ST
719
c.1

INTERRELATIONSHIPS OF NITROGEN, PHOSPHORUS, SULFUR, SODIUM, POTASSIUM AND MAGNESIUM ON THE YIELD AND COMPOSITION OF SUGAR BEETS

by

Arsalan Mahmood Mazaheri

A Thesis Submitted to the Faculty
of Agricultural Sciences in Partial Fulfillment of
The Requirements for the Degree of
MASTER OF SCIENCE IN AGRICULTURE

Major: Soils

Minor: Irrigation

Approved:

H. D. Fuehring
In Charge of Major Work

O. Sayegh

E. E. Barnard Jr.

Salim Macksoud

W. W. Worzella
Chairman, Graduate Committee

AMERICAN UNIVERSITY OF BEIRUT
SCIENCE & AGRICULTURE
LIBRARY

American University of Beirut

1965

AMERICAN UNIVERSITY OF BEIRUT
LIBRARY

SUGAR BEET NUTRITION

Mazaheri

ACKNOWLEDGMENT

The author wishes to acknowledge with sincere gratitude the constant guidance and supervision and constructive suggestions of Dr. Howard Dale Fuehring during the course of this experiment and his excellent remarks during the writing of the manuscript.

The author also wishes to thank Miss Lucy Unkababian for her help in some laboratory work. Appreciation is due to Miss Arpi Unkababian for typing this manuscript.

Arsalan Mazaheri

AMERICAN UNIVERSITY OF BEIRUT
SCIENCE & AGRICULTURE
LIBRARY

ABSTRACT

An irrigated field experiment was conducted in Beqa'a Plain, Lebanon to study the interrelationship of N, P, S, Na, K and Mg (each varied at five levels) on the yield and composition of sugar beets. A central composite rotatable incomplete factorial design was used for this purpose.

The yields of beets obtained were generally high with an average of 103.6 m.tons per hectare indicating the great potentiality of the area for sugar beet production.

Although N had a significantly positive first order effect, when all the quadratic effects were considered the yield of beets was found to be depressed by high levels of N application. Similarly K and Mg tended to decrease the yields whereas P, S and Na tended to produce favorable effects. The effects of P and S were particularly positive when both were present at high levels due to their positive interaction.

Application of N produced a significantly positive effect on the yield of tops and N content of roots and tops, but it tended to decrease the sucrose concentration of roots. Application of P decreased the N concentration in roots significantly as indicated by the negative first order effect of P and the negative N-P interaction.

It was found in this experiment that petiole analysis gave a better picture of the nutritional status of sugar beet plants than analysis of leaf blades. The nitrate-N concentration of petioles decreased as the season advanced, but it was always positively related with the level of applied N. The "critical level" of nitrate-N in the petioles was estimated to be about 4,000 ppm. at three months after planting and gradually decreased to about 700 ppm. at one month before harvest. The phosphate-P content of the petioles was very positively related with the level of applied P, but this positive relationship decreased as the season advanced. The "critical level" of phosphate-P was estimated to be about 2,700 ppm. at three months after planting and about 1,000 ppm. at five months after planting after which it remained almost constant. The sulfate-S concentration in petioles was positively related to the level of applied S throughout the season whereas the effect of the other elements changed as the season advanced. The estimated "critical level" of sulfate-S in the petioles was found to be about 400 ppm. On the contrary, the total S content of leaf blades was found to be relatively high. The acid soluble Na and K in the petioles did not change appreciably during the season. Application of Na and N generally tended to increase the concentration of Na in the petioles. The level of total Na in leaf blades tended to decrease as the level of applied S and K increased. The tentative "critical level" for seasonal Na concentration in petioles was estimated to be 1.87 percent.

The generally high correlation coefficients between the observed and calculated yields and the relatively high percentage of equation sufficiency indicated that the method of using the quadratic regression equation was effective and accurate.

TABLE OF CONTENT

Page

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

About one-third of the present world's supply of sugar comes from the sugar beet crop. It is the main source of sugar in the countries where the climatic conditions are not suitable for the growth of sugar cane. The ever increasing world demand for sugar and the interest of certain governments in having independence from external sugar supplies have resulted in the expansion of sugar beet acreage throughout the world.

The recorded yield levels vary greatly depending on the locality, type of soil, irrigation practices, insect and disease control and fertilization. Fertilization is one of the most important factors influencing the yield and quality of sugar beets.

The climate of the Beqa'a Plain in Lebanon, with warm sunny days, cool nights, and a long growing season is very favorable for the growth of sugar beets. The average yields obtained by the local farmers (35 m. tons/ha.), however, are less than one-third of that obtained by research workers under controlled conditions. This indicates that there is much to be done in improving cultural practices, irrigation programs and fertilization management to raise the production.

The fertilization of the soil with N requires special attention not only because of the influence on sugar beet yield, but also because of the effect on the sucrose concentration and processing quality of the roots. Phosphorus is regarded as less critical for sugar beets than N. It has been found that P not only improves the yield, but also enhances the response to N through its positive interaction with the latter. Na has been found to favor sugar beets both as a partial K substitute and for its own merit. The effect of S is not well known, but the numerous negative S-N, S-Na and S-P interactions have indicated a possible harmful effect and a need to keep S application low where S is already present in adequate amounts. Reports in the literature indicate that in some cases sugar beets have responded to the application of K and Mg fertilizers. The response to anyone of the above elements is influenced by the level of other elements. A thorough study of the interaction of the various elements, therefore, is needed to establish the nutrition of sugar beets.

Most of the soils in the Beqa'a Plain and other parts of the Middle East are deficient in N and usually in P. Due to the limited rainfall and relatively little weathering, however, they tend to be rich in minerals. Since high levels of certain elements may upset the nutrient balance and depress the yield, the nutrient excesses may be as important as the deficiencies.

The experiment reported here was conducted at the Agricultural Research and Education Center (AREC) of the American University of Beirut in the Beqa'a, Lebanon to study the interrelationships of N, P, S, Na, K and Mg on the growth and composition of sugar beets and to estimate the "critical levels" of the nutrients in the leaf petioles and blades. The central composite rotatable incomplete factorial design (13) used in this experiment allowed the study of the six variables at the same time with each covering a wide range of levels.

REVIEW OF LITERATURE

Due to the great economic importance of the sugar beet crop, considerable research effort has been expended and a large body of scientific literature has been accumulated. The following pages give a brief review of the work already done in sugar beet nutrient requirement studies in relation to the nutrient elements under investigation in this report.

Effect of Nitrogen

The works of many investigators have consistently revealed that sugar beets respond well to N application resulting in considerable increases in root and top tonnage (27, 30, 34, 44, 60, 67). Top-root ratio studies by Baird (10) indicated that N encouraged top growth more than root growth. Haddock (27) conducted a field experiment in Utah and concluded that the top-root ratio can serve as an indication for the nutrient status of beets. He reported that this ratio should approach 0.5 under the conditions of his experiments with N as the only growth factor varied. Severe decreases in yield of tops and roots have been observed under N deficient conditions (18, 45).

The recommended rates of N application per acre stated by different workers vary depending on the soil fertility level, length of the growing season and the general potential yield level. Tolman and Stoker (62) found a negative correlation between the increase in the root yield due to N application and the soil organic matter content. Application of 400 lbs. of N per acre resulted in an increase of 24 percent over the checks on soils containing 0.5 percent organic matter, but only 4 percent increase on soils with 2.5 percent organic matter. Haddock (28) pointed out that the soil must supply 10 lbs. of N for each ton of beets produced. Application of N to soils which can supply this quantity or more will result in no significant increase in beet yield, although it may depress the sucrose percentage appreciably. The A.U.B. workers at AREC, Beqa'a, Lebanon (20, 25, 30) have obtained profitable increase in root yield (100-130 m. tons/ha.) up to 350 lbs. N per acre under the conditions of a long growing season.

Most of the workers are in agreement that while there is a positive correlation between N application rate and root yield, sucrose concentration varies inversely with the level of N (48, 51, 53, 66). In many cases, however, the increase in root tonnage more than offsets the reduction in sucrose content resulting in increased total yield of sugar. Stout (59) pointed out that the reduction in sucrose percentage associated with high levels of N application is due to the increased leaf growth which causes greater expenditure of stored sugar. He also noted that sucrose percentage reduction is more pronounced with heavy application of N late in the season which results in improper timing of nitrate uptake.

Excessive N application decreases the quality of sugar beets by increasing the percentage of different nitrogenous compounds in the root and therefore impairing the processing and decreasing the sugar extraction (1, 31, 44, 49, 59). Goodban _et al_. (23) found an inverse relation between the purity of extracted juice and the beet N content ($r = -0.97$) and he indicated that to maintain the sugar beet quality at a satisfactory level, the root N content must not exceed 0.2 percent (fresh basis).

The interrelationship of N and other elements has been studied by several workers. Tolman and Johnson (61) found a positive interaction between N and P indicating that the positive response of roots and sugar yield to N was increased at higher levels of available P. Alexander _et al_. (6) reported an increase in P content of leaf blades due to N application. Dimitrov and Atanasov (16) reported that PK application decreased the content of nitrogenous impurities in sugar beets and therefore contributed to better beet quality and higher yield of sugar especially at higher levels of N application.

It has been found that the nitrate-N content of the petioles of recently matured leaves is a good criterion for the estimation of the N status of the soil and can be used as a guide in adjusting the fertilization program for obtaining high yields of sugar beets of good quality. The positive correlation between nitrage concentration of petioles and N application and the degree of response has been confirmed by many workers. Krantz and Mackenzie (40) reported that for optimum yield the nitrate-N concentration of petioles should be maintained above the"critical level" up to about 11-12 weeks before harvest. If the nitrate-N concentration remained above the"critical level"3-9 weeks before harvest, the sucrose percentage of roots was reduced. Ulrich (65) found that high application of N delayed the ripening of beets. For example, beets grown in sand culture with controlled temperature and light failed to "sugar up" after 83 days of growth when grown under a high N level, whereas those with a low N level started to accumulate sugar at this time.

Ulrich (65) studied the "critical level" of nitrate-N in petioles and came to the conclusion that beet tonnage increased significantly with nitrate concentration in petioles up to 1,000 ppm., but above that no significant increase in yield was obtained. He also noted that the sucrose concentration in roots and the nitrate concentration in petioles are negatively correlated. Results of field experiments reported by Carlson and Herring (12) were in agreement with those obtained by Ulrich. Haddock (26) however, got significant responses to N application when the nitrate concentration in petioles was 1,500 ppm., but no response at a nitrate concentration of 3,000 ppm. Magnitski (46) showed that the "critical levels" of nitrate-N varied with the phase of development being 500 ppm. (fresh basis) early in the season under Moscow conditions and 10 ppm. late in the season. Hashimi (30) in Lebanon estimated the "critical level" of nitrate-N to be 7,420 ppm. early in the season when all the N was applied at planting time. Haddad (25) in Lebanon found that the "critical level" of nitrate was 3,400 ppm. early in the season and gradually decreased to 1,100 ppm. at about one and a half months before harvesting. The "critical levels" reported by Hashimi and Haddad were for considerably higher yield levels than the yields obtained by Ulrich and Magnitski.

Ulrich (66) reported the results of pot experiments in which he showed that increase in the sucrose concentration due to 4-6 weeks of preharvest deficiency offset tonnage losses of 20-25 percent. This indicated that the nitrate-N content of the petioles must be below the "critical level" towards the end of the growing season. This factor must be taken into consideration in uncontrolled application of N.

It is observed that the available literature generally indicate the favorable effect of N on sugar beets. Since the degree of response depends on the N status of the soil and climatical conditions, and since excessive rates of N applications tend to lower the beet quality and sucrose concentration, the recommended rates of application involve a thorough study of these factors. The "critical levels" of nitrate-N must be determined in relation to the length of growing season, the expected yield levels and the time of fertilization.

Effect of Phosphorus

It has been observed that response to P application varies from place to place. Some investigators (32, 47) obtained no response to P, whereas significant increases due to P application have been reported by other workers. It appears that the degree of response is dependent upon the amount of available P in the soil. Tolman (60) reported that soils containing less than 5 ppm. available P_2O_5 (CO_2 soluble) responded highly to P application, but no positive response was obtained in soils with more than 50 ppm. P_2O_5. The results of field experiments by Carlson and Herring (12) indicated a definite response to P application in locations having 8.3 ppm. available P_2O_5 ($NaHCO_3$ soluble) whereas locations with 83-89 ppm. available P_2O_5 showed no response to the addition of P.

Olson et al. (50) found that ammonium phosphate and superphosphate were of equal availability, but they were both more available than calcium metaphosphate early in the season in calcareous soils.

Reviewing the results of many field experiments in England, Russell (53) concluded that P application favorably affected the root growth with no significant effect on sucrose percentage. Allos and Macksoud (7) conducted a field experiment in Lebanon and found that sugar beet tonnage was improved by N and P application, while no significant variation was noticed in sugar percentage. Davis _et al_. (15) and Larson and Pierre (42) also noted that P had no significant effect on percentage sugar or apparent purity. Some other workers (16, 58), however, pointed out that P improves the quality of sugar beet by reducing the harmful effect of excess N. Adams (4) reported that the results of 49 field studies indicated that the response of sugar beets to P was small as compared to N. Baird (10) and Black (11) reported a small effect of P on top growth as compared to root development.

Adams (3) reported that the response to P varied with the time of application. He found that spring application also resulted in faster growth early in the season. Davis _et al_. (15) found that only small applications (50-100 lbs. of P_2O_5 per acre) produced profitable increases in yield.

Measurements with radioactive P showed that sugar beets absorbed about 10-12 percent of the applied P and Grunes _et al_. (24) found a high correlation between beet yield and P absorbed from fertilizer application.

Grunes *et al.* (24) studied the interrelationship of P with other elements and found a positive P-N interaction indicating a higher level of P uptake when N supply was high. Tolman (60) obtained similar results and concluded that application of P in N deficient soils had depressing effects in some cases. It has been shown by a few investigators (5, 15, 32) that the application of P generally decreased the percentage of Mg, K and Ca in leaves and increased the Na percentage.

Alexander *et al.* (6) found that P application increased and N application decreased the P content of sugar beet leaves significantly. He also noted a gradual decrease of P content of tissues with time. Saric and Curie (54) showed that uptake of P was greatest at the start of growth, and gradually decreased later. They found that roots contained more P than leaves and growing leaves more than the older ones. Haddock (28) showed that the phosphate content of the petioles tended to decrease rapidly until July and then declined at a gradual rate reaching a minimum in October.

Ulrich (65) studied the "critical level" of P content in petioles and reported 750 ppm. of phosphate-P as the critical level. No significant response to P application was observed in the fields testing above this value even though the absorption of P was increased. Davis *et al.* (15)

concluded that to obtain the highest yield, the extractable P must not be allowed to fall below 0.15 percent (dry basis) throughout the growing season. Magnitski (46) stated that the P "critical level" changed as the season advanced and he showed it to be 40 ppm. of P in petioles (fresh matter basis) and gradually dropping to a constant level of 25 ppm. The results of Haddad's experiment (25) on the calcareous soil of Lebanon indicated that for relatively high yield levels, the "critical level" of phosphate-P in petioles was 3,000 ppm. early in the season and declined to 1,650 in midseason after which it did not change very much.

It appears that sugar beet response to P application is less than that to N and depends on the supply of available P in the soil. Excessive rates of P do not have any adverse effect on the sugar content and processing quality. The overapplication of P, therefore, is less critical than that of N. Since the P content varies as the season advances, the "critical levels" must be given in relation to the stage of growth.

Effect of Sulfur

Some crops in certain soils and environments deficient in S have shown response to S fertilization. Few cases of S deficiency have been reported in sugar beet plants. The lack of need for S application in most areas could be attributed to the indirect addition of adequate amounts of this element to the soil from superphosphates, ammonium sulfates, mixed fertilizers, irrigation water and atmospheric S compounds (14, 21). Gilbert (21) reported the localization of S deficiency in several states and a positive response to S application in the Pacific North-West of the United States.

