of application, respectively.

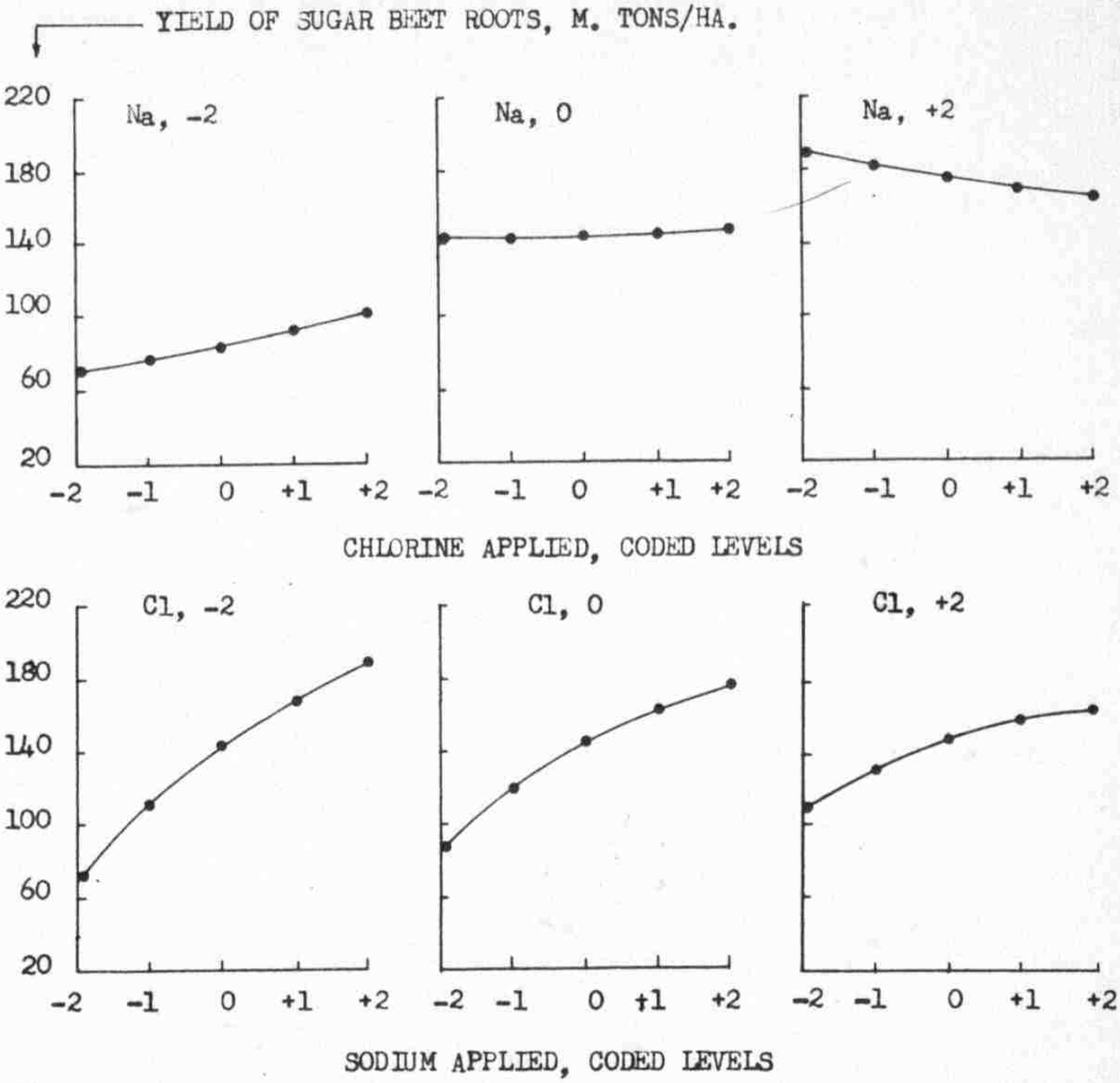

Figure 5. Yield of sugar beet roots as affected by levels of applied Cl at constant levels of applied Na (above) and by levels of applied Na at constant levels of applied Cl (below). N, P, S and B were held at the +1, +1, -2, and -2 levels of application, respectively.

sugar beets, the combination for the maximum economic yield of beets was determined by trial and error. The local prices of beets and fertilizers were used and the best combination was as follows:

+ 1N	or	300	kg/ha.
+ 2P	"	600	"
- 2S	"	37	"
- 2Cl	"	37	"
+ 1Na	"	300	"
- 2B	"	9	"

predicted yield= 191 m. tons/ha.

Only combinations with elements at the rates between -2 and +2 were used in calculation because the equation is less accurate at the extremes than in the center. In practice, the -2 levels for applied S, Cl and B could probably be considered as zero. Although the +2 level of N resulted in a higher profitable yield, a decrease in sucrose percentage and an undesirably high level of N in the roots (figure 8) ruled the +1N level as more feasible.

Effect of Fertilizer Treatments on Sucrose Concentration

The sucrose percentage of the roots ranged from 15.3% to 20.7% with an average of 18% (appendix table 6). The significant negative signs of the regression coefficients for the first order and second order squared terms of N (table 3) indicated that the sucrose concentration in roots decreased as the amount of applied N was increased (figure 8). Similar results were obtained by many workers (1, 27, 35, 38) and also by Hussieni (28) and Hashimi (25) under similar experimental conditions.

The negative regression coefficients of the first order and

Table 3. Regression coefficients (b) and their standard errors (s_b) for yield of roots (fresh basis), sucrose and nitrogen concentration of roots (fresh basis) and yield of sucrose as affected by various combinations of levels of N, P, S, Cl, Na and B.

Term	Yield of roots, M. tons/Ha.		Sucrose in roots, %		N in roots, %		Yield of sucrose, M. tons/Ha.	
	b	s_b	b	s_b	b	s_b	b	s_b
Mean	105.6		18.70		0.1346		19.65	
N	+6.8*	±2.5	-0.39*	±0.16	+0.0148**	±0.0026	+0.80	±0.37
P	+5.3	"	-0.11	"	-0.0018	"	+0.82	"
S	-2.4	"	-0.21	"	+0.0034	"	-0.61	"
Cl	+2.2	"	-0.03	"	-0.0055	"	+0.32	"
Na	+3.6	"	-0.09	"	+0.0012	"	+0.51	"
B	-6.3*	"	0.00	"	-0.0033	"	-1.14*	"
NN	-2.4	±2.1	-0.36*	±0.13	+0.0027	±0.0022	-0.81*	±0.32
PP	+1.4	"	-0.33	"	+0.0062*	"	-0.12	"
SS	+0.1	"	+0.02	"	+0.0028	"	+0.03	"
ClCl	+0.6	"	-0.04	"	-0.0013	"	+0.05	"
NaNa	-3.5	"	-0.24	"	-0.0004	"	-0.87*	"
BB	-0.3	"	+0.16	"	-0.0018	"	+0.15	"
N-P	+3.3	±2.9	+0.09	±0.18	-0.0008	±0.0030	+0.62	±0.44
N-S	-2.1	"	0.00	"	-0.0019	"	-0.37	"
N-Cl	+1.9	"	-0.28	"	-0.0079*	"	+0.05	"
N-Na	+3.8	"	-0.36	"	+0.0056	"	+0.28	"
N-B	-2.7	"	+0.14	"	-0.0005	"	-0.27	"
P-S	-1.5	"	0.00	"	-0.0058	"	-0.27	"
P-Cl	-0.2	"	+0.03	"	+0.0007	"	-0.03	"
P-Na	+1.3	"	+0.09	"	+0.0053	"	+0.26	"
P-B	-1.1	"	+0.10	"	+0.0085*	"	-0.03	"
S-Cl	+2.0	"	+0.13	"	-0.0077*	"	+0.51	"
S-Na	-5.4	"	+0.38	"	-0.0005	"	-0.61	"
S-B	-1.8	"	-0.04	"	-0.0032	"	-0.39	"
Cl-Na	-3.6	"	-0.03	"	-0.0088*	"	-0.70	"
Cl-B	-0.6	"	+0.20	"	-0.0002	"	+0.09	"
Na-B	-1.6	"	+0.06	"	-0.0014	"	-0.18	"

* Statistically significant at the 5% level.

** Statistically significant at the 1% level.

squared terms of P and Na indicated that both tended to decrease the sugar percentage of the roots particularly at high rates of application. The positive S-Na interaction had an appreciable effect on the sucrose percentage of roots indicating that as the level of S or Na was increased the response to the other tended to be less negative. The negative N-Na and N-Cl interactions indicated that the negative response of sucrose percentage of the roots to N applications tended to be greater as the level of Na or Cl was increased.

Effect of Fertilizer Treatments on Sucrose Yields

Although the positive first order effects of N, P and Na on the sucrose yields (table 3) were not significant, they tended to affect the yield of sugar in appreciable amounts. The positive first order effect of applied N on the yield of sucrose was not significant as was the case with the yield of roots because of the associated decreasing effect of N application on the concentration of sucrose (figure 8). Application of B, as with the yield of roots, significantly decreased the yield of sugar. Application of S tended to decrease the yield of sugar appreciably as shown by the negative first order regression coefficient. The squared terms, NN and NaNa had significant negative effects on sucrose yields indicating less positive effect of applied N and Na as the rate of application was increased. None of the interaction terms for sucrose yields were statistically significant. However, the magnitudes and signs were very similar to those for the yield of roots.