Tolman and Stoker (62) found a positive S-N interaction where no positive response was noticed to the application of S in plots deficient in N whereas in plots with high levels of applied N, an increase in positive response to N was observed due to the addition of S. Kalinevich (38) found similar results and attributed the positive S-N interaction to the similarity of the biological nature of reduction of sulfate to the reduced form to that of nitrate and ammonia and thus the ability of S to substitute for nitrate in certain processes and vice versa. It was observed that a high level of nitrate or sulfate retarded the reduction of the other.

Some of the A.U.B. workers in Lebanon (20, 25, 30) found that S application resulted in reduction in yields. They attributed this to the negative S-N, S-P and S-Na interactions which indicated that increasing the level of S decreased the positive responses to N, P and Na.

Ulrich <u>et al</u>. (68) found that sulfate-S content of the petioles was not as sensitive for determination of the S status of sugar beet plants as that of leaf blades. He recommended 250 ppm. as the "critical level" of sulfate-S in the leaf blades as a means of evaluating the S status.

Effect of Sodium

The question of considering Na as an essential element is still controversial. Many plants have been shown to complete their life cycles with very low levels of Na, whereas the maximum yield of many crops could be obtained only when a sufficient amount of Na was available. Black (11) reports that studies with cotton have indicated that Na may act for K in its role for balancing organic and inorganic anions, but not in its essential role in metabolic reactions. He indicated the favorable effect of Na on fodder beets which showed a significant response to the addition of $NaNO_3$ at all levels of K application whereas no increase in yield was obtained when $CaNO_3$ was used as the source of N. Truog and Berger (63) found that sugar beets responded well to the addition of this element even at high levels of K, but the amount of Na absorbed was more when the K supply was at a low level. Larson and Pierre (42) reported that Na and K were equally effective in increasing the yield of table beets in Harpster silt loam (calcareous) and Carrington loam soils and the largest yield resulted from the 2Na-K level. They also investigated the plant composition in relation to Na application and came to the conclusion that increasing the Na level resulted in a marked increase in the Na content of the foliage and was, in many cases, accompanied by reduction of the K content. According to this report the crops that take up the most Na with the least depression in K will respond the most to Na fertilization.

Davis et al. (15) reported that Na increased the P content of the roots. Finkner et al. (19) found that the beet Na content was increased by N. Lehr (43) introduced the concept of "cationic equilibrium" to explain the vital and complicated role of Na, Ca, K and Mg together in plant nutrition. According to this concept the relative amount of these elements rather than absolute quantities of each one must be considered as an indication for yield. He found that the higher yields of sugar beet were associated with higher contents of K-Na, whereas higher contents of Ca or divalent cations corresponded to low yields. This was confirmed by the results of the experiments conducted by other investigators (33, 35, 39) Contrary to these findings, the A.U.B. workers (20, 25, 30) were able to obtain very high yields on calcareous soils (about 15 percent $CaCO_3$) in Lebanon.

Harmer et al. (29) placed sugar beets in that category of crops which show large response to Na with ample supply of K. They found that application of NaCl increased the yield of sugar beets in soils of high K content whereas it caused a reduction in yield at low levels of K. Adams (2) obtained a significant response to the application of NaCl. He reported that his plant analysis data indicated that Na is an essential element for sugar beet and not merely a K substitute. Beneficial effect of Na on sugar beets has been reported by the A.U.B. workers in Lebanon (20, 25, 30). They found that Na application has a positive effect on the yields and it also enhances the positive effects of N and P application as indicated by the positive Na-N and Na-P interactions. Similarly Sayre and Shaffer (55) found a positive N-Na interaction indicating the favorable effects of N and Na when applied together while no significant response to N was observed without Na application.

No definite "critical level" for Na has been established. Magnitski (46) reported a concentration range of 0.16 - 0.20 percent (wet basis) of Na+K in the petioles as the "critical level" for sugar beets during the growing season.

There is evidence of beneficial effect of Na application on sugar beets. Its effect has been reported to be generally dependent on the level of other nutrients in soil. Therefore, a thorough study of the interaction of Na with other nutrient elements is needed.

Effect of Potassium

Potassium is an essential element for plant growth which is not actually incorporated in plant tissues, but rather catalyzes many plant activities. Its important role in photosynthesis, translocation and production of carbohydrates makes this element an important consideration in the nutrition of sugar beets.

Black (11) reported that the results of several field studies indicate a reduction in sucrose percentage and total yield of sugar under conditions of K deficiency. Russell (53) reported that exchangeable K was the primary source of K for plants and the determination of its level in the soil can be used in determining the need for K application. He found definite responses to K applications in fields where exchangeable K was below 5 milligrams per 100 grams of soil. This response decreased as the amount of exchangeable K increased and little increase in yields was observed due to the application of K to the soils having more than 100 milligrams of exchangeable K per 100 grams of soil. Carlson and Herring (12) found that K fertilization resulted in increase in the yield of sugar and roots in the fields with less than 880 lbs. exchangeable K per acre. In the fields having more than 1,000 lbs. per acre available K, however, any addition of K caused a reduction in the yield.

Sirochenko (57) studied the effect of various K fertilizers on sugar beet and found that KCl, K_2SO_4 and KMg salts increased the final root growth, the effect being greatest with KCl. The percentage increases of sugar concentration were 8.5 with KCl, 5.1 with KMg salts and 1.0 with K_2SO_4. Goltin et al. (22) investigated the effect of K and Na ions on root quality and yield of sugar beets in sand culture and found that absence of K from nutrient solution greately depressed growth. The absence of Na depressed K absorption. The best results were obtained at a K:Na ratio of 1:4 . Udvari (64) studied the effect of heavy application of complete fertilizers. He reported that the response was greatest with additional K. In this experiment heavy rates of P were effective only when applied in conjunction with K.

The composition of sugar beet plants as affected by the interaction of K with other elements has been studied by some workers. Alexander et al. (6) found a reduction in the Na content of leaf blades as a result of K application. It was also reported that N fertilization cut down the K uptake whereas application of N and P highly increased the percentage of K in the tops. The results of pot experiments conducted by Anitia et al. (8) indicated that with moderate soil N sugar content was increased by K while with high soil N, K treatment lowered the sugar content.

The negative relationship between Na and K has made the estimation of the "critical level" for K in sugar beets somewhat complicated. Ulrich et al. (68) gave 2.0 percent K in the leaf blade as the critical level. Below this level, K fertilization resulted in good response, while no response was obtained at K contents above 2.0 percent.

Since sugar beets require K in large amounts, application of this element to the soils with low levels of available K is important. The recommended rates depend on the original soil supply of K and the level of other nutrients which influence the yield through their interactions with K.

Effect of Magnesium

Magnesium is an integral part of chlorophyl molecules and plays an important role in the rate of photosynthesis. It is also related to P metabolism and translocation (53). It is possible, therefore, that in P-deficient calcareous soils, abundance of Mg will improve the situation by increasing the efficiency of P utilization within the plant.

Lachowski (41) found that application of 5-50 kilograms per acre of $MgSO_4$ increased the yield of roots by 6.2-17.4 percent and tops by 2.6-8.3 percent and percentage of sucrose was increased by 0.55 percent. It was shown in this experiment that heavy applications of P and lime lowered the effect of $MgSO_4$. Alexander and Cormany (5) studied the effect of spraying various compounds and found that two sprayings of $MgSO_4$ at the rate of 5 lbs. per acre or one spraying of $MgCl_2$ (10 lbs. per acre) increased the sucrose percentage significantly. The results obtained by Downie and Swink (17) are in general agreement with those of Alexander and Cormany.

Simmon and Roussel (56) studied the importance of Mg in the mineral fertilizing of sugar beets and reported that a disequilibrium reflected in high K in relation to Mg in the ammonium acetate extract of soil resulted in diseased plants containing an average of 0.07 percent Mg in the leaves and producing 2.6 tons per hectare of sugar as compared with 0.15 percent leaf Mg and 8.8 tons sugar in healthy beets.

MATERIALS AND METHODS

A field experiment was conducted at the Agricultural Research and Education Center (AREC) in the Beqa'a Plain, Lebanon to study the interrelationships of N, P, S, Na, K and Mg (each varied at five levels) on the growth and composition of sugar beets. A central composite rotatable incomplete factorial design (13) was employed to study the main effects and the interactions. This design avoids the necessity of a very large number of treatments. It also permits the calculation of a quadratic regression equation for the response surface, thus allowing the determination of the over all first order effects as well as the type and magnitude of the various interactions between the variables. There were 45 treatments with one of them (coded 0 level) being repeated 10 times and distributed at random in the three blocks for calculation of the experimental error (appendix table 12).

The rates of each element were varied according to the logarithmic scale to the base 2 in order to cover a wide range of application and to straighten the response curves (Table 1). The rates were coded -2.366, -1, 0, +1 and +2.366 for the calculation of the regression equations. It was assumed that 0 level represented an average rate, and other rates covered a wide range of application from possible deficiency, -2.366, to possible excess, +2.366 .

Table 1. Rates of application of N, P, S, Na, K and Mg for sugar beets.

Level	Coded rates	Kg. per ha.
1	-2.366	29
2	-1	75
3	0	150
4	+1	300
5	+2.366	782

Statistical Analysis

The statistical analyses were done according to the method described by Cochran and Cox (13). Regression equations of the quadratic form for yields and element concentrations were computed for the collected data. The form of the equation for 6 variables is as follows:

$$\begin{aligned} Y = {} & b_0 + b_1x_1 + b_2x_2 + b_3x_3 + b_4x_4 + b_5x_5 + b_6x_6 + \\ & b_{11}x_1^2 + b_{22}x_2^2 + b_{33}x_3^2 + b_{44}x_4^2 + b_{55}x_5^2 + \\ & b_{66}x_6^2 + b_{12}x_1x_2 + b_{13}x_1x_3 + b_{14}x_1x_4 + b_{15}x_1x_5 + \\ & b_{16}x_1x_6 + b_{23}x_2x_3 + b_{24}x_2x_4 + b_{25}x_2x_5 + b_{26}x_2x_6 + \\ & b_{34}x_3x_4 + b_{35}x_3x_5 + b_{36}x_3x_6 + b_{45}x_4x_5 + b_{46}x_4x_6 + \\ & b_{56}x_5x_6 . \end{aligned}$$

Where Y = the quantitative factor measured (estimated value)

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 K

x_6 = coded level of Mg

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 probabilities 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 equation sufficiency and coefficient of variance were calculated to determine the extent of fitting of the quadratic regression equation on the actual data collected.

Field Procedure

The fertilizers used to provide different elements were commercial grades of ammonium nitrate, concentrated superphosphate, calcium sulfate, magnesium sulfate, potassium sulfate, sodium nitrate, potassium nitrate, magnesium carbonate, sodium bicarbonate and potassium carbonate. The carriers were analyzed and their amounts varied in order to supply the required amount of each element. It was not possible to hold the level of calcium and carbonates constant. However, the soil was calcareous with about 15 percent $CaCO_3$ content and so it was expected that the effect of any additional calcium and carbonates present in the carriers would be negligible.

The treatments were assigned to different plots at random. Each plot consisted of 4 rows, 5 meters long and 0.5 meter apart. The fertilizers of each treatment were mixed together and spread uniformly at the bottom of furrows. The fertilizers were then covered by splitting the ridges and seeds of sugar beets (Beta vulgaris), Kleinwanzleben variety, were planted on the new ridges above the fertilizers at a depth of about 3 centimeters on March 31, 1964.

Irrigation was done every week using sprinklers for the first month and the furrow method later on. Thinning was started on May 7 and completed on May 21 leaving an average of 6 plants per meter. Insects such as flea beetles, leaf hoppers and aphids and the powdery mildew disease were controlled throughout the season by appropriate chemicals as needed.

Three sets of petiole samples were taken from the recently matured leaves of the two middle rows of each plot on the following dates: June 24, August 12 and September 23, 1964. The leaf blades of the second set of samples were separated from the petioles and retained. All the samples were dried at $70^\circ C$ and ground for chemical analysis.

On the 31st of October the beets from the middle 4 meters of the two center rows of each plot were harvested. Samples of tops and roots were taken for moisture, nitrogen and beet sucrose determination.

Analysis of the Petioles

1. Nitrate-N: Nitrate-N determination was run on a water extract using the phenol-disulphonic acid - method (37). Excess chloride was precipitated by silver sulfate.

2. P, acid soluble: 2 percent acetic acid soluble phosphate was determined with the chlorostanous - reduced molybdophosphoric blue color method (37).

3. S, acid soluble: The sulfate content of the 2 percent acetic acid extract was determined by the turbidimetric method (36). The extract was digested with H_2O_2 to remove the discoloration.

4. Na and K, acid soluble: The Na and K contents of the 2 percent acetic acid extract was determined with a Beckman D.U. emission spectrophotometer (36).

Analysis of the Leaf Blades

The dried and ground leaf blades from the second sampling were predigested with nitric acid at room temperature for a period of 12 hours. Then they were digested with perchloric acid at a temperature of 180-200^{0}C according to the procedure given by Jackson (36). The digested samples were washed and filtered with hot water. P, S, Na, K and Mg were determined on the nitric-perchloric digests using the same methods as described in petiole analysis for each respective element.

Analysis of the Tops and the Roots

1. Total N: Total N in both root and top samples was determined by the modified Kjeldahl method receiving the distillate in boric acid (36).

2. Sugar Percentage: Sucrose concentrations of the roots were determined by the A.O.A.C. method (9).

RESULTS AND DISCUSSION

The experiment reported here was conducted in the Beqa'a Plain, Lebanon, to study the effect of the macronutrients N, P, S, Na, K and Mg (each varied at five levels) on the yield of roots, yield of sugar, yield of tops, sucrose percentage, chemical composition of petioles and leaf blades, and total N content of roots and tops of sugar beets. A central composite, rotatable, incomplete factorial design as described by Cochran and Cox (13) was used. It was assumed that the response surface showing the relationship between yield and the six variables under investigation could be characterized with the quadratic regression equation which was discussed previously (page 22). This design allows the estimation of the regression coefficients of the terms in the quadratic equation. The magnitude of the individual regression coefficients indicates the relative effect of the variables and allows the determination of the statistical significance. A positive sign of the regression coefficient of the first order term for an element indicates an increasing effect of that element on the yield, while a negative sign denotes an overall depressing effect of the element. The magnitude of the regression coefficient of a squared quadratic term indicates the degree of curvature of the response to the variable and the sign shows whether this curvature is concave upward, positive, or concave downward, negative. The magnitude and the sign of the regression coefficient for the cross product terms denotes the degree and the type of interaction involved, respectively. A positive interaction between two elements indicates that an increase in the level of one element increases the requirement for the other. A negative interaction indicates that if the level of one element is high, the level of the other one must be low for a high yield.

In this report the term "highly significant" will be used to denote an effect with a probability of 0.99 or more of being true, while "significant" will be used for a probability of 0.95 to 0.99 of being true.

Results of Soil and Water Analysis

The results of soil analysis (Table 2) showed that the soil was a calcareous silty clay loam. Determination of the ammonium acetate soluble cations indicated that Ca formed 70 percent of the total cations. The available K content was found to be 935 lbs. per acre indicating an adequate level according to Russel (69). The soil P content (15 ppm. Olson Method) was found to be at a medium level . The organic matter (1.9%) and total N content (0.13%) were considered to be low. The nitrate-N concentration in the top soil, however, was found to be relatively high (41 ppm.).

Despite the clay nature of the soil, the field infiltration rate was satisfactory. A high degree of shrinkage and formation of cracks in drying promoted the water infiltration and improved the aeration of the soil.

The results of water analysis (Table 2) showed that the irrigation water was of good quality from a salinity standpoint. It was estimated that approximately 141 kg. of Ca, 113 kg. of Cl, 100 kg. of Mg, 65 kg. of Na, 22 kg. of K and 20 kg. of S per hectare were added through the irrigation water considering an estimated one meter depth applied during the season.