Effect of Fertilizer Treatments on N Concentration of Roots

The N concentration in roots ranged from 0.10 to 0.21 per cent (appendix table 6) and in general was less than the 0.20 level (fresh basis) which Goodban (21) has suggested as the maximum for acceptable quality of sugar beets from the standpoint of processing. The positive sign of the highly significant regression coefficient for the first order effect of N indicates that increasing N concentration of the root is due chiefly to the application of N (table 3). Similar results were obtained by other workers (25, 47). The positive PP term was significant indicating that the negative effect of P application on N concentration of roots was less and became positive at high rates. Examination of the interaction terms (table 3) showed that the positive P-B interaction had a significant effect on the N concentration of roots indicating that as the level of P or B was increased, the response to the other became more positive. The negative N-Cl, S-Cl and Cl-Na terms had significant effects on the N concentration of roots indicating that the positive effect of N, Na or S application was decreased as the level of Cl was increased.

Effect of Fertilizer Treatments on Yield of Sugar Beet Tops

The yield of tops varied widely ranging from 1.52 to 6.77 metric tons per ha. (appendix table 6). Application of N had a highly significant first order positive effect on the yield of tops (table 4). Hussieni (28) and Hashimi (25) also found that N application caused large increases in the yield of beet tops. The first order regression coefficients for P, S, Cl and Na presented in table 4, tended to be slightly positive while the first order effect of B was negative and of considerable size. Although none of the regression coefficients for the interaction terms were significant, the magnitude of the negative N-B term was of appreciable effect on the yield of tops indicating that the positive effect of N application decreased as the level of applied B was increased. The negative

S-Na and Cl-Na terms indicated that the positive effect of Na became less as Cl or S application was increased.

Effect of Fertilizer Treatments on N Concentration of Tops

The N concentration of tops varied from 1.98 to 3.25 per cent (appendix table 6). The regression coefficients (table 4) show that all the elements used had positive effects but only the N effect was significant. Hashimi (25), under similar conditions, obtained a slight positive effect of N on the N concentration of tops while Hussieni (28) obtained a negative effect of N and a positive significant effect of P on the N concentration of tops. These various results indicated that the N concentration of tops is not a reliable indication of N status of the soil. The positive N-B interaction had appreciable effect on the N concentration of tops indicating that the response of N concentration of tops to N application tended to increase at high level of B application. The negative S-B interaction indicated that the positive response of N concentration of tops to the applied S or B was decreased as the level of the other was decreased.

Total Nitrogen Uptake in Roots and Tops

The total N uptake by the plants, as calculated from the yield of roots and tops (appendix table 14), indicated that the N supplying capacity of the soil was of considerable magnitude even though the total N supply of the soil was only about .061 per cent. The average total uptake of N by the plants for those plots supplied with N at the coded -1 and 0 levels was 197 and 230 kg. per ha. while the applied N was 75 and 150 kg. per ha., respectively. Thus, at the -1 level, 122 kg. per ha. of

N was supplied by the soil. The soil where the experiment was located had not been irrigated previously and had been fallowed the previous year which probably accounted for the favorable N supplying situation. As the applied amount of N was increased, the amount of N uptake was increased but the proportion supplied from the original soil N was decreased and at the +1 coded level of N, the applied N (300 kg. per ha.) was more than the average total uptake by plants (288 kg. per ha.).

The average proportion of the total N uptake that was found in the roots was 61 per cent indicating that the beet pulp remaining after processing would serve as a considerable source of protein for animal use.

Influence of Fertilizer Treatments on Petiole Analysis

Nitrate-nitrogen Concentration of Petioles. The nitrate-N concentration of petioles was highly dependent upon the rates of N application (figure 6, appendix table 12). In the first sample (June 26) the concentration ranged from 10,485 ppm., for the highest N application, to 653 ppm. for the lowest N application (appendix table 8). In general there was a decrease in nitrate-N concentration of petioles as the season advanced (figure 6). These results are in agreement with those obtained by Hashimi (25), Magnitski (37) and Ulrich (52).

The critical levels of nitrate-N concentration of petioles for the three sampling dates during the growing season, as calculated from the regression equation, were 3,396 ppm. for June 26, 1,795 ppm. for August 10 and 1,112 ppm. for September 21 (figure 6). These levels were determined for the condition that all the N be applied at planting time. This shows that throughout the growing season, the critical level of nitrate-N of petioles was somewhat higher than that (1,000 ppm. dry basis) suggested by Ulrich (52). Under conditions similar to those of this experiment. Hashimi (25) obtained a critical level of 750 ppm., dry basis, for beet yields of about 136 m. ton per ha. for the nitrate-N concentration of petioles for the September 12 sampling.

In spite of the high response of beet yields to the rates of N application (figure 8), the N coded level +1 (300 kg./ha.) rather than a higher level was taken as the recommended level of N application for calculating the critical level of nitrate-N of petioles under the consitions of this experiment. The predicted N percentage of roots, as calculated from the regression equation when P, Na, S, Cl and B were held at +2, +1, -2, -2 and -2 respectively, dropped from 0.23 per cent (fresh basis) at the +2 N level to 0.18 per cent at the +1 level. Goodban <u>et al.</u> (21) considered 0.20 per cent of N in the roots as the maximum tentative limit above which the roots become of undesirable quality for processing. Also, the predicted percentage of sucrose in the roots increased from 15.8 at the + 2N level to 17.4 at the + 1N level of application thus offsetting the decrease in root yield.

The highly significant positive first order and squared terms for the effect of N on the nitrate-N concentration of petioles (table 4) indicated that the nitrate-N concentration of petiole was very sensitive to N application. The high response of nitrate-N concentration of petioles to N application indicates that petiole analysis is a good guide for assessing the N status of the soil as has been found by others (25, 52).

The negative N-B interaction had a significant effect indicating that the positive response of nitrate-N concentration of petioles to N application was less at high rates of B application. Also, the negative P-Na interaction was significant indicating that increasing the level of P

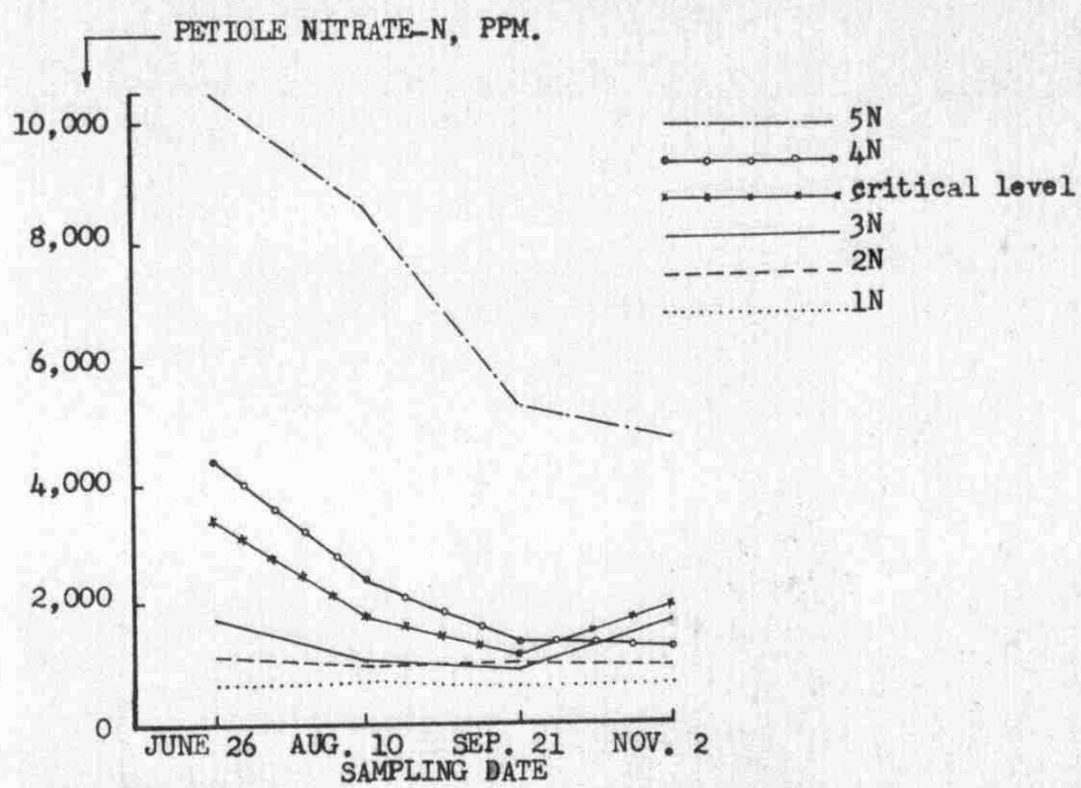

Figure 6. Observed seasonal change in average nitrate-N concentration of petioles (recently mature, dry basis). The critical level was calculated from the regression equation with N at the +1 coded level.

Table 4. Regression coefficients (b) and their standard errors (s_b) for yield of tops (dry basis), N concentration of tops (dry basis), nitrate-N and phosphate-P concentrations of petioles (seasonal mean, dry basis) as affected by various combinations of levels of N, P, S, Cl, Na and B.

Term	Yield of tops, M. tons/Ha.		N in tops, %		Petiole nitrate-N, log ppm.		Petiole phosphate-P %	
	b	s_b	b	s_b	b	s_b	b	s_b
Mean	3.40		2.670		3.120		0.1790	
N	+0.77**	±0.15	+0.087*	±0.034	+0.180**	±0.017	-0.0064**	±0.0009
P	+0.11	"	+0.006	"	+0.015	"	+0.0153**	"
S	+0.03	"	+0.009	"	+0.025	"	+0.0010	"
Cl	+0.12	"	+0.063	"	-0.014	"	-0.0008	"
Na	+0.13	"	+0.014	"	+0.018	"	-0.0007	"
B	-0.34	"	+0.019	"	+0.010	"	-0.0005	"
NN	+0.18	±0.13	+0.007	±0.029	+0.055**	±0.015	-0.0001	±0.0008
PP	-0.09	"	+0.045	"	-0.001	"	-0.0022*	"
SS	-0.001	"	-0.044	"	-0.005	"	-0.0033**	"
ClCl	+0.01	"	+0.009	"	+0.008	"	-0.0037**	"
NaNa	-0.12	"	-0.049	"	-0.010	"	-0.0047**	"
BB	+0.13	"	+0.013	"	-0.021	"	+0.0014	"
N-P	+0.09	±0.18	+0.020	±0.040	-0.004	±0.020	+0.0030*	±0.0011
N-S	-0.02	"	-0.033	"	-0.000	"	-0.0057**	"
N-Cl	+0.14	"	-0.008	"	-0.001	"	-0.0040**	"
N-Na	+0.18	"	-0.034	"	+0.044	"	+0.0025*	"
N-B	-0.35	"	+0.067	"	-0.049*	"	-0.0020	"
P-S	+0.09	"	+0.046	"	-0.037	"	-0.0033*	"
P-Cl	+0.02	"	+0.051	"	+0.004	"	+0.0013	"
P-Na	-0.03	"	-0.019	"	-0.069*	"	+0.0007	"
P-B	-0.04	"	-0.005	"	+0.019	"	+0.0045**	"
S-Cl	+0.07	"	-0.039	"	-0.001	"	-0.0050**	"
S-Na	-0.26	"	-0.019	"	-0.035	"	-0.0011	"
S-B	+0.22	"	-0.068	"	-0.002	"	+0.0025	"
Cl-Na	-0.33	"	+0.040	"	-0.016	"	-0.0052**	"
Cl-B	-0.19	"	+0.003	"	-0.011	"	+0.0033*	"
Na-B	-0.08	"	+0.027	"	+0.000	"	-0.0012	"

* Statistically significant at the 5% level.

** Statistically significant at the 1% level.

or Na decreased the positive effect of application of the other on the nitrate-N concentration of petioles.

Phosphate-phosphorous Concentration of Petioles. The seasonal mean of phosphate-P concentration of petioles ranged from 2,150 ppm. to 1,210 ppm. (appendix table 10). The phosphate-P concentrations of petioles were highest at the first sampling date (June 26), then declined and changed very little in the remaining period of the season (figure 7). The difference between phosphate-P concentration in petioles resulting from the various P treatments was highest early in the season. The critical level of phosphate-P concentration of petioles under the condition of this experiment as calculated from the regression equation was about 1,600 ppm. from August 10 and later which was more than double the 750 ppm. level suggested by Ulrich (52).

Study of the regression coefficients for phosphate-P concentration of petioles (table 4) indicated that the first order effect of applied P, as also found by Hashimi (25), was highly significant and positive. However, the positive response, as shown from the significant negative regression coefficient of the squared term for P, was less at high rates of P application. The application of N as indicated by the negative first order term had a highly significant depressing effect on the phosphate-P concentration of petioles. The negative squared terms SS, ClCl and NaNa had a highly significant effect on the phosphate-P concentration indicating that S, Cl and Na depressed the phosphate-P concentration of petioles at high rates of application. The positive N-P interaction had a significant effect on the phosphate-P concentration of petioles indicating that the response of phosphate-P concentration to P application was greater at the

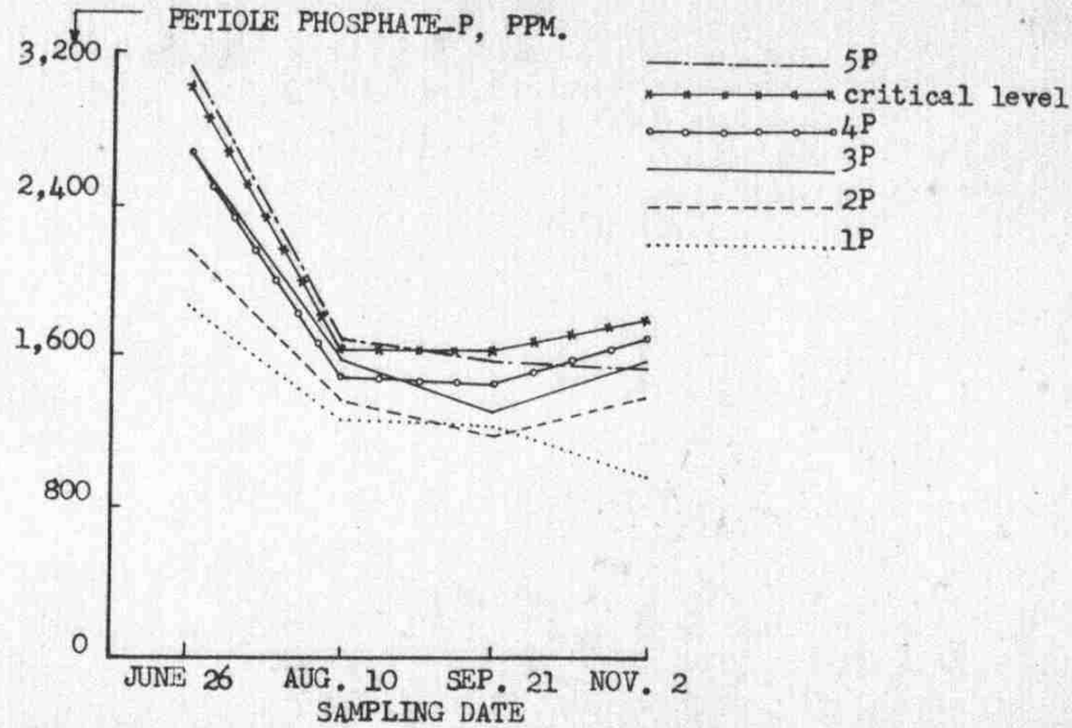

Figure 7. Observed seasonal change in average phosphate-P concentration of petioles (recently mature, dry basis). The critical level was calculated from the regression equation with P set at the +2 coded level.

higher levels of N application. The positive P-B interaction indicated a larger response of phosphate-P concentration to P application as the level of B application was increased. The positive N-Na interaction had a significant effect indicating that the negative response of phosphate-P concentration of petioles to the first order effect of N or Na application was decreased as the level of the other element was increased. The positive Cl-B interaction was significant indicating that low levels of both resulted in high phosphate-P concentration of petioles. The negative N-S, P-S and S-Cl interactions had significant effects on the phosphate-P concentration of petioles indicating that the effect of applied S was more negative (less positive) as the application rate of N, P, or Cl was increased. The negative N-Cl and Cl-Na interactions had highly significant effects indicating that the negative response of phosphate-P concentration of petioles to Cl application increased as the N or Na application was increased.

Sulfate-sulfur Concentration of Petioles. The sulfate-S concentration of petioles ranged from 0.052 to 0.146 per cent (appendix table 11). Ulrich et al. (53) cited an example where vigorous sugar beet plots had 0.053 per cent sulfate-S in the petioles while poor plants had 0.0085 per cent. This indicates that S was present in adequate amount in this experiment even at the lowest level of S application. This was also indicated by the general negative response to S application.

The regression coefficient for the positive first order effect of S application on sulfate-S concentration of petioles (table 5) was not statistically significant and was smaller in magnitude than those for P and Na indicating more influence of P (positive and significant) and Na (negative) on sulfate-S concentration of petioles than for S. The negative P-S interaction had a significant effect indicating that the positive response of sulfate-S concentration of petioles to P application was decreased as S application was increased.

Chlorine Concentration of Petioles. The Cl concentration of petioles ranged between 1.93 and 4.98 per cent (appendix table 11). These values are much higher than the critical level of 0.4 per cent suggested by Ulrich et al. (53). The regression coefficients for the first order effects of the applied elements on Cl concentration of petioles (table 5) show than an increase in Cl application significantly increased the Cl concentration of petioles and that the Cl concentration of petioles is a good indication for the Cl-status of the soil. The highly significant negative sign of the first order effect of N points out that increases in N applications decreased the Cl concentration in petioles. The regression coefficient of the negative S-B interaction (table 5) was significant indicating that the positive response of Cl concentration of petioles to B application was decreased as the level of S was increased.

Sodium Concentration of Petioles. The Na percentage of sugar beet petioles varied from 0.58 to 2.76 per cent (appendix table 11). The regression coefficients for the Na concentration of petioles (table 5) indicated that Na concentration was highly significantly increased by Na and N application. Petiole analysis for Na, as found by Hashimi (25), was a good indication for the Na status of the soil. The tentative critical level for Na percentage of the petioles for a beet yield of about 191 metric tons per ha., as calculated from the regression equation when N, P, S, Cl and B were held at +1, +2, -2, -2 and -2, respectively, was 1.73 per cent.

Table 5. Regression coefficients (b) and their standard errors (s_b) for the sulfate-S, Cl, Na and B concentrations of petioles (second sampling, dry basis) as affected by various combinations of levels of N, P, S, Cl, Na and B.