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

Soil Analysis				Water Analysis		
pH			7.8	Na,	m.e./liter	0.282
$CaCO_3$,		%	16.5	Ca,	"	0.705
Organic matter,		%	1.9	K,	"	0.056
Total N,		%	0.1344	Mg,	"	0.833
Nitrate-N,		ppm.	41.0	S,	"	0.125
Available P,		ppm.	15.0	Cl,	"	0.318
Ammonium acetate soluble cations, m.e./100 g.		(Ca	30.4	Electrical conductivity, m.mho/cm.		0.155
		(Mg	12.8			
		(K	1.2			
		(Na	0.7			
Bulk density (dry basis)			1.4			
Shrinkage,		%	15.3			
Soil Texture	(Sand	%	18.3			
	(Silt	%	46.9			
	(Clay	%	34.8			

Effect of Fertilizer Treatments on Yield of Roots

The recorded root yields ranged from 85 to 121.5 with an average of 103.6 m. tons per hectare (Appendix Table 12). The correlation coefficient between the observed yields and the yields calculated from the regression equation was 0.71 (Table 3) indicating a fairly close fit of the regression equation to the actual records. The insignificancy of the lack of fit term and the equation sufficiency of 72 percent indicated that there was probably no need for a cubic or higher order regression equation.

Study of the regression coefficients (b) and their standard errors (s_b) for the first order effects (Table 3) indicated that N had a significantly positive effect. It will be seen later, however, that considering all the first and second order effects, a relatively low level of N will be recommended. This shows that linear effects can not be considered independently of the quadratic terms.

The yield of roots tended to increase with P ($p^x = 0.80$) and S ($p = 0.75$). The negative first order ($p = 0.80$) and squared effects ($p = 0.93$) of Mg indicated the decreasing effects of this element on the root yields.

The regression coefficients for the quadratic squared terms were negative for all the variables. The negative squared effect of N ($p = 0.82$) indicated that at

---

[x] "p" denotes the probability of a true effect.

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

Term	Yield of roots, M. tons/Ha. b	s_b	Yield of sucrose, M. tons/Ha. b	s_b	Yield of tops, M. tons/Ha. b	s_b	Sucrose in roots, % b	s_b
Mean	110.7		18.61		5.08		18.85	
N	+2.8^{x}	±1.2	+0.24	±0.27	+0.50^{xx}	±0.10	-0.24	±0.21
P	+1.7	"	+0.33	"	+0.07	"	+0.07	"
S	+1.5	"	+0.35	"	-0.08	"	+0.10	"
Na	-0.9	"	-0.15	"	+0.13	"	-0.03	"
K	-0.1	"	-0.31	"	-0.26	"	-0.11	"
Mg	-1.6	"	-0.25	"	+0.12	"	-0.01	"
NN	-1.5	±1.0	-0.37	±0.23	+0.14	±0.08	-0.12	±0.18
PP	-1.4	"	-0.36	"	-0.04	"	-0.14	"
SS	-0.1	"	-0.17	"	-0.17	"	-0.17	"
NaNa	-2.6	"	-0.54	"	-0.07	"	-0.10	"
KK	-1.2	"	-0.00	"	-0.08	"	+0.19	"
MgMg	-2.2	"	-0.26	"	-0.03	"	+0.10	"
						"		
N-P	-0.7	±1.4	-0.43	±0.32	+0.22	±0.11	-0.30	±0.25
N-S	-0.7	"	-0.16	"	-0.10	"	-0.07	"
N-Na	-2.2	"	-0.39	"	+0.17	"	-0.07	"
N-K	+1.5	"	+0.17	"	+0.33^{xx}	"	-0.05	"
N-Mg	+0.7	"	+0.01	"	-0.16	"	-0.12	"
P-S	+2.3	"	+0.43	"	+0.19	"	+0.05	"
P-Na	-0.1	"	-0.06	"	-0.12	"	-0.00	"
P-K	-0.2	"	+0.15	"	+0.12	"	+0.13	"
P-Mg	-0.6	"	-0.14	"	-0.09	"	+0.00	"
S-Na	+0.4	"	+0.13	"	-0.19	"	+0.04	"
S-K	+1.0	"	-0.06	"	+0.15	"	-0.20	"
S-Mg	-0.3	"	+0.16	"	-0.21	"	+0.17	"
Na-K	+0.3	"	+0.13	"	-0.24	"	+0.12	"
Na-Mg	-2.6	"	-0.25	"	-0.06	"	+0.15	"
K-Mg	+0.6	"	+0.09	"	-0.03	"	+0.00	"
R^{+}	0.71		0.74		0.72		0.56	

[x] Statistically significant at the 5% level.

[xx] Statistically significant at the 1% level.

[+] The multiple correlation coefficient between the observed yields and the calculated yields.

higher levels of application the positive response to N decreased and tended to be negative (Figure 1). Although the direct first order effect of K was very small, its squared effect tended to be negative ($p = 0.75$) indicating the downward curvature of its response curve (Figure 1). The significantly negative regression coefficient for Na^2 indicated a great downward curvature of the response curve as shown in Figure 1 which indicated the increasing effect of Na up to +1 coded level of application beyond which the yield declined sharply.

The negative N-Na ($p = 0.81$) and Na-Mg ($p = 0.91$) interactions indicated that increasing the level of either N or Mg tended to decrease the positive response to Na. A positive interaction was found between N and K ($p = 0.75$) indicating that raising the level of one tended to increase the requirement for the other. It was found in this experiment that for a high yield both N and K must be kept at a low level.

The yield of roots was influenced by the positive P-S interaction ($p = 0.82$) which indicated that increasing the level of one tended to enhance the positive response to the other (Figure 2). Increasing the level of P or S tended to decrease the yield if the level of the other was kept low whereas the highest yield was obtained when both P and S were present at high levels.

Considering the above mentioned effects, it was

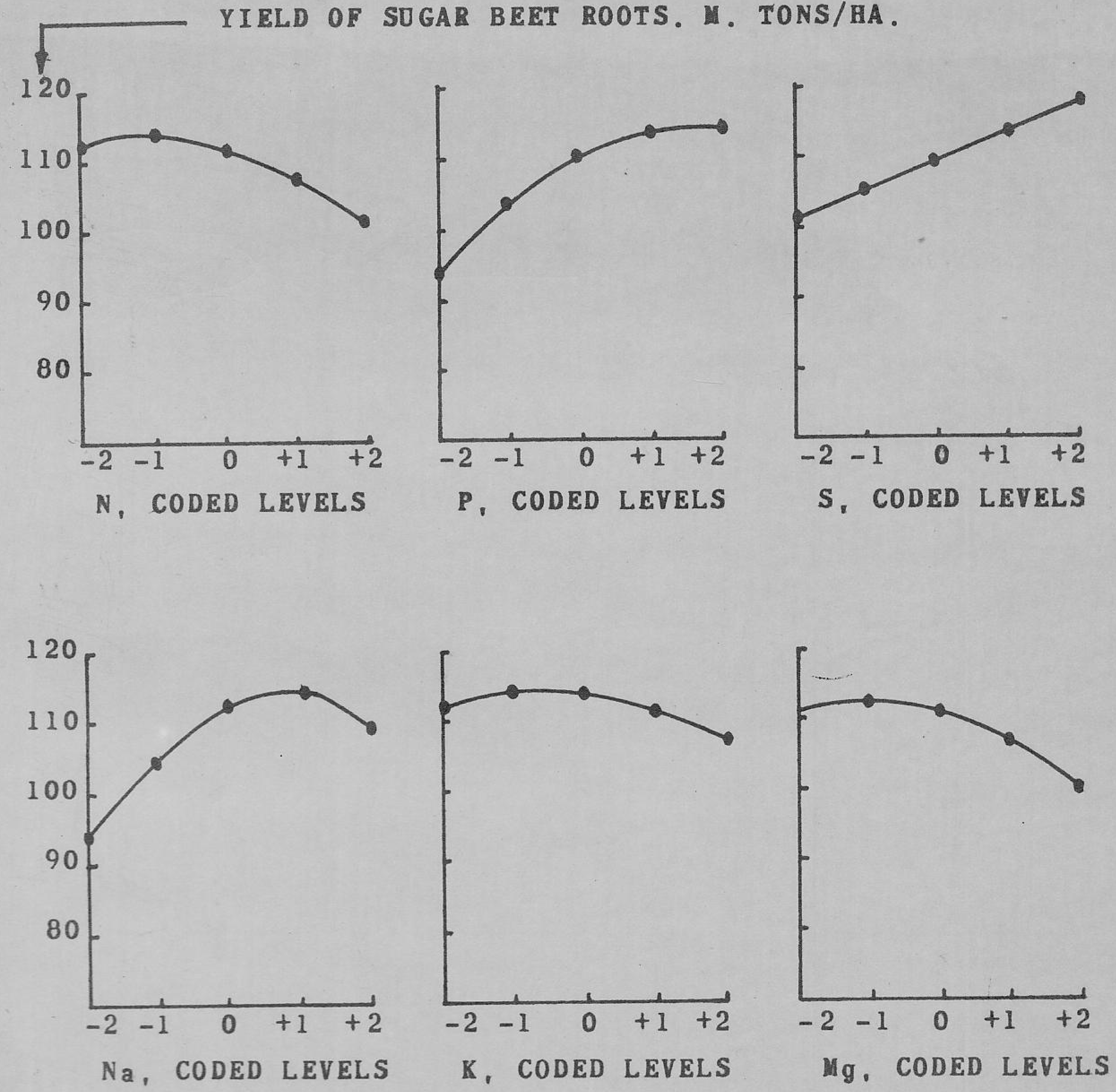

Figure 1. Effect of applied N, P, S, Na, K and Mg on the yield of sugar beet roots. Data were calculated from the regression equations. The coded levels of N, P, S, Na, K and Mg (when not varied) were held constant at -1, +1, +1, +1, -1 and -1, respectively.

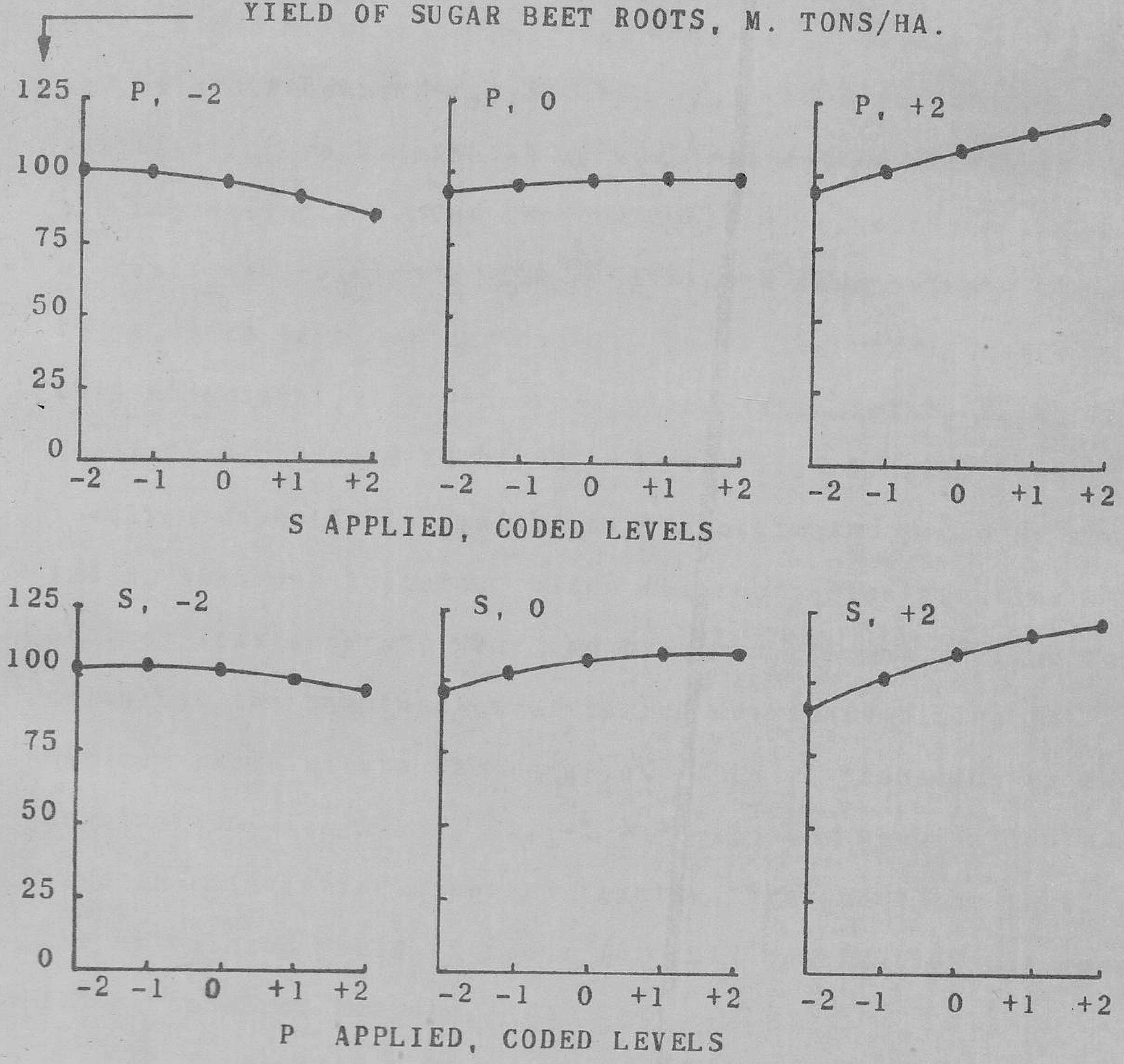

Figure 2. Yield of sugar beet roots as affected by levels of applied S at constant levels of P (above) and by levels of applied P at constant levels of S (below). The coded levels of application of N, Na, K and Mg were held constant at -1, +1, -1, and -1, respectively.

found in this experiment that for a high yield the levels of N, K and Mg must be kept low while high levels of P, S and Na are recommended. By the trial and error method of substituting various selected combinations of nutrients into the regression equation the combination for optimum yield of roots was obtained. The trials were made between the -2 to +2 coded level of variables. Under the conditions of this experiment, the optimum applied rates for N, P, S, Na, K and Mg were found to be -2, +2, +2, +1, -1 and -2 coded levels, respectively, which gave an estimated yield of about 124 m. tons per hectare. Since the regression equation becomes less accurate near the extremes, it was decided to calculate the combination of varied nutrients giving the maximum yield within the range of -1 to +1 resulting in the combination -1, +1, +1, +1, -1 and -1. This combination was used in calculating expected results throughout the text. The calculated yield of roots for this combination was about 115 m. tons per hectare.

Examination of the response curves in Figure 1 showed that the effect of N was slightly positive up to -1 coded level of application beyond which the root yields decreased rapidly as the level of N was raised. Increasing the level of Na from -2 to +1 coded level increased the yield by 20 m. tons per hectare. Similarly, the graphs show that increasing the levels of S and P from -2 to +2 increased the root yields by about 20 and 17 m. tons per hectare, respectively. It was observed that the negative effects of K and Mg were most pronounced at the higher levels of application.

The favorable responses to P and Na obtained in this experiment are in general agreement with the findings of some other A.U.B. workers in Lebanon (20, 25, 30). However, the above workers showed that S decreased the yield severely through its negative first order effect and its negative interactions with N, P and Na whereas the results of this experiment indicated that application of S tended to increase the yield.

Effect of Fertilizer Treatments on Yield of Sucrose

The yields of sucrose (Appendix Table 12) ranged from 13.4 to 21.8 with an average of 17.3 m. tons per hectare. The multiple correlation coefficient between actual yields and those calculated from the regression equation (Table 3) was 0.74 indicating a fairly close fit of the regression equation to the actual data. The equation sufficiency term (Appendix Table 12) indicated that about 70 percent of the treatment variations were covered by the regression equation.

Study of the first order regression coefficients (Table 3) revealed that S and P application tended to have a favorable effect on the sucrose yield. At low levels of application, N had little effect, but yield of sucrose decreased rapidly as the level of N was increased (Figure 3).