Term	Sulfate-S, % b	Sulfate-S, % s_b	Cl, % b	Cl, % s_b	Na, % b	Na, % s_b	B, ppm. b	B, ppm. s_b
Mean	0.0941		3.165		1.42		57.6	
N	+0.0020	±0.0029	-0.392**	±0.074	+0.22**	±0.03	+0.3	±1.4
P	+0.0092*	"	+0.146	"	+0.02	"	+0.9	"
S	+0.0043	"	-0.076	"	+0.01	"	-0.1	"
Cl	+0.0009	"	+0.256*	"	-0.07	"	+0.1	"
Na	-0.0051	"	+0.091	"	+0.16**	"	+0.7	"
B	+0.0004	"	+0.088	"	+0.01	"	+3.5*	"
NN	+0.0021	±0.0025	+0.028	±0.064	-0.03	±0.03	+3.5*	±1.2
PP	+0.0031	"	-0.001	"	-0.06	"	+1.1	"
SS	-0.0007	"	+0.002	"	-0.03	"	+2.0	"
ClCl	+0.0020	"	+0.064	"	-0.03	"	+4.5*	"
NaNa	-0.0034	"	-0.005	"	+0.04	"	+0.9	"
BB	+0.0011	"	-0.036	"	+0.06	"	+1.7	"
N-P	-0.0019	±0.0034	-0.072	±0.086	-0.03	±0.04	-5.7*	±1.7
N-S	+0.0001	"	-0.018	"	+0.02	"	+3.2	"
N-Cl	+0.0068	"	-0.075	"	-0.08	"	+1.6	"
N-Na	-0.0072	"	+0.108	"	+0.08	"	-1.8	"
N-B	-0.0032	"	+0.042	"	0.00	"	+3.3	"
P-S	-0.0091*	"	+0.050	"	+0.02	"	-1.2	"
P-Cl	+0.0013	"	+0.084	"	-0.01	"	-5.3*	"
P-Na	+0.0019	"	+0.059	"	-0.11*	"	-0.9	"
P-S	+0.0046	"	-0.006	"	+0.04	"	+0.2	"
S-Cl	+0.0056	"	+0.167	"	-0.06	"	-4.3*	"
S-Na	+0.0001	"	-0.106	"	-0.07	"	-0.5	"
S-B	-0.0015	"	-0.273*	"	+0.04	"	+3.8	"
Cl-Na	-0.0053	"	-0.158	"	-0.07	"	+4.2*	"
Cl-B	+0.0002	"	+0.046	"	0.00	"	+4.7*	"
Na-B	-0.0059	"	-0.028	"	-0.05	"	-1.7	"

* Statistically significant at the 5% level.

** Statisfically significant at the 1% level.

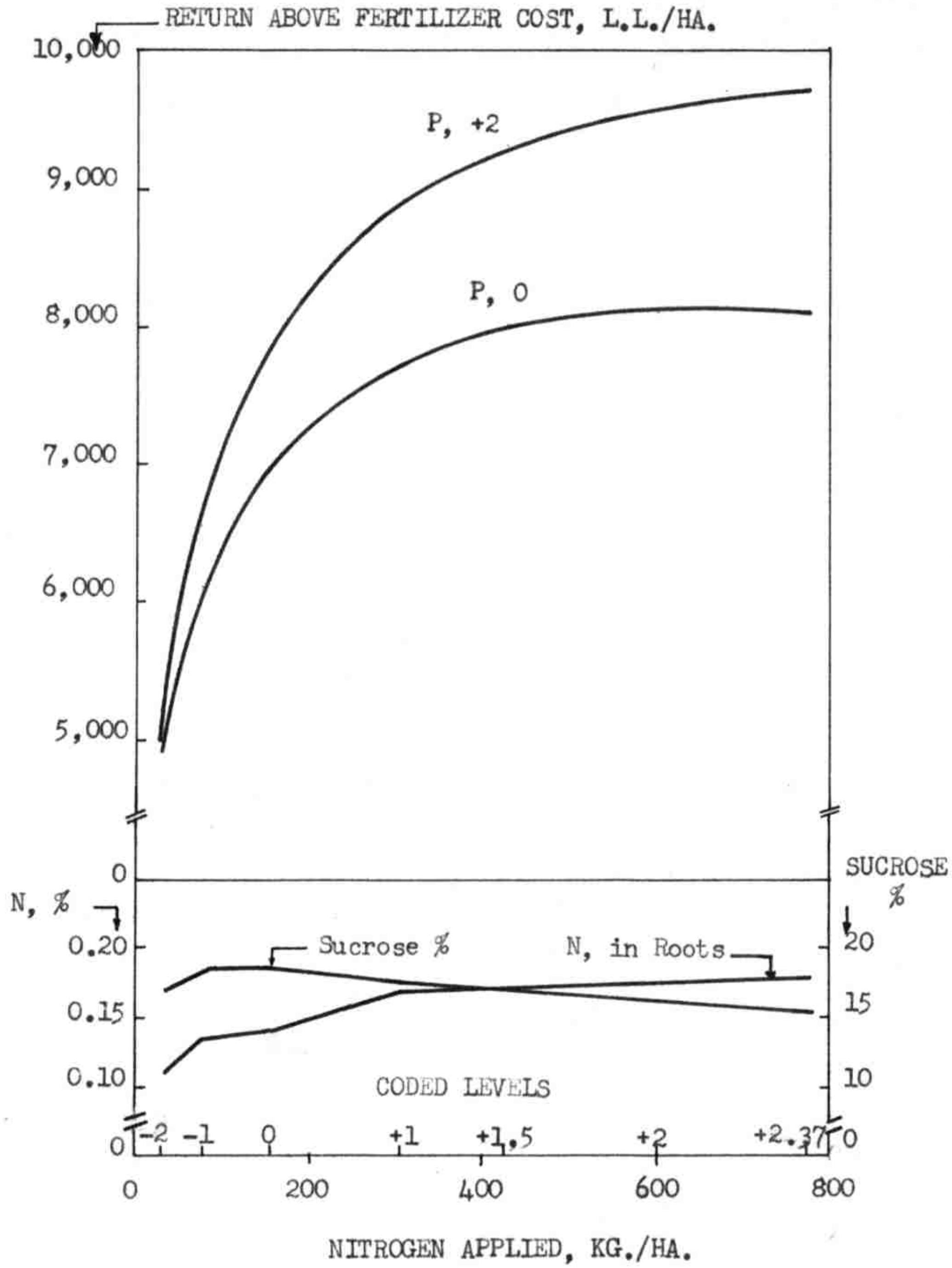

Figure 8. Effect of applied N on the predicted return above fertilizer costs for sugar beet roots. Data were calculated from the regression equation at two levels of P (+2, 0). S, Cl, Na, and B were held at the -2, -2, +1 and -2 levels of application, respectively. Prices used were : beets at 49.50 L.L./ton, tops at 90 L.L./ton (dry basis), N at 1 L.L./kg., P at 1.45 L.L./kg. and Na at 0.15 L.L./kg. (upper graph). Effect of applied N on N concentration and sucrose percentage in roots (fresh basis) calculated from actual data (lower graph).

The negative P-Na interaction had a significant effect indicating that the positive response of Na concentration of petioles to Na application was decreased as the P application was increased.

Boron Concentration of Petioles. The B concentration of petioles varied from 40 to 109 ppm. (appendix table 11). Study of the regression coefficients for B concentration of petioles (table 5) indicated that among the linear terms only B had appreciable and significant positive effect indicating that the B concentration of petioles increased as the B application rate was increased. The positive NN and ClCl squared terms had significant effect indicating that the positive response of B concentration of petioles to N or Cl application is higher at high rates than at low rates of application. The negative N-P interaction was significant indicating that the positive response of B concentration of petioles to N or P application was decreased as the level of the other was increased. The negative P-Cl and S-Cl interactions had significant effects on the B concentration of petioles indicating the response of B concentration to Cl application was less positive as the level of P or S was increased. The positive and significant Cl-Na and Cl-B interactions indicated that the positive response of B concentration of the petioles to B and Na application was increased as the level of Cl application was increased.

The general depressing effect of B application on sugar beet yeids, indicated that the soil supply was adequate. Yang (56) reported that sugar beet plants with 40 ppm. B in the leaves were free of B deficiency symptoms. In the experiment the lowest petiole B concentration found was 40 ppm. Since petiole concentration is commonly less than leaf concentration, this is further confirmation of an adequate B supply.

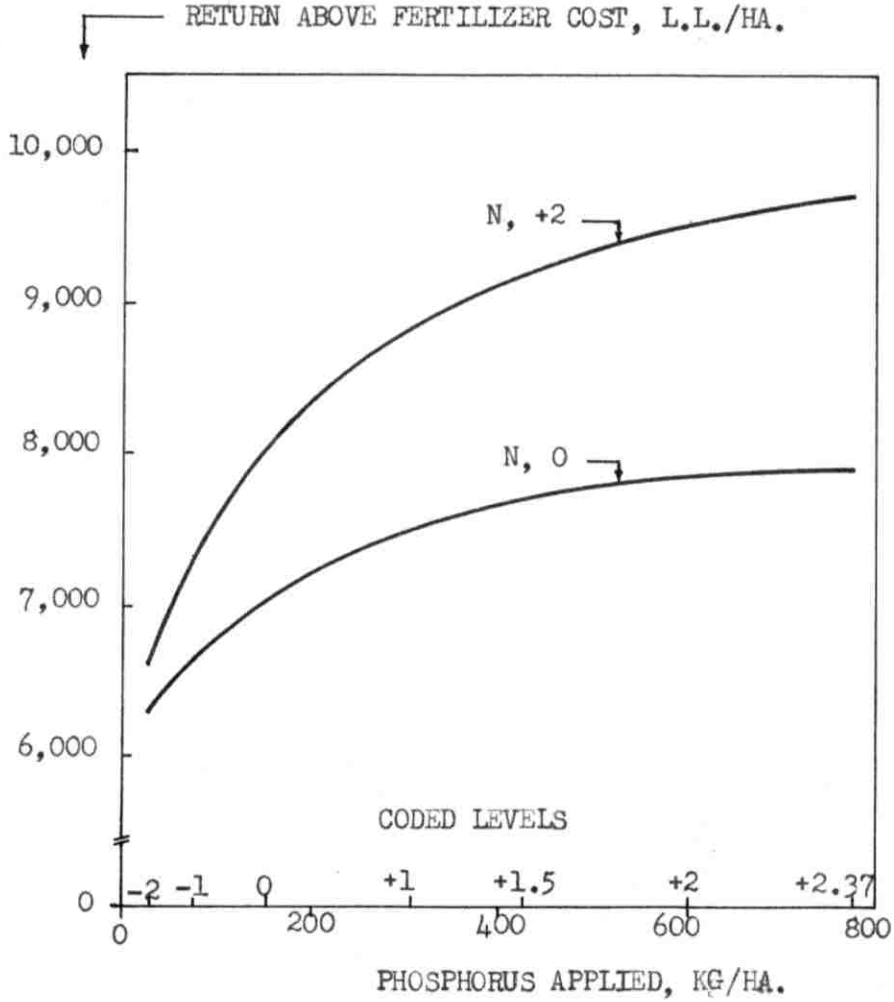

Figure 9. Effect of applied P on the predicted return above fertilizer costs for sugar beet roots. Data were calculated from the regression equation at two levels of N (+2, 0). S, Cl, Na and B were held at the -2, -2, +1 and -2 levels of application, respectively. The prices used were: beets at 49.50 L.L./ton, tops at 90 L.L./ton (dry basis), N at 1 L.L./Kg. , P at 1.45 L.L./kg. and Na at 0.15 L.L./kg.

SUMMARY AND CONCLUSIONS

The effects of N, P, S, Cl, Na and B and their interactions on the yield and chemical composition of sugar beets were studied in a field experiment on an irrigated calcareous soil in 1963. The application rates of the macroelements, N, P, S, Cl and Na were varied at the 5 levels between 782 and 29 kg. per ha. and B application was varied between 185 and 7 kg. per ha. (table 1). At four periods during the growing season, petiole samples of recently natured leaves were taken for chemical analysis. The beets were harvested 320 days after planting and samples of tops and beets were taken for analysis. A central composite, rotatable, incomplete factorial design was used because it permits the calculation of regression equations for the collected data in the quadratic form. In evaluating the regression coefficients the "t" test was used.

Relatively high yields of beets were obtained with an average of 102.3 metric tons and a maximum of 147.8 metric tons per ha. (appendix table 6). The effect of applied N was positive on the yields of tops, beets and sucrose with the relative magnitudes in that order (table 3 and 4). Application of P and Na also tended to have positive effects on yields particularly at high N levels (figure 9) because of the positive N-P and N-Na interactions. These two positive interactions also indicated a greater positive response to N application at high levels of P or Na. The application of S tended to decrease the positive effects of N, P and Na on the yields of roots and sucrose due to the negative N-S, P-S and Na-S interactions. It was concluded that S application for sugar beets in fertilizers such as single superphosphate or ammonium sulfate should be avoided where the supply of S is adequate. Application of B had a significant negative first order effect on yields of roots and sucrose and also negative interactions with N, P and Na indicating that the addition of B was detrimental to yields. Although the first order effect of Cl application tended to be positive, this was counteracted by the interactions with Na and S indicating that under the conditions of this experiment, $NaNO_3$ was preferable to NaCl as the Na carrier. Considering the above results it was concluded that the combination for the best yield of sucrose along with an acceptable N percentage (less than 0.2%) of roots was as follows:

+1N or 300 kg/ha.
+2P or 600 kg/ha.
-2S or 37 kg/ha.
-2Cl or 37 kg/ha.
+1Na or 300 kg/ha.
-2B or 9 kg/ha.

Predicted yield = 191 m. tons/ha.

Only values between +2 and -2 for each element were considered because the regression equation tended to become less accurate at the extreme values. In practice, the recommended levels for applied S, Cl and B could be considered as zero.

The sucrose percentage of roots was depressed as the N application was increased (figure 8) and this depressing effect was increased as the level of Na or Cl was increased due to the negative N-Na and N-Cl interactions. Along with decreasing effect of N application on the sucrose percentage of roots, the N percentage in roots was highly increased at high levels of N application (figure 8). Therefore it was concluded that the +1 coded level of N or 300 kg. per ha. was the most practical level of application under the conditions of high yield potential in this experiment even though higher yields of roots and tops were possible at higher levels.

Analysis of sugar beet tops for total N (table 4) revealed that only the N application had a significant positive effect. The average total N uptake by the plants, as calculated from the yield of beets and tops, for those plots supplied with N at the coded -1 level (75 kg. per ha.) was 197 kg. per ha. indicating that about 122 kg. per ha. was taken from the initial soil supply. The total uptake of N increased as the application rate of N was increased but the excess of N uptake over the amount of applied N decreased and became negative at high application levels of N (appendix table 14).

The analysis data for nitrate-N concentration of petioles (table 4, appendix table 12, figure 6) indicated that the nitrate-N concentration of petioles was highly related to the N supply and decreased as the season advanced. The positive effect of N applications on the nitrate-N concentration of petioles was depressed by increasing the levels of B application due to the negative N-B interaction. The negative P-Na interaction indicated that as the level of P or Na application was increased, while the other was held constant, the positive effect of P or Na on the nitrate-N concentration of petioles was decreased. Considering 300 kg. per ha. as the recommended rate of N application for the predicted yield of about 191 metric tons per ha., tentative critical levels for nitrate-N concentration of petioles on a dry basis (figure 6) for the growing season were estimated to be about 3,400 ppm. at 3 months after planting, 1,800 ppm. at 4 months and 1,100 ppm. at 5 months and thereafter. The critical levels were determined for the condition that all the N be applied at planting time. These critical levels were somewhat higher than that (1,000 ppm., dry basis) suggested by Ulrich (52) all through the growing season. However, the high yields obtained in this study would indicate a requirement for a more rapid rate of nutrient uptake during the growing season.

The phosphate-P concentration of petioles (table 4) responded positively and significantly to P application (figure 7). However, the application of N depressed the phosphate-P concentration of petioles significantly. The positive response of phosphate-P concentration of petioles to P application was decreased as the level of S application was increased due to the negative P-S interaction and it was increased as the level of B application was increased due to the positive P-B interaction. Among the other interactions N-S, N-Cl, S-Cl and Cl-Na were significantly negative on the phosphate-P concentration of petioles, while the N-P, N-Na and Cl-B interaction were significantly positive. Considering the +2 coded level of P application (for predicted yield of about 191 tons per ha.) as the recommended rate (600 kg./ha.) the critical level of phosphate-P concentration of petioles was estimated to be about 1,600 ppm. at 4 months after planting and later in the season (figure 7). This was more than double the 750 ppm. suggested by Ulrich (52). This high critical level of phosphate-P concentration in petioles indicated a high requirement for P under the high yield conditions of this experiment (figure 9).

The Na concentration of petioles was positively related to N and Na application. The positive first order effect of N and the positive N-Na interaction indicated a higher uptake of applied Na as the N application rate was increased. The positive effect of Na application on the Na concentration in the petioles was decreased as the P application was increased due to the negative P-Na interaction. The tentative critical level of Na in sugar beet petioles under the conditions of this experiment was estimated to be 1.73 percent at midseason for a predicted yield of about 191 metric tons per ha. Since there was considerable yield response to Na application and the Na concentration of petioles was highly related to Na application, it was concluded that petiole analysis was a good guide for assessing the Na status of sugar beet plants. The Cl concentration of petioles was increased as Cl application was increased but decreased as N application was increased with N having a relatively greater effect than Cl. The positive response of Cl concentration of petioles to B application was decreased as the level of S was increased due to the negative S-B interaction. Since the general effect of Cl application was negative in this experiment, it was concluded that the critical level of Cl in petioles was less than 2 per cent.

The B concentration of petioles was positively related to B application and this positive response was increased as the Cl application was increased. Since the resultant effect of Cl under the condition of this experiment was detrimental to yields, this might be due to the increasing uptake of B resulting in higher toxic effect of B. Furthermore, the positive Cl-Na interaction indicated higher B concentration when both Cl and Na were at high levels. The N-P, P-Cl and S-Cl interactions were significantly negative.

The sulfate-S concentration of petioles was affected positively by S application but to considerably less extent than by P application (also positive). The positive response to S or P application was decreased as the application level of the other was increased due to the negative P-S interaction. The negative effect of S application on the yield of beets resulted in the conclusion that the S supply was adequate and no definite critical level of S for sugar beets could be established from this experiment.

It was concluded that petiole analysis of sugar beet plants was effective as a method of determining the present nutrient status, especially for N and P. Also, the diagnosis could be made early enough in the season for additional nutrients to be applied.

The analysis of variance (appendix table 7, 9) indicated that in about half of the characterizations made, the proportion of the total treatment sum of squares accounted for by the quadratic regression equation (equation sufficiency) was 80 per cent or better and most of the balance were above 65 per cent. The highest equation sufficiencies were for sucrose percentage in roots (94.4%), Nitrate-N and phosphate-P concentrations in petioles (93.5% and 86.9%, respectively) and the lowest were for sulfate-S concentration in petioles (55.6%) and for N percentage in the tops (36.0%) indicating a poor fit of the equation. The results in general, indicated a good fit of the regression equation to the actual data.

It was concluded that the method of using quadratic regression equations to evaluate the data for six variables, each at 5 levels, was efficient and effective.

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APPENDICES

Table 6. Yield of tops (dry basis), yield of roots (fresh basis), nitrogen and sucrose concentration of roots (fresh basis), nitrogen concentration in tops (dry basis) and yield of sucrose as affected by various combinations of levels of N, P, S, Cl, Na and B.