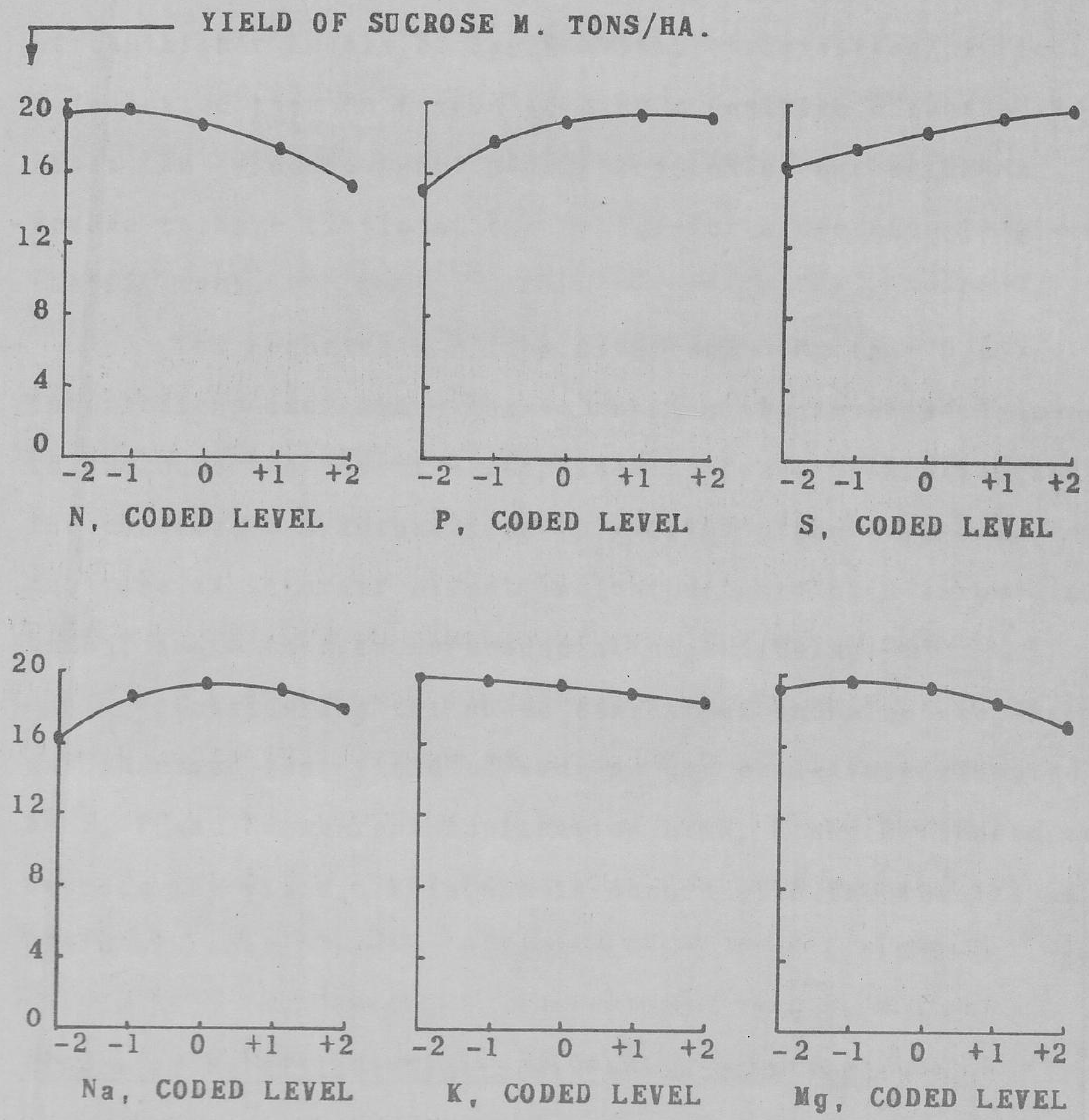

Figure 3. Effect of applied N, P, S, Na, K and Mg on the yields of sucrose. Data were calculated from the regression equations. The levels of N, P, S, Na, K and Mg (when not varied) were held constant at -1, +1, +1, +1, -1, and -1, respectively.

AMERICAN UNIVERSITY OF BEIRUT
SCIENCE & AGRICULTURE
LIBRARY

Similarly the depressing effect of Mg was more pronounced at the higher levels of application. Examination of Figure 3 indicated that Na tended to have a positive effect up to about the -½ coded level of application beyond which Na tended to have little effect except for a decrease in yield at the +2 level.

The negative N-P ($p = 0.70$) and N-Na ($p = 0.65$) interactions indicated that increasing the level of N tended to decrease the positive responses to P and Na application. The positive P-S interaction ($p = 0.70$) along with the positive first order effects indicated that for a large yield both P and S tend to be needed at high levels.

Considering the above effects of the elements, it was observed that yield of sucrose was positively affected by S, P and Na whereas application of N, K and Mg tended to depress the yield. This was in accord with the results on yield of roots.

Effect of Fertilizer Treatments on Sucrose Percentage

The sucrose percentage of roots ranged from 13.5 to 19.1 percent with an average of 16.7 (Appendix Table 12). The overall first order effect of N tended to be negative ($p = 0.80$) (Table 3). The depressing effect of N on sucrose content of roots has been also reported by other A.U.B. investigators (20, 25, 30). The other applied elements appeared to have only slight effects on sucrose percentage in this experiment. The sucrose concentration was little influenced by the interaction effects.

Effect of Fertilizer Treatments on Yield of Tops

The yield of harvested sugar beet tops (Appendix Table 12) ranged from 2.06 to 8.28 with an average of 4.99 m. tons per hectare (dry basis).

The positive linear effect of N on the yield of tops was highly significant. Other A.U.B. workers (20, 25, 30) also found that N gave the highest increase in the yield of beet tops. The very positive effect of N application on the top growth probably accounts for the depressive effect of N on sucrose concentration due to expenditure of carbohydrates for the production of leaves rather than storage in the roots.

The first order effects of Na, P and Mg were positive, but small, whereas that of K was significantly negative (Table 3). The yield of tops was influenced by the significantly positive N-K interaction (Figure 4) indicating that the positive response to N was increased as the level of K was raised. The decreasing effect of K was most severe at low levels of N, but as the level of N was increased the depressive effect became less and tended to be positive at high levels of N (Figure 4). The negative Na-K interaction ($p = 0.93$) indicated that a high level of K reduced the positive response to Na. The positive S-K interaction

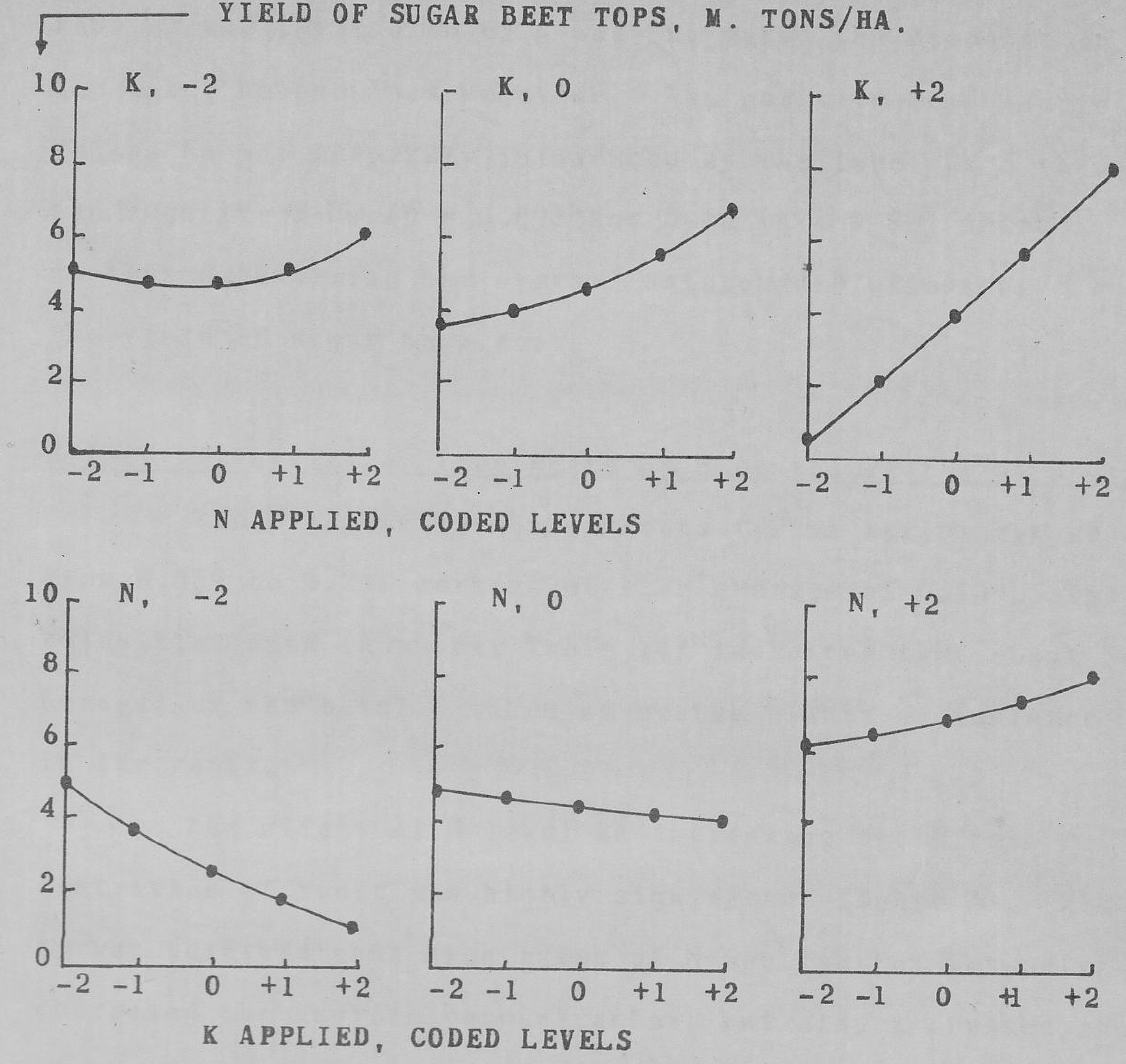

Figure 4. Yield of sugar beet tops as affected by levels of applied N at constant levels of K (above) and by levels of applied K at constant levels of N (below). Levels of P, S, Na, and Mg were held constant +1, -1, 0, and -1 coded levels of application, respectively.

(p = 0.77) had some effect on the yields of tops indicating that as the level of S or K was increased the response to the other became less negative. The positive response to Mg and Na was adversely influenced by the level of S through the negative S-Mg (p = 0.89) and S-Na (p = 0.86) interactions emphasizing the overall unfavorable effect of S on the yield of sugar beet tops.

Effect of Fertilizer Treatments on N concentration of Roots

The N concentration of roots (fresh basis) ranged from 0.089 to 0.201 percent with an average of 0.139. The calculated data (Appendix Table 14) indicated that about 54 percent of the total N taken up by the plants accumulated in the roots.

The effect of N level on increasing the N concentration of roots was highly significant (Table 4). Thus it was observed that high rates of N application not only decreased the sucrose concentration, but also increased the level of undesirable nitrogenous compounds in roots. The concentrations of N in the roots, in this experiment, were mostly below the "critical level" of 0.2 percent indicated by Goodban *et al*. (23). Application of P decreased the root N content significantly. The significantly negative N-P interaction also indicated that as the level of P in soil was raised the positive response to N application was reduced. This is in agreement with the findings of some

Table 4. Regression coefficients (b) and their standard errors (s_b) for nitrogen concentration of roots (fresh basis) and nitrogen concentration of tops (dry basis) as affected by various combinations of levels of N, P, S, Na, K and Mg.

Term	N in roots, %		N in tops, %	
	b	s_b	b	s_b
Mean	0.1388		2.385	
N	+0.0216[xx]	±0.0013	+0.208[xx]	±0.019
P	-0.0157[xx]	"	-0.042	"
S	-0.0001	"	-0.016	"
Na	-0.0018	"	-0.011	"
K	+0.0010	"	-0.056[x]	"
Mg	+0.0003	"	-0.038	"
NN	-0.0007	±0.0012	+0.035	±0.016
PP	+0.0011	"	+0.002	"
SS	-0.0020	"	+0.014	"
NaNa	-0.0011	"	+0.024	"
KK	-0.0017	"	-0.009	"
MgMg	+0.0042[xx]	"	+0.018	"
N-P	-0.0052[x]	±0.0016	-0.020	±0.022
N-S	+0.0021	"	-0.037	"
N-Na	-0.0042[x]	"	-0.044	"
N-K	+0.0018	"	-0.034	"
N-Mg	-0.0029	"	-0.062[x]	"
P-S	-0.0001	"	+0.064[x]	"
P-Na	-0.0001	"	-0.005	"
P-K	-0.0058[xx]	"	-0.014	"
P-Mg	+0.0001	"	-0.030	"
S-Na	-0.0006	"	+0.045	"
S-K	+0.0012	"	+0.063[x]	"
S-Mg	+0.0035[x]	"	-0.055[x]	"
Na-K	+0.0003	"	-0.036	"
Na-Mg	-0.0018	"	-0.008	"
K-Mg	+0.0042[x]	"	-0.043	"
R[+]	0.97		0.89	

---

[x] Statistically significant at the 5% level.

[xx] Statistically significant at the 1% level.

[+] The multiple correlation coefficient between the observed yields and calculated yields.

13

other workers (20, 78) who showed that P improved the quality of sugar beets by reducing the harmful effect of excess N. The effect of N was similarly influenced by the significantly negative N-Na interaction with the high levels of Na tending to repress N accumulation in the roots.

The highly significant positive regression coefficient for the squared effect of Mg (Table 4) indicated the great upward curvature of its response curve. The overall first order effect of K on N concentration was very small. The higher rates of K application, however, tended to favor N accumulation by enhancing the positive effect of Mg and reducing the depressing effect of P application as indicated by positive K-Mg and negative P-K interactions.

It appears, therefore, that under the conditions of this experiment N, Mg and K tended to increase while P and Na tended to decrease the percentage of total N in roots.

Effect of Fertilizer Treatments on N Concentration of Tops

The data for N percentage of tops (dry basis) indicated a range of 1.58 to 3.12 percent with an average of 2.45 percent (Appendix Table 12). The N content was significantly increased by N application (Table 4), while K and P tended to lower the N concentration with K having a greater depressing effect than P. The negative first order effect of Mg and the significantly negative N-Mg interaction indicated that the N accumulation of tops, unlike that of roots, was considerably depressed as the level of Mg was increased. Similarly all the other elements tended to reduce the positive effect of N through their negative interactions with N.

Among the interaction terms, S-P and S-K were found to be significantly positive indicating that increasing the level of either P or K tended to reduce the negative effect of S. The significantly negative S-Mg interaction indicated that a high level of one increased the negative effect of the other.

It appears, therefore, that among the varied elements only N application was positively correlated with total N content of tops, whereas the addition of all the other elements tended to depress the N accumulation in tops.

Total N Uptake by Sugar Beet Plants

Study of the calculated data (Appendix Table 14) indicated that the N supplying power of the soil was high. The plants for the plot which had received the lowest rate of N application (29 kg. per ha.) had a total N uptake of 199 kg. per ha. indicating the high amount of N supplied by the soil. The average total uptake of N by the plants for the plots supplied with N at the 2, 3, 4 and 5 levels of application were 217, 271, 313 and 341 kg. per ha., respectively, while the applied N was 75, 150, 300 and 782 kg. per ha., respectively. Thus, although the proportion of N supplied by the soil decreased as the level of N application increased, the soil had an appreciably high N supplying capacity. The soil where this experiment was located had not been irrigated previously and had been fallowed the previous year which probably accounted for the favorable N supplying situation. This was also indicated by the relatively high level of nitrate-N in the soil as was shown by soil testing (Table 2).

Effect of Fertilizer Treatments on Petiole Analysis

Nitrate-N Concentration of Petioles: The average seasonal concentrations of nitrate-N in petioles (Appendix Table 15) had a range of 586 to 7,081 ppm. The study of the regression coefficients (Table 5[x]) indicated that the nitrate-N concentration was positively related to N application rates (Figure 5) at all three sampling times during the season. The effect was greatest at the first sampling date (June 24) and decreased as the season advanced. Examination of (Figure 5) revealed that the nitrate concentration decreased as the season advanced with the greatest decrease occuring in the second sampling date (August 12). The only exception was the plants from the plot which had received the lowest level of N application were nitrate-N

---

[x] The nitrate-N concentration of petioles had a great range in values with the result that the effect of a few extremely high values over shadowed the effect of all other values. To counteract this effect, the statistical analysis of petiole nitrate content required a conversion of the concentration values in ppm. to logarithms.

Table 5. Regression coefficients (b) and their standard errors (s_b) for the nitrate-N concentrations of the petioles (log. ppm. dry basis) at three sampling dates and the seasonal mean as affected by various combinations of levels of N, P, S, Na, K and Mg.

Term	June 24		August 12		Sept. 23		Mean	
	b	s_b	b	s_b	b	s_b	b	s_b
Mean	3.440		3.095		3.145		3.278	
N	+0.337^{xx}	±0.041	+0.211^{xx}	±0.034	+0.108^{xx}	±0.030	+0.221^{xx}	±0.025
P	-0.005	"	+0.134^{xx}	"	-0.037	"	+0.004	"
S	+0.037	"	-0.040	"	+0.008	"	+0.038	"
Na	-0.059	"	+0.073	"	+0.093^{x}	"	-0.003	"
K	+0.042	"	+0.115	"	-0.074^{x}	"	+0.007	"
Mg	+0.001	"	-0.039	"	+0.017	"	+0.011	"
NN	-0.039	±0.035	+0.020	±0.029	+0.027	±0.026	+0.025	±0.022
PP	-0.006	"	-0.071^{x}	"	-0.020	"	-0.013	"
SS	-0.011	"	-0.015	"	+0.021	"	-0.021	"
NaNa	+0.039	"	+0.019	"	+0.035	"	+0.039	"
KK	+0.002	"	-0.020	"	-0.007	"	+0.001	"
Mg	+0.057	"	-0.001	"	-0.003	"	+0.036	"
N-P	-0.076	±0.048	+0.007	±0.040	+0.034	±0.035	-0.034	±0.029
N-S	-0.031	"	+0.021	"	-0.020	"	-0.027	"
N-Na	-0.014	"	+0.051	"	+0.024	"	+0.007	"
N-K	-0.037	"	+0.007	"	+0.108^{x}	"	+0.012	"
N-Mg	-0.006	"	+0.020	"	+0.010	"	-0.012	"
P-S	+0.135^{x}	"	+0.059	"	+0.014	"	+0.078^{xx}	"
P-Na	+0.003	"	-0.090	"	+0.043	"	+0.004	"
P-K	+0.038	"	-0.043	"	-0.049	"	+0.023	"
P-Mg	+0.056	"	+0.037	"	+0.024	"	-0.035	"

Cont. p. 47.

Table 5 continued.

Term	June 24		August 12		Sept. 23		Mean	
	b	s_b	b	s_b	b	s_b	b	s_b
S-Na	-0.105	±0.048	-0.016	±0.040	-0.009	±0.035	-0.051	±0.029
S-K	+0.053	"	+0.076	"	-0.010	"	+0.046	"
S-Mg	-0.053	"	-0.013	"	+0.019	"	-0.003	"
Na-K	+0.080	"	-0.150	"	-0.009	"	+0.029	"
Na-Mg	-0.078	"	+0.083	"	-0.044	"	-0.033	"
K-Mg	+0.059	"	+0.040	"	-0.004	"	+0.025	"
R^+	0.81		0.85		0.79		0.84	

x Statistically significant at the 5% level.

xx Statistically significant at the 1% level.

\+ The multiple correlation coefficient between the observed yields and the calculated yields.

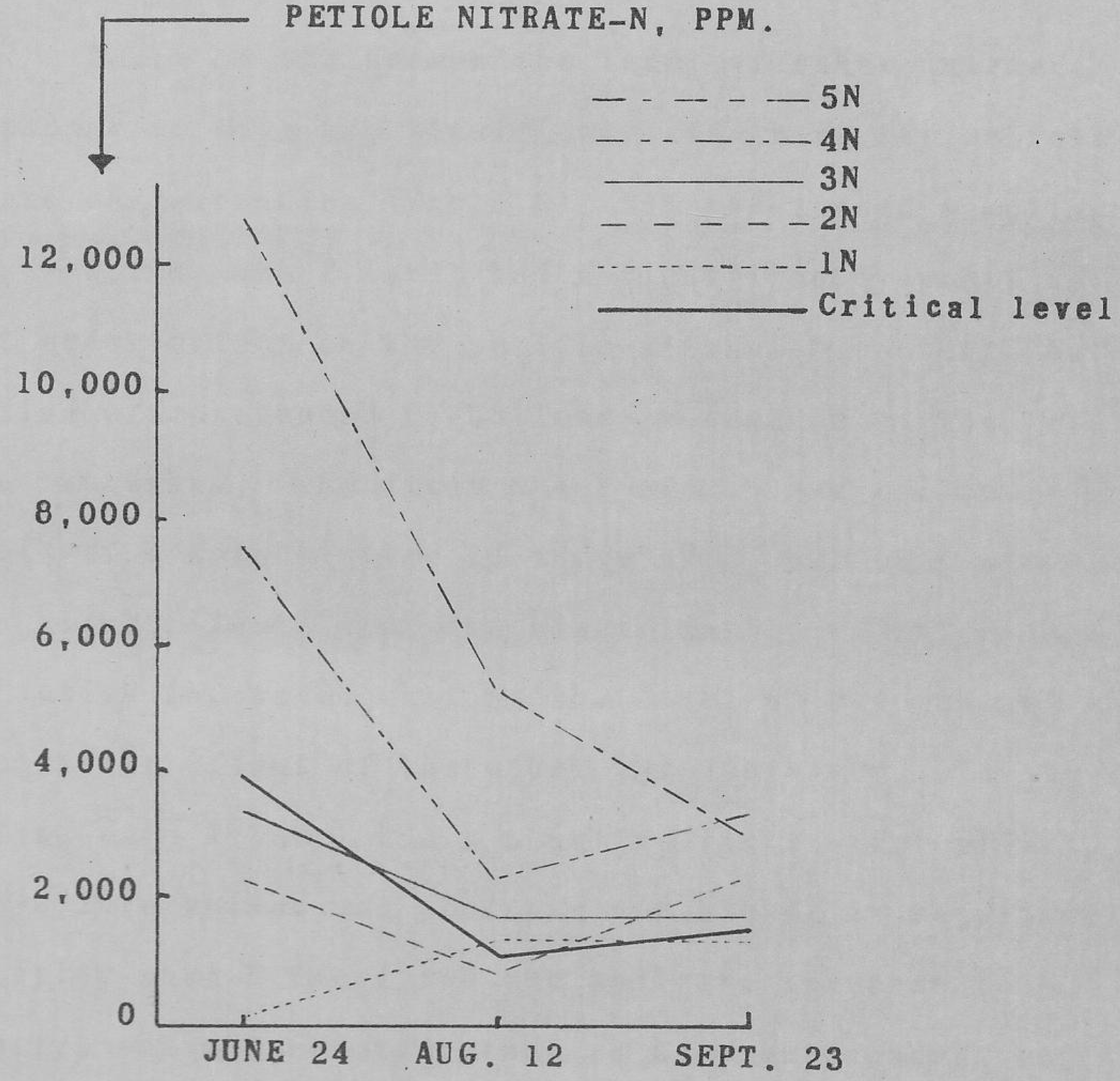

Figure 5. Observed seasonal change in average nitrate-N concentration of petioles (recently mature, dry basis). The "critical level" was calculated from the regression equation with N, P, S, Na, K and Mg at -1, +1, +1, +1, -1 and -1, respectively.

content tended to increase up to the second sampling date after which it remained almost constant. This could be probably due to the fact that as the plants developed deeper roots they were able to take up more N from the soil original N supply.

Early in the season the level of other nutrients did not appear to have any significant effect on the petiole nitrate concentration (Table 5). At the second sampling date, however, the P level had a significantly positive first order effect on the petiole nitrate-N content, but this positive effect tended to be less pronounced as the level of P was increased. The first order effect and the squared effect of K were similar to those of P, but they were less in magnitude (Table 5). The significantly negative Na-K interaction indicated that as the level of one was increased the positive effect of the other was decreased. In the last sampling date K level had a negative first order effect, but the N-K interaction was positive and higher in magnitude indicating that K increased the positive response to N slightly. It was observed that as the season advanced, Na tended to increase the nitrate-N concentration in petioles and late in the season this effect became significantly positive (Table 5). These changes in effects of certain elements on the petiole composition indicated that the combinations of nutrients in soil and the physiological condition of the plants changed during the season.

18

The only element which was consistantly positively related to nitrate-N concentration in the petioles was N. This supports the view of many other investigators (25, 30, 67) who indicated that petiole analysis is a good guide for assessing the N status of the soil and plant.

The "critical levels" of nitrate-N concentration of petioles for the three sampling dates during the growing season, as calculated from the regression equation with N, P, S, Na, K and Mg at -1, +1, +1, +1, -1 and -1 coded levels, respectively, were 3,981 ppm. for June 24, 851 ppm. for August 12 and 692 ppm. for September (Figure 4). These levels were determined for the condition that all the N be applied at planting time. It was observed that in the second and third sampling date, the "critical levels" of nitrate-N in this experiment were below the "critical level" of 1,000 ppm. indicated by Ulrich (65). Some A.U.B. workers (25, 30) also reported higher "critical levels" than those obtained under the conditions of this experiment.

Phosphate-P Concentration of Petioles: The recorded data for the seasonal means of phosphate-P concentration of petioles (Appendix Table 8) indicated a range of 1,022 ppm. to 2,017 ppm. The phosphate-P content was highest early in the season, then declined sharply at the second sampling date (August 12) after which the rate of decline was less (Figure 6).

Examination of the regression coefficients (Table 6)

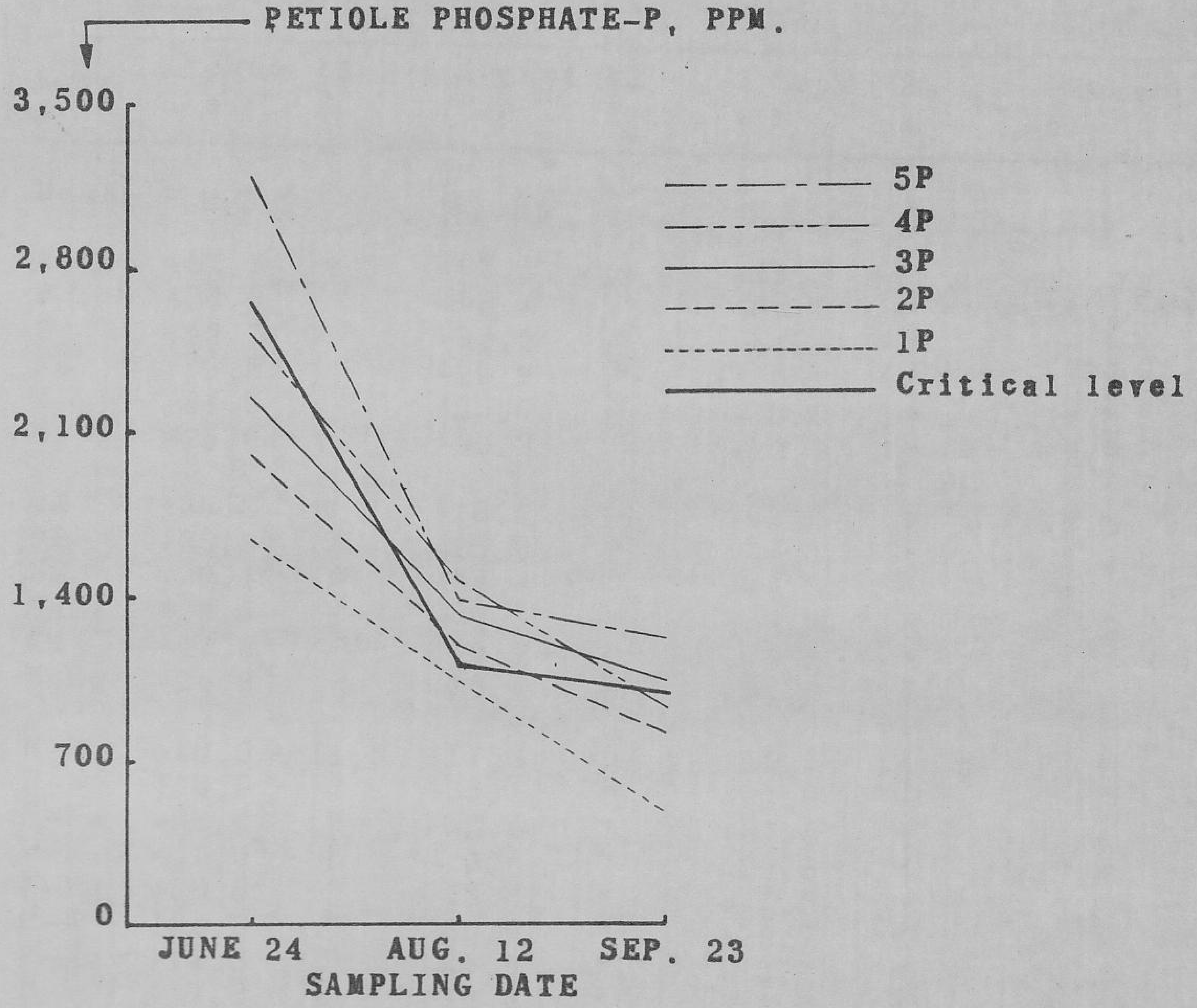

Figure 6. Observed seasonal change in average phosphate-P concentrations of petioles (recently mature, dry basis). The "critical level" was calculated from the regression equation with N, S, P, Na, K and Mg at -1, +1, +1, +1, -1 and -1, respectively.

Table 6. Regression coefficients (b) and their standard errors (s_b) for the phosphate-P concentrations of the petioles (ppm., dry basis) at three sampling dates and the seasonal mean as affected by various combinations of levels of N, P, S, Na, K and Mg.

Term	June 24		August 12		Sept. 23		Mean	
	b	s_b	b	s_b	b	s_b	b	s_b
Mean	2,305		1,336		1,134		1,585	
N	$+62.6^{xx}$	±9.7	$+93.1^{xx}$	±22.9	+22.9	±57.3	+18.0	±25.8
P	$+30.0^{xx}$	"	$+98.6^{xx}$	"	+86.8	"	$+119.6^{xx}$	"
S	$+43.7^{xx}$	"	-54.3^{x}	"	-11.6	"	-82.3^{x}	"
Na	+ 2.3	"	-20.9	"	+ 0.2	"	+36.1	"
K	-64.5^{xx}	"	$+55.7^{x}$	"	- 8.8	"	-47.3	"
Mg	-25.8^{x}	"	-20.2	"	+20.2	"	+32.9	"
NN	$+65.3^{xx}$	±8.3	+18.2	±19.6	-93.0	±49.0	+12.1	±22.0
PP	$+25.9^{x}$	"	-25.9	"	-66.1	"	- 6.4	"
SS	-29.1^{x}	"	+44.4	"	-16.9	"	-44.4	"
NaNa	- 3.5	"	- 2.1	"	+54.2	"	+31.8	"
KK	-47.8^{xx}	"	+ 0.7	"	-43.8	"	-14.6	"
MgMg	-26.8^{x}	"	-38.4	"	-37.0	"	-18.5	"
N-P	+10.0	±11.3	+17.3	±26.7	-86.1	±66.8	+37.7	±30.0
N-S	+ 0.8	"	+35.1	"	-90.9	"	+37.8	"
N-Na	-32.4^{x}	"	+53.6	"	+67.6	"	-27.6	"
N-K	-41.0^{xx}	"	- 0.6	"	-20.6	"	+35.4	"
N-Mg	$+38.8^{x}$	"	+48.4	"	+77.8	"	- 0.8	"
P-S	+21.8	"	-20.9	"	+26.7	"	+66.1	"
P-Na	+14.3	"	-30.9	"	- 3.7	"	-19.4	"
P-K	- 7.8	"	+52.6	"	+56.7	"	$+90.8^{x}$	"
P-Mg	-32.4^{x}	"	-39.9	"	+17.4	"	-75.6^{x}	"
S-Na	-111.6^{xx}	"	-34.4	"	-43.1	"	-120.0^{xx}	"
S-K	+ 9.9	"	$+68.6^{x}$	"	+39.3	"	$+95.0^{x}$	"
S-Mg	+20.4	"	-51.1	"	-25.6	"	-75.0^{x}	"
Na-K	-22.8	"	+58.1	"	+17.2	"	-39.4	"
Na-Mg	-21.4	"	- 5.3	"	- 6.7	"	+46.3	"
K-Mg	-16.0	"	+ 3.6	"	+16.8	"	-54.7	"
R^{+}	0.94		0.83		0.81		0.78	

---

[x] Statistically significant at the 5% level.