Treatment level N P S Cl Na B	Yield of tops, M. tons/Ha.	N in tops, %	Yield of roots, M. tons/Ha.	N in roots, %	Sucrose %	Yield of sucrose, M. tons/Ha.
2 2 2 2 2 2	2.04	2.74	80.4	0.11	19.2	15.4
4 2 2 2 4 2	6.23	2.00	116.7	0.18	18.0	21.0
2 4 2 2 4 2	3.90	2.16	105.6	0.13	18.6	19.6
4 4 2 2 2 2	4.17	2.69	114.0	0.13	18.7	21.3
2 2 4 2 2 4	3.94	2.08	90.1	0.12	17.6	15.9
4 2 4 2 4 4	3.73	3.09	81.0	0.19	17.7	14.3
2 4 4 2 4 4	2.53	2.36	64.8	0.15	18.3	11.9
4 4 4 2 2 4	3.54	2.87	84.2	0.15	17.5	14.7
2 2 2 4 2 4	2.36	2.63	86.8	0.12	20.2	17.5
4 2 2 4 4 4	2.82	2.70	90.7	0.11	16.6	15.1
2 4 2 4 4 4	2.20	3.14	94.0	0.13	19.5	18.3
4 4 2 4 2 4	4.04	3.00	105.0	0.18	18.8	19.7
2 2 4 4 2 2	3.27	2.26	101.0	0.18	18.1	18.3
4 2 4 4 4 2	4.45	2.90	88.7	0.16	17.4	15.4
2 4 4 4 4 2	2.99	2.90	103.7	0.10	18.8	19.5
4 4 4 4 2 2	5.39	2.84	123.8	0.12	17.5	21.6
2 2 2 2 4 4	3.97	2.69	102.2	0.11	17.5	17.9
4 2 2 2 2 4	1.97	2.88	74.5	0.16	19.0	14.2
2 4 2 2 2 4	2.64	1.98	112.0	0.12	17.2	19.3
4 4 2 2 4 4	4.21	3.08	138.0	0.18	17.8	24.6
2 2 4 2 4 2	1.71	2.71	94.6	0.15	18.7	17.7
4 2 4 2 2 2	3.21	2.39	93.0	0.20	17.2	16.0
2 4 4 2 2 2	3.14	3.14	110.8	0.14	17.2	19.1
4 4 4 2 4 2	5.15	2.50	127.0	0.21	16.3	20.7
2 2 2 4 4 2	3.27	2.67	96.5	0.13	18.4	17.8
4 2 2 4 2 2	5.75	2.73	121.1	0.16	17.8	21.6
2 4 2 4 2 2	3.21	2.15	97.8	0.14	18.0	17.6
4 4 2 4 4 2	5.31	3.12	147.8	0.17	15.3	22.6
2 2 4 4 4 4	2.02	2.44	73.9	0.11	19.3	14.2
4 2 4 4 2 4	3.58	2.73	105.0	0.13	17.2	18.1
2 4 4 4 2 4	3.27	3.09	104.2	0.14	17.1	17.8
4 4 4 4 4 4	4.13	2.65	105.0	0.14	17.7	18.6

Table 6 continued.

Treatment level N P S Cl Na B	Yield of tops, M. tons/Ha.	N in tops, %	Yield of roots, M. tons/Ha.	N in roots, %	Sucrose %	Yield of sucrose, M. tons/Ha.
5 3 3 3 3 3	6.77	2.81	114.0	0.18	15.7	17.9
1 3 3 3 3 3	1.63	2.51	72.5	0.11	17.3	12.5
3 5 3 3 3 3	2.53	2.50	112.1	0.15	16.8	18.8
3 1 3 3 3 3	2.92	3.25	116.7	0.18	16.5	19.3
3 3 5 3 3 3	3.88	2.33	113.3	0.15	18.2	20.6
3 3 1 3 3 3	2.54	2.42	101.0	0.14	19.0	19.2
3 3 3 5 3 3	3.99	2.70	117.9	0.12	17.7	20.8
3 3 3 1 3 3	2.57	2.65	101.8	0.13	18.9	19.2
3 3 3 3 5 3	3.11	2.29	114.7	0.12	16.8	19.3
3 3 3 3 1 3	2.02	2.41	59.6	0.14	17.5	10.4
3 3 3 3 3 5	3.42	2.55	92.0	0.12	18.6	17.1
3 3 3 3 3 1	4.45	2.84	118.6	0.12	20.2	24.0
3 3 3 3 3 3	3.21	2.41	91.4	0.17	18.8	17.2
3 3 3 3 3 3	2.86	2.55	100.3	0.12	18.8	18.9
3 3 3 3 3 3	4.36	2.76	124.3	0.16	18.1	22.5
3 3 3 3 3 3	2.61	2.52	97.1	0.13	20.7	20.1
3 3 3 3 3 3	3.90	2.75	118.0	0.14	17.9	21.1
3 3 3 3 3 3	1.52	3.17	76.5	0.12	19.9	15.2
3 3 3 3 3 3	3.88	2.77	114.7	0.12	18.5	21.2
3 3 3 3 3 3	3.40	2.82	116.7	0.13	18.0	21.0
3 3 3 3 3 3	5.08	2.18	110.1	0.13	17.4	19.2
3 3 3 3 3 3	3.26	2.78	105.6	0.13	18.8	19.9

Table 7. Analysis of variance for yield of roots (fresh basis), yield of tops (dry basis), yield of sucrose, N concentration of tops (dry basis) and N and sucrose concentration of roots (fresh basis) as affected by various combinations of levels of N, P, S, Cl, Na and B.

Source	Yield of roots, M. tons/Ha.	Yield of tops, M. tons/Ha.	Yield of Sucrose M. tons/Ha.	N, in tops, %	N, in roots, %	Suc-rose %
d.f.						
Total	53	53	53	53	53	53
Block	2	2	2	2	2	2
Linear	6	6	6	6	6	6
Quadratic	21	21	21	21	21	21
Lack of fit	17	17	17	17	17	17
Error	7	7	7	7	7	7
S.S.						
Total	16568.0	70.67	456.8	5.22	0.0354	62.8
Block	893.0	0.08	8.3	0.17	0.0005	5.1
Linear	6009.3	32.70	144.9	0.52	0.0119	9.5
Quadratic	4498.0	19.25	156.3	1.17	0.0159	38.1
Lack of fit	3323.2	11.38	106.1	3.00	0.0051	2.8
Error	1843.8	7.26	41.3	0.36	0.0020	7.3
M.S.						
Block	446.9	0.04	4.1	0.08	0.0002	2.5
Linear	1001.6	5.45*	24.1*	0.09	0.0020*	1.6
Quadratic	214.2	0.91	7.4	0.06	0.0076	1.8
Lack of fit	195.5	0.67	6.2	0.18*	0.0003	0.2
Error	263.4	1.04	5.9	0.05	0.0003	1.0
C.V. %	15.9	29.0	12.4	8.50	12.5	5.5
Equation sufficiency[1], %	76.0	82.0	73.9	36.00	84.5	94.4

* Statistically significant at the 5% level.

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

Table 8. Nitrate-N concentrations in the petioles (dry basis) at four sampling dates and the seasonal mean as affected by various combinations of levels of N, P, S, Cl, Na and B.

Treatment levels N P S Cl Na B	June 26, ppm.	August 10, ppm.	Sept. 21, ppm.	Nov. 2, ppm.	Mean ppm.
2 2 2 2 2 2	963	650	196	798	652
4 2 2 2 4 2	6798	5941	1650	1654	4011
2 4 2 2 4 2	653	825	400	678	639
4 4 2 2 2 2	5294	1752	1373	1084	2376
2 2 4 2 2 4	1235	824	995	800	964
4 2 4 2 4 4	6795	4606	1193	974	3393
2 4 4 2 4 4	1430	1036	805	776	1012
4 4 4 2 2 4	4724	2317	1505	1079	2406
2 2 2 4 2 4	868	738	809	717	783
4 2 2 4 4 4	4856	1194	299	196	1636
2 4 2 4 4 4	1087	1187	1456	1672	1351
4 4 2 4 2 4	6862	2130	577	993	2641
2 2 4 4 2 2	1440	1557	898	615	1128
4 2 4 4 4 2	8149	2638	1110	2231	3532
2 4 4 4 4 2	1052	751	589	495	722
4 4 4 4 2 2	3160	1814	1503	1076	1888
2 2 2 2 4 4	2526	1303	1613	1296	1685
4 2 2 2 2 4	896	1624	585	785	973
2 4 2 2 2 4	953	1665	1695	1363	1419
4 4 2 2 4 4	3801	2162	1458	1913	2334
2 2 4 2 4 2	849	1465	297	786	849
4 2 4 2 2 2	1899	2158	1700	1174	1733
2 4 4 2 2 2	761	1108	2601	1465	1484
4 4 4 2 4 2	1846	2200	2789	1475	2078
2 2 2 4 4 2	938	1083	1022	309	838
4 2 2 4 2 2	1043	2113	908	1648	1428
2 4 2 4 2 2	952	831	1111	893	947
4 4 2 4 4 2	6634	1481	2572	1919	3152
2 2 4 4 4 4	1141	970	986	975	1018
4 2 4 4 2 4	4019	2256	1189	896	2090
2 4 4 4 2 4	1154	736	2115	1314	1330
4 4 4 4 4 4	2801	1562	900	1270	1633

Table 8 continued.

Treatment levels N P S Cl Na B	June 26, ppm.	August 10, ppm.	Sept. 21, ppm.	Nov. 2, ppm.	Mean, ppm.
5 3 3 3 3 3	10485	8637	5295	4711	7282
1 3 3 3 3 3	673	751	602	791	704
3 5 3 3 3 3	1224	1019	991	1161	1099
3 1 3 3 3 3	1135	1189	1019	1133	1119
3 3 5 3 3 3	1841	1291	1779	887	1450
3 3 1 3 3 3	1356	1014	193	502	766
3 3 3 5 3 3	1519	1292	495	897	1051
3 3 3 1 3 3	2190	895	1159	1587	1458
3 3 3 3 5 3	1742	656	195	1207	950
3 3 3 3 1 3	1716	1238	298	794	1012
3 3 3 3 3 5	1518	1175	488	1240	855
3 3 3 3 3 1	1147	916	890	804	839
3 3 3 3 3 3	3036	747	1090	895	1442
3 3 3 3 3 3	2691	739	582	1537	1387
3 3 3 3 3 3	1472	1010	766	2196	1361
3 3 3 3 3 3	1935	464	496	1296	1048
3 3 3 3 3 3	779	1952	1354	1898	1496
3 3 3 3 3 3	2008	1006	395	1497	1227
3 3 3 3 3 3	1444	919	1089	1748	1300
3 3 3 3 3 3	1457	634	1906	1601	1400
3 3 3 3 3 3	1640	1763	1649	3518	2143
3 3 3 3 3 3	1449	1569	100	407	881

Table 9. Analysis of variance for nitrate-N, phosphate-P (seasonal means), sulfate-S, Cl, Na and B (second sampling) concentrations of petioles (dry basis) as affected by various combinations of levels of N, P, S, Cl, Na and B.