[xx] Statistically significant at the 1% level.

[+] The multiple correlation coefficient between the observed yields and the calculated yields.

indicated that the relation of phosphate-P concentration in petioles to the applied nutrients varied greatly as the season advanced. At the first sampling date (June 24), the phosphate-P content was highly related to the level of applied P. The linear effects of N and S were also significantly positive indicating that they increased the uptake of P. The increasing effect of P tended to be less positive at higher rates of application. The effects of K and Mg, as shown by their negative first order and squared terms (Table 6) were depressing on the phosphate concentration in petioles. The N-Na and S-Na interactions produced negative effects indicating that a high level of Na tended to depress the positive effects of N and S on the phosphate-P concentration. Similar effects were produced by K and Mg as shown by the negative N-K and P-Mg interactions. It appears, therefore, that early in the season, a high level of any of the cations Na, K and Mg decreased the phosphate-P concentration in the petioles.

Petiole analysis at the second sampling date (August 12) showed that the phosphate concentration was still positively related to P and N levels, but it was negatively related with the level of applied S. The high levels of K had an increasing effect not only by its positive first order effect, but also by reducing the decreasing effect of S as indicated by the positive S-K interaction. The regression coefficients (Table 6) revealed that the level of

21

phosphate-P in the petioles was not significantly affected by the level of applied P or other nutrient elements at the third sampling date. Analysis of variance for phosphate-P concentration at the third sampling date (Appendix Table 18) indicated a relatively large error term which made the differences statistically insignificant.

The"critical level"of the phosphate-P concentration of petioles under the conditions of this experiment, as calculated from the regression equation, was 2,695 ppm. for June 24, 1,004 ppm. for August 12 and 1,043 ppm. for September 23 (Figure 6). This shows that early in season the "critical level" was very high whereas the values for midseason and late in the season were closer to the 750 ppm. critical level suggested by Ulrich (67).

Sulfate-S Concentration of Petioles: The seasonal mean of sulfate-S concentrations in petioles ranged from 176 ppm. to 504 ppm. with an average of 298 ppm. (Appendix Table 19). Itwas observed the sulfate-S concentrations in petioles were much lower than the levels reported by Haddad (25) and Hashimi (30) under similar conditions. This can partly explain why, contrary to the results of other A.U.B. workers (20, 25, 30), S application tended to produce a favorable response on sugar beet yields in this experiment.

Examination of Figure 7 indicated that there were some variations in the level of sulfate-S in petioles as the season advanced, it generally increased until the second

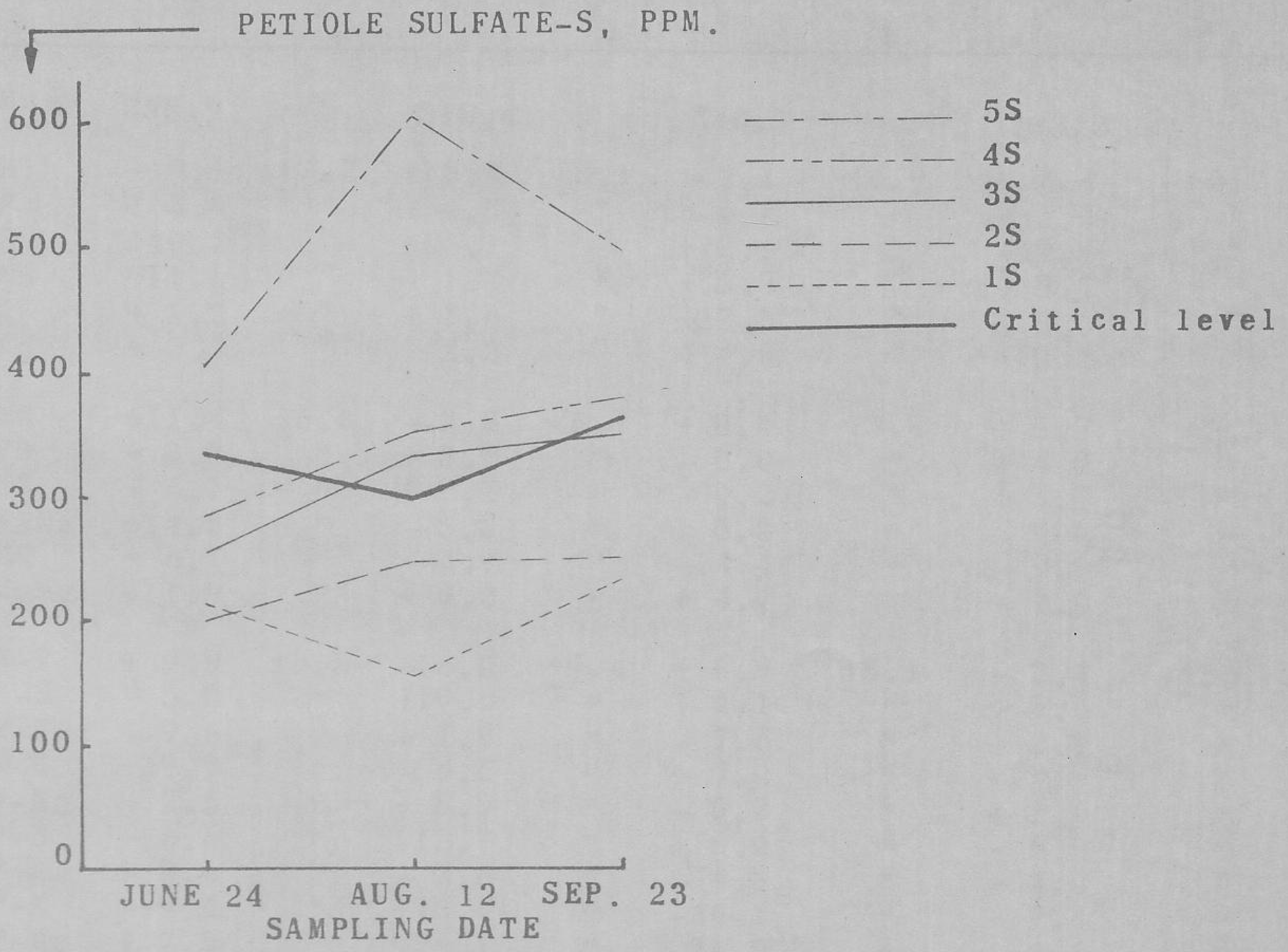

Figure 7. Observed seasonal change in average sulfate-S concentration of petioles (recently mature, dry basis). The "critical level" was calculated from the regression equation with N, P, S, Na, K and Mg at -1, +1, +1, +1, -1 and -1, respectively.

Table 7. Regression coefficients (b) and their standard errors (s_b) for the sulfate-S concentrations of the petioles (ppm., dry basis) at three sampling dates and the seasonal mean as affected by various combinations of levels of N, P, S, Na, K and Mg.

Term	June 24		August 12		Sept. 23		Mean	
	b	s_b	b	s_b	b	s_b	b	s_b
Mean	258.9		310.4		340.7		303.3	
N	-10.1	±7.3	+18.4	±8.1	- 2.1	±6.9	+ 2.4	±2.7
P	+ 4.4	"	+ 6.5	"	- 6.6	"	+ 1.8	"
S	$+40.2^{xx}$	"	$+66.1^{xx}$	"	$+72.3^{xx}$	"	$+59.9^{xx}$	"
Na	+11.1	"	+ 1.4	"	+15.8	"	$+ 9.7^{xx}$	"
K	+ 1.2	"	+ 1.6	"	$+27.5^{xx}$	"	$+ 8.0^{x}$	"
Mg	+ 0.3	"	- 2.2	"	+ 4.0	"	+ 0.4	"
NN	+11.4	±6.3	- 3.8	±6.9	+ 8.4	±5.9	+ 5.7	±2.3
PP	+ 8.5	"	+ 3.9	"	- 0.8	"	+ 4.2	"
SS	+ 4.1	"	+ 9.1	"	- 0.2	"	+ 4.7	"
NaNa	-14.8^{x}	"	- 5.5	"	- 8.3	"	$- 9.2^{xx}$	"
KK	- 6.7	"	- 4.9	"	-10.4	"	$- 9.9^{xx}$	"
MgMg	-11.9	"	+ 0.3	"	+ 4.7	"	- 2.0	"
N-P	+ 2.9	±8.5	-16.0	±9.4	+ 6.9	±8.1	- 2.4	±3.1
N-S	- 5.8	"	+19.8	"	+ 4.1	"	+ 5.6	"
N-Na	+ 9.6	"	+ 7.8	"	- 7.6	"	+ 2.9	"
N-K	$+29.9^{xx}$	"	- 4.5	"	+ 9.0	"	$+11.9^{xx}$	"
N-Mg	- 2.6	"	+ 5.9	"	- 0.3	"	+ 1.6	"
P-S	- 6.6	"	-12.7	"	+ 0.0	"	- 6.9	"
P-Na	- 3.6	"	- 2.6	"	- 4.5	"	- 3.8	"
P-K	- 9.4	"	+10.4	"	-24.1^{x}	"	$- 7.3^{x}$	"
P-Mg	+ 7.5	"	+21.1	"	-21.9^{x}	"	+ 2.6	"
S-Na	-10.6	"	- 4.9	"	- 7.4	"	$- 8.0^{x}$	"
S-K	-10.3	"	- 2.4	"	+ 7.6	"	- 1.3	"
S-Mg	- 0.8	"	- 7.9	"	- 2.8	"	- 3.5	"
Na-K	-22.7^{x}	"	+ 0.3	"	+15.8	"	- 1.9	"
Na-Mg	+ 7.1	"	+ 2.5	"	$+22.3^{x}$	"	+11.0	"
K-Mg	- 3.0	"	- 0.8	"	-23.1^{x}	"	- 9.6	"
R^{+}	0.84		0.84		0.82		0.91	

[x] Statistically significant at the 5% level.

[xx] Statistically significant at the 1% level.

[+] The multiple correlation coefficient between the observed yields and the calculated yields.

sampling date and thereafter it tended to decrease.

The concentration of sulfate-S in petioles was positively related to the level of applied S throughout the season (Table 7). Application of Na had a positive first order effect, but the significantly negative Na^2 and Na-K terms indicated that high levels of Na had a depressive effect and also decreased the positive response to K. The regression coefficient for N-K (Table 7) was positive indicating that high levels of K might have some favorable effect on the sulfate content by reducing the negative first order effect of N.

At the third sampling date (September 23), K tended to increase the sulfate-S concentration significantly whereas the effect of P was depressing particularly at high levels of K as indicated by its first order effect and its significantly negative interaction with K. A similar interaction was found between Mg and K. The positive Na-Mg interaction (Table 7) indicated that these two elements when present at high levels tended to increase the sulfate-S concentration of petioles.

It was observed, therefore, that the influence of most of the applied elements changed as the season advanced whereas the level of applied S was consistantly related with sulfate-S concentration in petioles. The analysis of petioles, therefore, could probably be used as a guide for assessing the S status of the soil. The tentative "critical level" for seasonal mean concentration in the petioles as calculated from the regression equation when N, P, S, Na, K and Mg were at -1, +1, +1, +1, -1 and -1, respectively, was 412 ppm.

<u>Sodium Concentration of Petioles</u>: The seasonal mean concentrations of Na in petioles ranged from 1.20 to 2.81 percent with an average of 1.86 (Appendix Table 21). The petiole analysis at the three sampling dates showed that the Na concentration did not change appreciably during the season. The effect of applied Na level on the Na concentrations, however, changed as the season advanced. They were positively related at the first and the second sampling dates, but this positive relation was no longer significant at the third sampling date. Studying the regression coefficients for the seasonal means (Table 8) indicated that Na and N increased the Na content of the petioles significantly. The Na percentage was also influenced by the levels of P as shown by the significantly positive P-S and P-Na interactions which indicated that high levels of P increased the positive effect of Na and reduced the depressing effect of S and thus generally raised the level of Na in the petioles. The positive first order effect of Mg and the positive S-Mg interaction indicated that at high levels of S, Mg tended to have an increasing effect on petiole Na content. The tentative "critical level" for seasonal Na concentration in the petioles was estimated to be 1.87 percent.

Table 8. Regression coefficients (b) and their standard errors (s_b) for the observed acetic acid extractable Na of the petioles (%, dry basis) at three sampling dates and the seasonal mean as affected by various combinations of levels of N, P, S, Na, K and Mg.

Term	June 24 b	June 24 s_b	August 12 b	August 12 s_b	Sept. 23 b	Sept. 23 s_b	Mean b	Mean s_b
Mean	2.236		1.056		2.058		1.941	
N	+3.871^{xx}	±0.070	+0.029	±0.017	+0.101^{x}	±0.038	+0.172^{xx}	±0.020
P	-0.044	"	+0.044^{x}	"	+0.061	"	+0.021	"
S	-0.044	"	+0.039	"	+0.028	"	-0.043	"
Na	+0.234^{x}	"	+0.147^{xx}	"	+0.052	"	+0.144^{xx}	"
K	+0.007	"	+0.007	"	+0.027	"	+0.014	"
Mg	+0.117	"	+0.038	"	-0.037	"	+0.039	"
NN	-0.074	±0.059	+0.042^{x}	±0.014	+0.036	±0.032	-0.010	±0.017
PP	-0.025	"	+0.029	"	-0.080^{x}	"	-0.037	"
SS	-0.054	"	-0.003	"	-0.058	"	+0.034	"
NaNa	-0.045	"	+0.074^{xx}	"	+0.001	"	-0.002	"
KK	-0.120	"	-0.019	"	-0.017	"	-0.064^{x}	"
MgMg	-0.007	"	+0.003	"	-0.013	"	-0.018	"
N-P	+0.015	±0.081	-0.041	±0.020	+0.111^{x}	±0.045	+0.028	±0.023
N-S	-0.038	"	-0.017	"	+0.036	"	-0.006	"
N-Na	-0.033	"	-0.010	"	-0.046	"	-0.008	"
N-K	-0.030	"	-0.048^{x}	"	-0.004	"	-0.028	"
N-Mg	+0.082	"	-0.044	"	-0.018	"	+0.006	"

Cont. p. 60.

Table 8 continued.

Term	June 24		August 12		Sept. 23		Mean	
	b	s_b	b	s_b	b	s_b	b	s_b
P-S	+0.167	±0.081	+0.072^{x}	±0.020	+0.036	±0.045	+0.091^{xx}	±0.023
P-Na	+0.170	"	+0.015	"	+0.021	"	+0.068^{x}	"
P-K	+0.085	"	-0.027	"	-0.085	"	-0.009	"
P-Mg	-0.010	"	+0.016	"	-0.013	"	-0.002	"
S-Na	+0.022	"	+0.037	"	-0.060	"	-0.001	"
S-K	+0.101	"	-0.037	"	-0.102	"	-0.012	"
S-Mg	-0.033	"	+0.069^{x}	"	+0.196^{xx}	"	+0.077^{x}	"
Na-K	+0.087	"	-0.026	"	-0.050	"	+0.003	"
Na-Mg	+0.003	"	-0.031	"	-0.034	"	+0.002	"
K-Mg	+0.055	"	+0.009	"	+0.022	"	+0.029	"
R^{+}	0.83		0.81		0.78		0.83	

x Statistically significant at 5% level.

xx Statistically significant at 1% level.

\+ The multiple correlation coefficient between the observed yields and the calculated yields.

Potassium Concentration of Petioles: The seasonal mean of acid soluble K in petioles had a range of 3.56 to 5.72 percent with an average of 4.21 (Appendix Table 22). The recorded data for the petiole analysis at the three sampling dates indicated that the concentration of acid soluble K did not change much during the season for the plots which had received the -1 to +2 coded levels of K application. The plants in the plot with the -2 level of K, however, showed a decrease in K concentration as the season advanced having 4.13 percent K at the first sampling date (June 24) and gradually decreasing to 1.5 percent at the third sampling date (September 23).

Study of the regression coefficients (Table 9) indicated that the concentration of K in the petioles and the level of applied K were positively related at the first and the second sampling dates, but they tended to be negatively related late in the season. On a seasonal mean basis, K application tended to have a positive effect, but the effect was not significant. The effect of N level changed during the season being slightly positive early in the season, but tending to produce a negative effect as the season advanced. The first order effect of N on petiole K content, as indicated by the seasonal mean data (Table 9), was significantly negative.

The petiole analysis at the first sampling date indicated that P application increased the level of K in petioles.

Table 9. Regression coefficients (b) and their standard errors (s_b) for the acetic acid extractable K of the petioles (%, dry basis) at three sampling dates and the seasonal mean as affected by various combinations of levels of N, P, S, Na, K and Mg.

Term	June 24 b	s_b	August 12 b	s_b	Sept. 23 b	s_b	Mean b	s_b
Mean	4.037		4.227		4.595		4.286	
N	+0.017	±0.031	-0.400^{x}	±0.092	-0.297	±0.143	-0.194^{x}	±0.073
P	+0.109^{xx}	"	+0.022	"	-0.126	"	+0.001	"
S	-0.014	"	+0.064	"	-0.036	"	+0.002	"
Na	-0.086^{x}	"	-0.028	"	-0.200	"	-0.078	"
K	+0.054	"	+0.172	"	-0.188	"	+0.138	"
Mg	+0.030	"	-0.188	"	-0.207	"	-0.120	"
NN	+0.174^{xx}	±0.026	+0.036	±0.079	-0.254	±0.123	-0.013	±0.062
PP	+0.079^{x}	"	-0.009	"	-0.189	"	-0.040	"
SS	+0.009	"	+0.028	"	-0.018	"	+0.007	"
NaNa	+0.080^{x}	"	-0.047	"	-0.160	"	-0.041	"
KK	+0.083^{x}	"	+0.004	"	-0.106	"	-0.005	"
MgMg	+0.076^{x}	"	+0.010	"	-0.045	"	+0.014	"
N-P	-0.011	±0.036	+0.011	±0.107	-0.080	±0.167	-0.029	±0.085
N-S	-0.041	"	+0.072	"	+0.021	"	+0.014	"
N-Na	-0.009	"	+0.048	"	+0.119	"	+0.049	"
N-K	-0.027	"	-0.212	"	-0.141	"	-0.126	"
N-Mg	+0.054	"	+0.042	"	+0.129	"	+0.077	"
P-S	-0.146^{xx}	"	+0.031	"	-0.082	"	-0.064	"
P-Na	-0.121^{xx}	"	-0.024	"	+0.014	"	-0.045	"
P-K	+0.087^{x}	"	-0.041	"	-0.099	"	-0.016	"
P-Mg	+0.068	"	-0.106	"	-0.134	"	-0.057	"

Cont. p. 63.

Table 9 continued.

Term	June 24		August 12		Sept. 23		Mean	
	b	s_b	b	s_b	b	s_b	b	s_b
S-NA	-0.036	±0.036	-0.007	±0.107	-0.039	±0.167	-0.024	±0.085
S-K	-0.049	"	+0.053	"	-0.081	"	-0.026	"
S-Mg	-0.042	"	-0.113	"	+0.176	"	+0.004	"
Na-K	-0.009	"	-0.184	"	-0.089	"	-0.094	"
Na-Mg	-0.149[xx]	"	-0.142	"	+0.076	"	-0.073	"
K-Mg	-0.011	"	-0.061	"	-0.177	"	-0.078	"
R^+	0.77		0.84		0.81		0.79	

[x] Statistically significant at 5% level.

[xx] Statistically significant at 1% level.

[+] The multiple correlation coefficient between the observed yields and the calculated yields.

The negative first order effect of Na and its significantly negative interaction with P and Mg indicated that a high level of Na in the soil cut down the uptake of K resulting in a lower K concentration in petioles. High levels of S tended to depress the positive response to P as indicated by the negative P-S interaction (Table 9). At the second and third sampling dates, however, the above mentioned effects of P, Na and S were not reproduced and the effects of the other elements on the percentage of K in petioles were not significant. The observed concentrations of acid soluble K in the petioles were much higher than the "critical level" of 1.0 suggested by Ulrich (68).

It was observed that the concentration of acid soluble K in the petioles was not significantly affected by the level of applied K. This could be probably due to the high level of K in the soil as was indicated by soil analysis (Table 2).

Effect of Fertilizers Treatments on Leaf Blade Analysis:

The total concentrations of P, S, Na, K and Mg were determined on the perchloric acid digest of the blade samples collected at the second sampling date (August 12).

Total P Concentration of Blades: The blade analysis data (Appendix Table 24) showed a range of 1,052 to 2,554 ppm. with an average of 1,998 ppm. Total P concentration was positively related to the level of P application (Table 10). The levels of S and Na tended to decrease the P content as

Table 10. Regression coefficients (b) and their standard errors (s_b) for the concentrations of total P and S in the leaf blades (%, dry basis) at the second sampling date as affected by various combinations of levels of N, P, S, Na, K and Mg.

Term	P, ppm.		S, %	
	b	s_b	b	s_b
Mean	2022.4		0.8120	
N	+81.7	±40.2	+0.0167	±0.0122
P	+113.2[x]	"	+0.0495[xx]	"
S	-88.1	"	+0.0193	"
Na	-50.0	"	+0.0387[x]	"
K	+51.9	"	+0.0034	"
Mg	-33.6	"	-0.0132	"
NN	+27.0	±34.4	-0.0103	±0.0104
PP	-57.6	"	-0.0369[xx]	"
SS	+20.0	"	-0.0091	"
NaNa	+26.2	"	+0.0405[xx]	"
KK	-29.3	"	+0.0078	"
MgMg	-16.5	"	+0.0028	"
N-P	+35.4	±46.8	+0.0314	±0.0142
N-S	-15.4	"	-0.0100	"
N-Na	-56.3	"	+0.0456[x]	"
N-K	+98.2	"	-0.0426[x]	"
N-Mg	+32.7	"	-0.0211	"
P-S	- 8.5	"	+0.0490[x]	"
P-Na	+38.4	"	+0.0123	"
P-K	+ 3.4	"	-0.0466[x]	"
P-Mg	-12.9	"	-0.0059	"
S-Na	-86.7	"	+0.0099	"
S-K	+92.8	"	-0.0219	"
S-Mg	-52.6	"	-0.0143	"
Na-K	+ 9.9	"	-0.0357[x]	"
Na-Mg	-44.5	"	-0.0142	"
K-Mg	-24.3	"	+0.0140	"
R[+]	0.73		0.81	

---

[x] Statistically significant at the 5% level.

[xx] Statistically significant at the 1% level.

[+] The multiple correlation coefficient between the observed yields and the calculated yields.

indicated by the negative first order effects of Na and S and the negative S-Na interaction. It appears, therefore, that increasing the level of P while keeping Na and S at low levels tended to raise total P content of the leaf blades.

Total S Concentration of Blades: The total S concentration in blades ranged from 0.17 to 1.40 percent with an average of 0.93 (Appendix Table 24). It was observed that unlike sulfate-S concentrations in the petioles which were relatively low, the total S contents in the leaf blades were very high. This appeared to be contradictory, but no explanation was found. The level of applied S had a tendency to increase the concentration of total S in the blades, but the effect was not significant (Table 10). The positive first order response produced by P and Na was significant with P having a greater effect. The highly negative P^2 term, however, indicated that at higher levels of application the positive effect of P diminished considerably, whereas the significantly positive Na^2 term indicated that the increasing effect of Na was maintained even at high levels. The positive P-S and N-Na interactions further emphasized the favorable effects of P and Na levels. These interactions showed that P enhanced the positive effect of S, and Na reduced the negative effect of N on the S concentration. Thus it appears that high levels of P and Na increased the total S content of blades in this experiment.

Total Na Concentration of Blades: The blade perchloric acid digest analysis indicated a range of 1.78 to 3.08 percent with an average of 2.41 of Na (Appendix Table 24). The study of the regression coefficients (Table 11) showed that Na concentration was increased as the level of Na in the soil was raised. The significantly negative squared terms of S and K indicated that the blade Na percentage was depressed at higher levels of S and K application. The level of Na in leaf blades did not appear to be influenced by the level of N, P, and Mg in the soil, and none of the interactions tended to produce any significant effect.

Total K Concentration of Blades: The recorded data (Appendix Table 24) indicated that the K concentration in blades ranged from 3.25 to 6.85 percent with an average of 4.98. These values were much higher than the "critical level" of 1.0 percent indicated by Ulrich *et al.* (67). The study of regression coefficients (Table 11) indicated that the Na and N levels had significant negative effects on the K concentration. The first order effect of P was small, but its significantly negative squared term indicated its depressing effect at higher levels of application. The K percentage in blades was not very closely related to the level of applied K suggesting that the total K concentration is probably not a good measure of assessing K level in soil where the general level of available K is high.

Table 11. Regression coefficients (b) and their standard errors (s_b) for the concentrations of total P, K, Na and Mg in the leaf blades (dry basis) at the second sampling date as affected by various combinations of levels of N, P, S, Na, K and Mg.

Term	K, %		Na, %		Mg, %	
	b	s_b	b	s_b	b	s_b
Mean	5.436		2.637		1.339	
N	-0.268^x	±0.078	-0.062	±0.054	-0.040	±0.050
P	+0.013	"	+0.072	"	+0.032	"
S	-0.065	"	+0.048	"	+0.082	"
Na	-0.186	"	+0.159^x	"	+0.081	"
K	+0.027	"	-0.037	"	-0.004	"
Mg	-0.112	"	+0.039	"	+0.092	"
NN	-0.194^x	±0.067	-0.029	±0.046	+0.023	±0.043
PP	-0.238^x	"	-0.032	"	-0.007	"
SS	+0.001	"	-0.120^x	"	-0.037	"
NaNa	+0.014	"	+0.008	"	+0.022	"
KK	-0.052	"	-0.115^x	"	+0.032	"
MgMg	-0.164	"	+0.018	"	+0.077	"
N-P	-0.056	±0.091	-0.030	±0.062	-0.060	±0.058
N-S	+0.006	"	-0.020	"	+0.026	"
N-Na	+0.162	"	+0.045	"	+0.071	"
N-K	+0.075	"	-0.032	"	-0.024	"
N-Mg	-0.139	"	-0.087	"	-0.013	"
P-S	-0.091	"	-0.037	"	+0.064	"
P-Na	-0.113	"	+0.069	"	-0.019	"
P-K	-0.125	"	-0.115	"	-0.006	"
P-Mg	+0.185	"	-0.043	"	+0.006	"
S-Na	+0.143	"	+0.106	"	+0.056	"
S-K	+0.023	"	-0.093	"	-0.040	"
S-Mg	-0.120	"	-0.024	"	-0.056	"
Na-K	+0.005	"	-0.029	"	-0.054	"
Na-Mg	+0.038	"	+0.003	"	+0.055	"
K-Mg	-0.011	"	-0.004	"	+0.044	"
R$^+$	0.85		0.74		0.79	

[x] Statistically significant at the 5% level.

[+] The multiple correlation coefficient between the observed yields and the calculated yields.

Total Mg Concentration of Blades: The analysis data (Appendix Table 24) indicated a range of 0.70 to 2.29 percent with an average of 1.43 of Mg content. The effects of none of the elements were significant, but S, Na and Mg levels had a tendency to increase the Mg content (Table 11). The interactions were all of very small effect.

SUMMARY AND CONCLUSIONS

An irrigated field experiment was conducted on a calcareous soil, in Lebanon to study the interrelationships of N, P, S, Na, K and Mg on the growth and composition of sugar beets. Each of the variables were varied at five levels ranging from a low level, possible deficiency, to a high level, possible excess. A central composite rotatable incomplete factorial design was employed to study the main effects and the interactions. This design also permits the calculation of a quadratic regression equation for the response surface. There were 45 treatments with one of them (coded 0 level) being repeated 10 times and distributed at random in the three blocks for calculation of the experimental error. The significance of the magnitude of each individual regression coefficient was evaluated by determining the probability of a true effect using the "t" test. 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.

Three sets of petiole samples were taken from the recently mature leaves on June 24, August 12 and September 23. The leaf blades of the second set of samples were separated and retained. The samples were oven dried and analyzed for the nutrient contents. The beets were harvested 210 days after planting. Samples from tops and roots were taken for total N and beet sucrose determination.

Analysis of variance for yields and concentrations of nutrients in the petioles and leaf blades generally accounted for most of the treatment variability and it was not considered necessary to use cubic or higher order terms in the equation. The correlation coefficients between yields and concentration of elements in the petioles and those calculated from the regression equation were generally high indicating a close fit of the regression equation to the actual data. It was concluded, therefore, that the method of using quadratic regression equations to evaluate the data for six variables, each at five levels, was efficient and effective.

The yields of roots were generally high ranging from 85.0 to 121.5 m. tons per hectare with an average of 103.6. Although N had a significantly positive first order effect, when all the quadratic effects were considered, N was found to depress the yield at high levels. Application of Mg and K were also found to decrease the yield whereas S, P and Na tended to increase the yield. The effect of S and P was particularly positive when both were applied at high levels. Sodium tended to increase the yield up to the +1 coded level of application, but higher levels of Na depressed the yield severely. High levels of N and Mg tended to reduce the positive effect of Na due to negative Na-N and Na-Mg interactions.

The yield of tops responded positively and significantly to N, but negatively to K application. A high level of N also decreased the negative effect of K and the highest response to N was obtained at high levels of K as was indicated by the significantly positive N-K interaction. The yield of tops tended to be depressed by S and K.

Application of N increased the total N content of roots and tops significantly whereas P decreased the N concentration in roots as indicated by the significantly negative first order effect of N and the negative N-P interaction. Sodium was also found to reduce the increasing effect of N on the N content of roots.

The concentration of nitrate-N in the petioles decreased as the season advanced, but it was always positively related with the level of applied N. The "critical level" of nitrate-N in the petioles was estimated to be about 4,000 ppm. at three months after planting and decreased to about 700 ppm. at about one month before harvest. It was found that the soil of the experimental plots had an appreciably high N supplying power as was indicated by the high total uptake of plants even where the applied N was low and the high nitrate-N content of the soil.

Application of P significantly increased the phosphate-P content in the petioles early in the season, but its effect became less as the season advanced. Early in the season, a high level of any of the cations (Na, K and Mg) decreased the phosphate-P level in the petioles. Sodium also decreased the positive effect of N and S due to the negative Na-N and Na-S interactions. The "critical level" of phosphate-P in the petioles was estimated to be about 2,700 ppm. on the first sampling date and gradually decreased to about 1,000 ppm. on the second sampling date after which it did not change very much. Total P concentration in the leaf blades was increased by P, but tended to be decreased by S and Na application. The depressing effects of S and Na were more pronounced when both were present at high levels due to the negative S-Na interaction.

The sulfate-S concentration in the petioles was positively related to the level of applied S throughout the season. The level of K was positively related to sulfate-S late in the season whereas P was negatively related. The sulfate-S content of petioles was increased by Na and Mg late in the season particularly when both were present at high levels as indicated by the positive Na-Mg interaction. The estimated seasonal "critical level" for sulfate-S was found to be about 400 ppm. However, the total S content of the leaf blades was appreciably high indicating that S was accumulating in the plant. Effect of applied S on the total S concentration was positive, but not significant, whereas the effects of Na and P application were significantly positive.

The concentration of acid soluble Na and K in the petioles did not change appreciably during the season. Application of Na and N generally tended to increase the level of Na in the petioles. The seasonal "critical level" of acid soluble Na in the petioles was estimated to be 1.87 percent. Effect of K on the K concentration in the petioles tended to be positive whereas that of N was significantly negative. It appeared that the total K concentration in the leaf blades was not very closely related to the level of applied K probably because the soil was relatively high in available K. The level of Mg in the leaf blades was not significantly affected by any of the elements applied.