Source	nitrate-N, log. ppm.	phosphate-P, %	sulfate-S, %	Cl, %	Na, %	B, ppm.
d.f.						
Total	53	53	53	53	53	53
Block	2	2	2	2	2	2
Linear	6	6	6	6	6	6
Quadratic	21	21	21	21	21	21
Lack of fit	17	17	17	17	17	17
Error	7	7	7	7	7	7
S.S.						
Total	2.52	0.0254	0.0362	24.8	10.9	18735.0
Block	0.07	0.0013	0.0013	1.0	2.2	6033.1
Linear	1.47	0.0119	0.0058	11.4	3.5	577.8
Quadratic	0.74	0.0088	0.0122	6.2	2.2	7463.5
Lack of fit	0.15	0.0031	0.0144	4.5	2.8	4041.8
Error	0.09	0.0003	0.0025	1.7	0.3	618.8
M.S.						
Block	0.03	0.0006**	0.0007	0.5	1.1**	3016.6**
Linear	0.24**	0.0020**	0.0010	1.9**	0.6**	96.3
Quadratic	0.04	0.0004**	0.0006	0.3	0.1	355.4*
Lack of fit	0.01	0.0002*	0.0008	0.3	0.2*	237.8
Error	0.01	0.0004	0.0004	0.2	0.05	88.4
C.V., %	3.6	3.5	20.0	15.3	15.8	16.4
Equation sufficiency[1], %	93.5	86.9	55.6	79.5	66.8	66.5

* 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 10. Phosphate-P concentration in the petioles (dry basis) at four sampling dates and the seasonal mean as affected by various combinations of levels of N, P, S, Cl, Na and B.

Treatment levels N P S Cl Na B	June 26, %	August 10, %	Sept. 21, %	Nov. 2, %	Mean, %
2 2 2 2 2 2	0.214	0.127	0.105	0.146	0.148
4 2 2 2 4 2	0.235	0.071	0.182	0.164	0.163
2 4 2 2 4 2	0.293	0.140	0.099	0.205	0.184
4 4 2 2 2 2	0.271	0.126	0.129	0.135	0.165
2 2 4 2 2 4	0.262	0.163	0.117	0.124	0.167
4 2 4 2 4 4	0.214	0.104	0.123	0.140	0.145
2 4 4 2 4 4	0.279	0.176	0.173	0.129	0.189
4 4 4 2 2 4	0.250	0.075	0.104	0.190	0.155
2 2 2 4 2 4	0.216	0.123	0.104	0.138	0.145
4 2 2 4 4 4	0.131	0.118	0.106	0.172	0.132
2 4 2 4 4 4	0.287	0.123	0.181	0.179	0.193
4 4 2 4 2 4	0.245	0.190	0.184	0.197	0.204
2 2 4 4 2 2	0.208	0.170	0.137	0.146	0.166
4 2 4 4 4 2	0.141	0.119	0.077	0.148	0.121
2 4 4 4 4 2	0.254	0.142	0.107	0.124	0.157
4 4 4 4 2 2	0.215	0.145	0.148	0.104	0.153
2 2 2 2 4 4	0.238	0.100	0.099	0.131	0.142
4 2 2 2 2 4	0.206	0.114	0.111	0.126	0.139
2 4 2 2 2 4	0.257	0.156	0.127	0.173	0.178
4 4 2 2 4 4	0.253	0.205	0.160	0.177	0.199
2 2 4 2 4 2	0.314	0.109	0.123	0.137	0.171
4 2 4 2 2 2	0.228	0.179	0.112	0.093	0.153
2 4 4 2 2 2	0.356	0.083	0.138	0.154	0.183
4 4 4 2 4 2	0.240	0.200	0.188	0.208	0.208
2 2 2 4 4 2	0.238	0.186	0.154	0.121	0.175
4 2 2 4 2 2	0.207	0.169	0.096	0.161	0.158
2 4 2 4 2 2	0.239	0.191	0.159	0.191	0.195
4 4 2 4 4 2	0.236	0.153	0.183	0.190	0.191
2 2 4 4 4 4	0.231	0.187	0.146	0.134	0.175
4 2 4 4 2 4	0.161	0.125	0.094	0.140	0.130
2 4 4 4 2 4	0.344	0.129	0.163	0.224	0.215
4 4 4 4 4 4	0.265	0.158	0.104	0.143	0.168

Table 10 continued.

Treatment levels N P S Cl Na B	June 26, %	August 10, %	Sept. 21, %	Nov. 2, %	Mean, %
5 3 3 3 3 3	0.230	0.138	0.154	0.121	0.161
1 3 3 3 3 3	0.299	0.180	0.129	0.163	0.193
3 5 3 3 3 3	0.313	0.169	0.156	0.153	0.198
3 1 3 3 3 3	0.186	0.126	0.123	0.0%	0.133
3 3 5 3 3 3	0.287	0.154	0.152	0.126	0.180
3 3 1 3 3 3	0.217	0.120	0.096	0.122	0.139
3 3 3 5 3 3	0.247	0.148	0.102	0.109	0.152
3 3 3 1 3 3	0.222	0.167	0.120	0.138	0.162
3 3 3 3 5 3	0.192	0.129	0.104	0.106	0.133
3 3 3 3 1 3	0.276	0.157	0.112	0.135	0.170
3 3 3 3 3 5	0.281	0.157	0.154	0.144	0.184
3 3 3 3 3 1	0.265	0.158	0.164	0.159	0.187
3 3 3 3 3 3	0.268	0.183	0.112	0.182	0.186
3 3 3 3 3 3	0.246	0.161	0.118	0.167	0.173
3 3 3 3 3 3	0.270	0.138	0.104	0.206	0.180
3 3 3 3 3 3	0.257	0.130	0.127	0.155	0.167
3 3 3 3 3 3	0.262	0.162	0.151	0.135	0.178
3 3 3 3 3 3	0.255	0.164	0.160	0.166	0.186
3 3 3 3 3 3	0.285	0.169	0.137	0.153	0.186
3 3 3 3 3 3	0.272	0.159	0.159	0.142	0.183
3 3 3 3 3 3	0.273	0.153	0.121	0.161	0.177
3 3 3 3 3 3	0.288	0.160	0.113	0.161	0.181

Table 11. Sulfate-S, Cl, Na and B concentrations in petioles (dry basis) of the second sampling, as affected by various combinations of levels of N, P, S, Cl, Na and B.

Treatment levels N P S Cl Na B	Sulfate-S, %	Cl, %	Na, %	B, ppm.
2 2 2 2 2 2	0.073	3.26	1.00	49
4 2 2 2 4 2	0.062	2.88	2.68	54
2 4 2 2 4 2	0.114	4.03	1.54	77
4 4 2 2 2 2	0.134	2.07	1.81	52
2 2 4 2 2 4	0.083	2.81	1.14	48
4 2 4 2 4 4	0.073	2.40	2.76	57
2 4 4 2 4 4	0.126	3.04	1.37	65
4 4 4 2 2 4	0.094	2.48	2.61	72
2 2 2 4 2 4	0.105	4.61	1.50	42
4 2 2 4 4 4	0.042	3.32	1.76	93
2 4 2 4 4 4	0.125	4.98	1.58	69
4 4 2 4 2 4	0.136	2.82	1.46	46
2 2 4 4 2 2	0.083	3.85	1.37	40
4 2 4 4 4 2	0.146	3.53	1.80	41
2 4 4 4 4 2	0.102	4.10	1.41	40
4 4 4 4 2 2	0.125	3.90	1.41	42
2 2 2 2 4 4	0.083	3.52	1.14	45
4 2 2 2 2 4	0.084	3.44	0.66	82
2 4 2 2 2 4	0.094	3.11	0.97	110
4 4 2 2 4 4	0.114	4.22	1.46	57
2 2 4 2 4 2	0.117	3.82	1.29	88
4 2 4 2 2 2	0.084	1.93	1.03	89
2 4 4 2 2 2	0.084	3.61	1.17	84
4 4 4 2 4 2	0.052	2.65	1.50	90
2 2 2 4 4 2	0.062	2.77	0.81	100
4 2 2 4 2 2	0.083	2.43	1.17	81
2 4 2 4 2 2	0.083	3.82	0.63	88
4 4 2 4 4 2	0.114	2.87	1.46	77
2 2 4 4 4 4	0.052	3.22	0.58	91
4 2 4 4 2 4	0.146	2.75	1.03	109
2 4 4 4 2 4	0.135	4.81	1.07	71
4 4 4 4 4 4	0.094	3.01	1.25	90

Table 11 continued.

Treatment levels N P S Cl Na B	Sulfate-S, %	Cl, %	Na, %	B, ppm.
5 3 3 3 3 3	0.115	2.13	1.67	78
1 3 3 3 3 3	0.104	3.96	0.66	84
3 5 3 3 3 3	0.125	3.16	1.03	71
3 1 3 3 3 3	0.104	2.60	1.03	64
3 3 5 3 3 3	0.114	2.68	1.07	73
3 3 1 3 3 3	0.073	3.12	1.29	73
3 3 3 5 3 3	0.083	3.99	1.41	88
3 3 3 1 3 3	0.135	2.50	1.03	86
3 3 3 3 5 3	0.063	3.13	2.05	67
3 3 3 3 1 3	0.094	2.59	1.07	66
3 3 3 3 3 5	0.093	2.85	1.76	91
3 3 3 3 3 1	0.115	2.52	1.62	51
3 3 3 3 3 3	0.125	2.49	1.10	53
3 3 3 3 3 3	0.084	2.78	1.50	50
3 3 3 3 3 3	0.094	3.12	1.17	61
3 3 3 3 3 3	0.146	3.46	1.50	51
3 3 3 3 3 3	0.093	3.43	1.50	47
3 3 3 3 3 3	0.094	2.85	1.29	42
3 3 3 3 3 3	0.093	4.15	1.86	67
3 3 3 3 3 3	0.083	3.17	1.33	68
3 3 3 3 3 3	0.063	2.87	1.50	66
3 3 3 3 3 3	0.063	3.54	1.54	68

Table 12. Regression coefficients (b) and their standard errors (s_b) for the observed nitrate-N concentrations of petioles (log. ppm., dry basis) at four sampling dates as affected by various combinations of levels of N, P, S, Cl, Na and B.

Term	June 26 b	June 26 s_b	Aug. 10 b	Aug. 10 s_b	Sept. 21 b	Sept. 21 s_b	Nov. 2 b	Nov. 2 s_b
Mean	3.223		2.988		2.857		3.168	
N	+0.262**	±0.022	+0.181**	±0.025	+0.093	±0.059	+0.088	±0.042
P	+0.005	"	-0.028	"	+0.069	"	+0.047	"
S	+0.015	"	+0.020	"	+0.091	"	+0.023	"
Cl	+0.007	"	-0.028	"	-0.028	"	-0.041	"
Na	+0.049	"	+0.007	"	-0.022	"	+0.004	"
B	+0.035	"	+0.001	"	-0.014	"	+0.003	"
NN	+0.046*	±0.019	+0.085**	±0.021	+0.091	±0.051	+0.017	±0.036
PP	-0.017	"	+0.020	"	+0.046	"	-0.024	"
SS	+0.005	"	+0.023	"	+0.005	"	-0.066	"
ClCl	+0.016	"	+0.018	"	+0.024	"	-0.021	"
NaNa	+0.012	"	+0.004	"	-0.064	"	-0.036	"
BB	-0.009	"	+0.015	"	+0.014	"	-0.034	"
N-P	+0.042	±0.026	-0.025	±0.029	-0.007	±0.069	-0.004	±0.048
N-S	-0.006	"	+0.010	"	+0.029	"	+0.017	"
N-Cl	+0.022	"	-0.022	"	-0.075	"	+0.008	"
N-Na	+0.046	"	+0.005	"	+0.048	"	+0.036	"
N-B	-0.023	"	-0.015	"	-0.136	"	-0.104	"
P-S	-0.058	"	-0.032	"	-0.011	"	-0.046	"
P-Cl	+0.018	"	-0.003	"	-0.020	"	+0.029	"
P-Na	-0.096**	"	-0.047	"	-0.037	"	+0.008	"
P-B	+0.009	"	+0.048	"	-0.020	"	+0.049	"
S-Cl	+0.020	"	+0.003	"	-0.017	"	+0.032	"
S-Na	-0.043	"	-0.006	"	-0.089	"	+0.008	"
S-B	+0.022	"	-0.008	"	0.000	"	-0.002	"
Cl-Na	-0.012	"	-0.047	"	-0.007	"	-0.023	"
Cl-B	-0.021	"	-0.022	"	-0.045	"	-0.007	"
Na-B	0.000	"	-0.006	"	-0.002	"	+0.007	"

* Statistically significant at the 5% level.

** Statistically significant at the 1% level.

Table 13. Regression coefficients (b) and their standard errors (s_b) for the observed phosphate-P concentrations of petioles (percentage, dry basis) at four sampling dates as affected by various combinations of levels of N, P, S, Cl, Na and B.

Term	June 26, b	June 26, s_b	Aug. 10, b	Aug. 10, s_b	Sept. 21, b	Sept. 21, s_b	Nov. 2, b	Nov. 2, s_b
Mean	0.268		0.158		0.130		0.161	
N	-0.021**	±0.0018	-0.004	±0.0024	+0.001	±0.0015	-0.002	±0.0026
P	+0.026**	"	+0.008*	"	+0.012**	"	+0.015**	"
S	+0.008**	"	+0.001	"	0.000	"	-0.006	"
Cl	-0.010**	"	+0.006*	"	0.000	"	0.000	"
Na	-0.005*	"	-0.001	"	+0.004*	"	0.000	"
B	0.000	"	-0.001	"	-0.002	"	+0.001	"
NN	-0.002	±0.0015	-0.001	±0.0020	+0.002	±0.0013	0.000	±0.0022
PP	-0.004*	"	-0.003	"	+0.002	"	-0.003	"
SS	-0.004*	"	-0.005	"	-0.001	"	-0.003	"
ClCl	-0.007*	"	-0.001	"	-0.003*	"	-0.004	"
NaNa	-0.007*	"	-0.004	"	-0.004*	"	-0.004	"
BB	0.000	"	-0.001	"	-0.005*	"	+0.001	"
N-P	+0.002	±0.0021	+0.009*	±0.0028	+0.004*	±0.0017	-0.003	±0.0030
N-S	-0.010**	"	-0.002	"	-0.009**	"	-0.001	"
N-Cl	-0.003	"	-0.003	"	-0.009**	"	-0.001	"
N-Na	-0.003	"	-0.001	"	+0.004	"	+0.010*	"
N-B	-0.001	"	-0.002	"	-0.007*	"	+0.002	"
P-S	+0.001	"	-0.010**	"	-0.002	"	-0.002	"
P-Cl	+0.008**	"	-0.005	"	+0.005*	"	-0.004	"
P-Na	-0.004	"	+0.012**	"	-0.003	"	-0.003	"
P-B	+0.006*	"	+0.004	"	+0.004*	"	+0.004	"
S-Cl	-0.005	"	-0.004	"	-0.008*	"	-0.003	"
S-Na	-0.005	"	+0.007*	"	-0.003	"	-0.003	"
S-B	+0.005	"	0.000	"	+0.001	"	+0.004	"
Cl-Na	-0.002	"	-0.004	"	-0.007**	"	-0.008*	"
Cl-B	+0.010**	"	-0.006	"	+0.003	"	+0.006	"
Na-B	-0.002	"	+0.005	"	0.000	"	-0.009*	"

* Statistically significant at the 5% level.

** Statistically significant at the 1% level.

Table 14. Total N uptake by plants in relation to applied N as affected by various combinations of levels of N, P, S, Cl, Na and B.

Treatment levels N P S Cl Na B	N in roots, kg./Ha.	N in tops, kg./Ha.	Total uptake of N. kg./Ha.	Applied N kg./Ha.
2 2 2 2 2 2	88	56	144	75
4 2 2 2 4 2	211	124	335	300
2 4 2 2 4 2	136	84	220	75
4 4 2 2 2 2	145	112	257	300
2 2 4 2 2 4	108	82	190	75
4 2 4 2 4 4	152	115	267	300
2 4 4 2 4 4	99	60	159	75
4 4 4 2 2 4	124	102	226	300
2 2 2 4 2 4	106	62	168	75
4 2 2 4 4 4	103	76	178	300
2 4 2 4 4 4	123	69	192	75
4 4 2 4 2 4	186	121	307	300
2 2 4 4 2 2	178	74	252	75
4 2 4 4 4 2	138	129	267	300
2 4 4 4 4 2	107	87	194	75
4 4 4 4 2 2	142	153	295	300
2 2 2 2 4 4	112	107	219	75
4 2 2 2 2 4	116	57	173	300
2 4 2 2 2 4	137	52	189	75
4 4 2 2 4 4	354	130	384	300
2 2 4 2 4 2	141	46	187	75
4 2 4 2 2 2	188	77	265	300
2 4 4 2 2 2	152	99	249	75
4 4 4 2 4 2	271	129	400	300
2 2 2 4 4 2	123	87	210	75
4 2 2 4 2 2	189	157	346	300
2 4 2 4 2 2	132	69	201	75
4 4 2 4 4 2	248	166	414	300
2 2 4 4 4 4	82	49	131	75
4 2 4 4 2 4	138	98	236	300
2 4 4 4 2 4	141	101	242	75
4 4 4 4 4 4	151	109	260	300

Table 14 continued.

Treatment levels N P S Cl Na B	N in roots, kg./Ha.	N in tops, kg./Ha.	Total uptake of N. kg./Ha.	Applied N kg./Ha.
5 3 3 3 3 3	201	190	391	782
1 3 3 3 3 3	83	41	124	29
3 5 3 3 3 3	164	63	237	150
3 1 3 3 3 3	214	95	309	150
3 3 5 3 3 3	167	90	257	150
3 3 1 3 3 3	142	61	203	150
3 3 3 5 3 3	141	108	249	150
3 3 3 1 3 3	127	68	195	150
3 3 3 3 5 3	135	71	206	150
3 3 3 3 1 3	82	49	131	150
3 3 3 3 3 5	109	87	196	150
3 3 3 3 3 1	142	126	268	150
3 3 3 3 3 3	155	77	232	150
3 3 3 3 3 3	115	73	188	150
3 3 3 3 3 3	195	120	315	150
3 3 3 3 3 3	130	66	196	150
3 3 3 3 3 3	164	107	271	150
3 3 3 3 3 3	91	48	139	150
3 3 3 3 3 3	141	107	248	150
3 3 3 3 3 3	148	96	244	150
3 3 3 3 3 3	146	111	237	150
3 3 3 3 3 3	139	91	230	150