The estimated "critical levels" of the nutrients in the petioles were generally high probably due to the high level of yield obtained in this experiment. The expected yield of beets when N, P, S, Na, K and Mg were applied at -2, +2, +2, +1, -1, and -2 coded levels, respectively, was found to be about 124 m. tons per hectare. This combination was the maximum yield within the range of -2 to +2 for the variables. The climate of Beqa'a, Lebanon with its warm sunny days, cool nights and long growing season is favorable for sugar production. It was concluded, therefore, that with adequate irrigation, proper cultural practices, insect and disease control, and adequate fertilization, very high yields of sugar beets can be obtained in the area.

LITERATURE CITED

1. Adams, S.N. The value of calcium nitrate and urea for sugar beets and the effect of late nitrogenous top dressing. J. Agri. Sci. 54:395-398. 1960.

2. ___________. The effect of sodium and potassium on sugar beets on the Lincolnshire limestone. J. Agri. Sci. 56:283-288. 1961.

3. ___________. The effect of time of application of phosphate and potash on sugar beets. J. Agri. Sci. 56:127-130. 1961.

4. ___________. The response of sugar beets to fertilizer and the effect of farmyard manure. J. Agri. Sci. 58:219-226. 1962.

5. Alexander and Cormany, C.E. Effect of growth promoting substances on sugar beets. Proc. Amer. Soc. Sug. Beet Tech. Sixth Gen. Meeting :390-393. 1950.

6. Alexander, J.T., Schmer, C.C., Orleans, L.P., and Cotton, R.H. The effect of fertilizer application on leaf analysis and yields of sugar beets. Proc. Amer. Soc. Sug. Beet Tech. 8:370-380. Part II. 1954.

7. Allos, H.F., and Macksoud, S.W. Yield of sugar beet and sugar content as influenced by applications of Chilean nitrate, superphosphate, and water. American University of Beirut, Lebanon. FAS. Pub. No. 5. 1958.

8. Anitia, N.; Ilk, C. and Voiculesca, M. The effect of varying levels of potassium on the root yield of sugar beet. Acad. Rep. pop. Rom. Stud. cerc. Biol. Ser. 15, 479, 7496 (Soils and Fertilizers 27:1836. 1964).

9. Association of official Agriculture Chemists. Methods of analysis, 7th Ed. A.O.A.C. Washington, D.C. 1960.

10. Baird, B.L. The response of sugar beets to fertilizers in Western South Dakota. Proc. Am. Soc. Sug. Beet Tech. 7:189-195. 1952.

11. Black, C.A. Soil - Plant Relationships. John Wiley and Sons. Inc., N.Y. 1957.

12. Carlson, C.W., and Herring, R.B. The effect of fertilizer treatments upon yield and sugar content of sugar beets at Garden City, Kansas. Proc. Am. Soc. Sug. Beet Tech. 8:42-48. Part I. 1954.

13. Cochran, W.C., and Cox, G.M. Experimental Designs. 2nd Ed., John Wiley and Sons. Inc., N.Y. 1957.

14. Cressman, H.K., and Davis, J.F. Sources of sulfur for crop plants in Michigan and effect of sulfur fertilization on plant growth and composition. Agron. J. 54:341-344. 1962.

15. Davis, J.F., Nichol, G. and Thurlow, D. The interaction of rates of phosphate application with fertilizer placement and fertilizer applied at planting time on the chemical composition of sugar beet tissues, yield, percent sucrose and apparent purity of sugar beet roots. J. Am. Soc. Sug. Beet Tech. 12:259-267. (Soils and Fert. 26:2105. 1963).

16. Dimitrov, T.S., and Atanasov, A. Comparative investigation of various forms of nitrogen fertilizers for wheat and sugar beet on leached chernozem - Smonitza. Izv. Inst. Pochrozran. Agrotekh. "Pushkarov" 6:123-158. (Bulg. r.g.) (Soils and Fert. 26:3191. 1963).

17. Downie, A.R. and Swink, J.F. A report of nutrient spray tests on sugar beets. Proc. Am. Soc. Sug. Beet Tech. Sixth Gen. Meeting :393-396. 1950.

18. Duck, W.R. and Hills, F.J. Possibilities of improved nitrogen fertilization of sugar beets through the use of leaf analysis. Proc. Am. Soc. Sug. Beet Tech. 7:252-254. 1952.

19. Finkner, R.E., Ogden, D.B., Hanzas, P.C. and Olsen, R.F. The effect of fertilizer treatment on calcium, sodium, potassium, raffinose, golactinol, nine amino acids and total amino acid content of three varieties of sugar beets grown in Red River Valley of Minnesota. Proc. Am. Soc. Sug. Beet Tech. 10:272-280. 1959.

20. Fuehring, H.D. Unpublished data. Sugar beet experiment, American University of Beirut, 1962.

21. Gilbert, F.A. The place of sulfur in plant nutrition. Bot. Rev. 17:671-691. 1961.

22. Goltin, J, Anie, J, and Velikonja, N. Investigations on the effect of potassium and sodium ions on root quality and yield of different sugar beet varieties. Zemlj, Bilj. II, 451-456 (Fac. Agric. Zagreb, Yugoslavia), (Soils and Fert. 27:3186. 1964).

23. Goodban, A.E., Morgan, A.I., Teranshi, R., Walker, H.G., Jr., Knowles, R.E. and McCready, R.M. Effect of sugar beet nitrogen on juice purification. Proc. Am. Soc. Sug. Beet Tech. 11:533-541. 1962.

24. Grunes, D.L., Haise, H.R. and Fine, L.O. Proportionate uptake of soil and fertilizer phosphorus by plants as affected by nitrogen fertilization. II. Field experiment with sugar beets and potatoes. Soil Sci. Soc. Am. Proc. 22:49-52. 1958.

25. Haddad, K.S. Interrelationship of nitrogen, phosphorus, sulfur, sodium, boron and chlorine on the yield and composition of sugar beets. M.S. Thesis. American University of Beirut. 1964.

26. Haddock, J.L. Nutritional status of sugar beets as revealed by chemical analysis of petioles. Proc. Am. Soc. Sug. Beet Tech. 6:344-348. 1950.

27. __________. The nitrogen requirement of sugar beets, Proc. Am. Soc. Sug. Beet Tech. 7:159-165. 1952.

28. ___________. Yield quality and nutrient content of sugar beets as affected by irrigation regime and fertilizers. Proc. Am. Soc. Sug. Beet Tech. 10:344-355. 1959.

29. Harmer, P.M., Benne, E.J. and Key, C. Factors affecting crop response to sodium applied as common salt on Michigan muck soil. Soil Sci. 76: 1-17. 1953.

30. Hashimi, M.A.A. Interrelationships of nitrogen, phosphorous, sulfur, sodium and chlorine on the growth and composition of sugar beets. M.S. Thesis. American University of Beirut. 1963.

31. Hill, K.W. Effect of nitrogen supply on sucrose percentage of sugar beets. Proc. Am. Soc. Sug. Beet Tech. 7:201-206. 1952.

32. Hills, F.J. and Veaco, R.G. The effect of phosphate fertilizer on yield of sugar beets. Proc. Am. Soc. Sug. Beet Tech. Fifth Gen. Meeting :427-432. 1948.

33. Holst, E.M. and Cormany, C.E. A study of the effect of magnesium sulfate on yield and sucrose content of sugar beets. Proc. Am. Soc. Sug. Beet Tech. 8:32-36. Part I. 1954.

34. Hussieni, K.K. Interrelationships of nitrogen, phosphorus, potassium, magnesium and sodium on the growth and composition of sugar beets. M.S. Thesis. American University of Beirut. 1961.

35. Italie, T.B. Van. The role of sodium in the cation balance of different plants. Trans. Third Int. Congress Soil Sci. I:191-195. 1935.

36. Jackson, M.L. Soil chemical analysis. Prentice Hall, Inc., Englewood Cliffs, N.J. 1958.

37. Johnson, C.M. and Ulrich, A. Analytical methods for use in plant analysis. Calif. Agri. Expt. Sta. Bull. 766. 1959.

38. Kalinevich, A.F. Concerning some metabolic process in the assimilation of sulfur by plants. Plant physiol. (translated from Russian). 6:360-363. 1959.

39. Kaudy, J.C., Truog, E. and Berger, K.C. Relation of sodium uptake to that of potassium by sugar beets. Agron. J. 45:444-447. 1953.

40. Krantz, B.A. and Mackenzie, A.J. Response of sugar beets to nitrogen fertilizers in the Imperial Valley, California. Proc. Am. Soc. Sug. Beet Tech. 8:36-42, Part I. 1954.

41. Lachowski, J. The effect of magnesium sulfate on sugar beet yields in Poland. Roczn. Nauk. rol. 85,667-682. (Soils and Fert. 25:2983, 1962).

42. Larson, W.E. and Pierre, W.H. Interaction of sodium and potassium on yield and cation composition of selected crops. Soil Sci. 76:51-64. 1953.

43. Lehr, J.J. Exploratory pot experiments on sensitiveness of different crops to sodium. Plant and Soil 4:37-48. 1949.

44. Loomis, R.S. and Nevins, D.J. Interrupted nitrogen nutrition effect on growth, sucrose accumulation and foliar development of sugar beet plant. J. Am. Soc. Sugar Beet Tech. 12: 309-322. (Soil and Fert. 26:2701, 1963).

45. ____________, and Ulrich, A. Response of sugar beets to nitrogen depletion in relation to root size. Proc. Am. Soc. Sug. Beet Tech. 10: 499-512. 1959.

46. Magnitski, K.P. The diagnosis of mineral nutrition of plant according to chemical composition of leaves. <u>In</u>. W. Reuther, <u>ed</u>. plant analysis and fertilizer problems. Am. Inst. Biol. Sci. Washington 6, D.C. 159-179. 1960.

47. McQueen, G.R. Effect of various nutrient levels of soil and foliar spray application on sugar beet yields. Proc. Am. Soc. Sug. Beet Tech. 8:46-49, Part I. 1954.

48. Nelson, R.T., Rhoades, H.F. and Mellor, J.L. Harvest results of inorganic fertilizer tests on sugar beets conducted in four states, 1947. Proc. Am. Soc. Sug. Beet Tech. Fifth Gen. Meeting :407-421. 1948.

49. Ogden, D.B., Finkner, R.E., Olson, R.F. and Hanzas, P.C. The effect of fertilizer treatment upon three different varieties in Red River Valley of Minnesota for stand, yield, sugar purity and non-sugar components. Proc. Am. Soc. Sug. Beet Tech. 10:265-271. 1958.

50. Olsen, S.R., Gardner, R. and Schmehl, W.R. Utilization of phosphorus from various materials by sugar beets in Colorado. Proc. Am. Sug. Beet Tech. :317-322. 1950.

51. Rhoades, H.F. and Harris, L. Cropping and fertilization practices for production of sugar beets in Western Nebraska. Proc. Am. Sug. Beet Tech. 8:71-80. Part I. 1954.

52. Russel, D.A. A laboratory Manual for Soil Fertility Students. Wm. C. Brown Co., Dubuque, Iowa. 3rd ed. 1958.

53. Russell, E.J. Soil Conditions and Plant Growth. Longmans, Green & Co., N.Y. 8th ed. 1953.

54. Saric, M. and Curie R. Stage of growth in relation to the uptake of phosphorus by the sugar beet. Agrochimica 6:375-384. 1962.

55. Sayre, C.B. and Shaffer, J.I., Jr. Effect of side dressing of different sodium and nitrogenous salts on yield of beets. Am. Soc. Hort. Sci. Proc. 44:453-456. 1944.

56. Simmon, M. and Roussel, N. Importance of magnesium in the mineral fertilizing of sugar beet. Publ. Tech. Inst. Belge Amélior. Better 31:87-97. (Soils and Fert. 27:2472. 1964).

57. Sirochenko, I.A. Effect of various forms of potassium fertilizer on yield and quality of sugar beets. Nauch. Trudy Akrain. Nauchissled. Inst. Fiziol. Rast. 12, 41-49 (R.) (Soils and Fert. 25:1827. 1962).

58. Stefan, V., Boti, D., Botea, M. et al. (1962). Phosphorus assimilation by sugar beet. Acad. Rep. Pop. Rom. Probl. Agric. 14, No. 4, 33-41. (Rm.). C.A. 57:6336. (Soils and Fert. 26: 1048. 1963).

59. Stout, M. A new look at some nitrogen relationships affecting the quality of sugar beet. Proc. Am. Soc. Sug. Beet Tech. 11:388-398. 1961.

60. Tolman, B. Response to nitrogen and phosphate fertilizers in the intermountain area. Proc. Am. Soc. Sug. Beet Tech. Fourth Gen. Meeting : 45-54. 1946.

61. __________, and Johnson, R.C. Effect of nitrogen on the yield and sucrose content of sugar beets. Proc. Am. Soc. Sug. Beet Tech. 10:255-257. 1958.

62. __________, and Stoker, G.C. Sulfur and nitrogen deficiency relationships in sugar beets grown for seed in Oregon. J. Am. Soc. Agron. 33:1072-1079. 1941.

63. Truog, E., Berger, K.C. and Attoe, O.J. Response of nine economic plants to fertilization with sodium. Soil. Sci. 76:41-51. 1953.

64. Udvari, L. Experiments with heavy applications of fertilizers to sugar beets. Kisérl. Közlem. 55 A, 1962, No. 2, 59-63. (Soils and Fert. 27:1834. 1964).

65. Ulrich, A. Critical nitrate levels of sugar beets estimated from analysis of petioles and blades, with special reference to yield and sucrose concentration. Soil Sci. 69:291-309. 1950.

66. __________, Nitrogen fertilization of sugar beets in the Woodland area of California. II. Effects upon the nitrate-N of petioles and its interrelationship to sugar production. Proc. Am. Soc. Sug. Beet Tech. Sixth Gen. Meeting : 372-390. 1950.

67. __________, Plant analysis in sugar beet nutrition. In. W. Reuther, ed. Plant Analysis and Fertilizer Problems. Am. Inst. Biolog. Sci. Washington 6 D.C. 190-211. 1960.

68. __________, Hills, F.J., Ririe, D., George, A.G., and Morse, M.D. Plant analysis - a guide for sugar beet fertilization. Calif. Agri. Expt. Sta. Bull. 766. 1959.

APPENDICES

Table 12. Yield of roots (fresh basis), yield of tops (dry basis), nitrogen and sucrose concentration of roots (fresh basis), N concentration in tops (dry basis) and yield of sucrose as affected by various combinations of levels of N, P, S, Na, K and Mg.

Treatment level						Yield of roots M.tons/Ha.	N in roots %	Yield of tops M.tons/Ha.	N in tops, %	Suc-rose %	Yield of sucrose, M.tons/Ha.
N	P	S	Na	K	Mg						
2	2	2	2	2	2	106.5	0.13	4.58	2.01	16.1	17.2
4	2	2	2	4	2	110.1	0.19	4.92	2.98	16.0	17.6
2	4	2	2	4	2	86.3	0.08	3.65	2.12	16.5	14.2
4	4	2	2	2	2	107.9	0.16	4.75	2.56	16.2	17.5
2	2	4	2	2	4	102.9	0.12	6.14	1.95	16.6	17.1
4	2	4	2	4	4	111.5	0.20	5.13	2.49	15.3	17.1
2	4	4	2	4	4	106.2	0.11	5.32	2.11	17.0	18.1
4	4	4	2	2	4	114.0	0.16	5.01	2.35	16.0	18.2
2	2	2	4	2	4	94.1	0.12	7.42	2.65	15.4	14.5
4	2	2	4	4	4	106.4	0.18	6.60	2.39	16.0	17.0
2	4	2	4	4	4	94.8	0.12	3.82	1.85	17.3	16.4
4	4	2	4	2	4	99.3	0.13	8.28	2.77	13.5	13.4
2	2	4	4	2	2	102.1	0.12	5.41	2.28	16.5	16.9
4	2	4	4	4	2	113.8	0.19	5.89	2.53	15.3	17.4
2	4	4	4	4	2	117.4	0.09	4.51	2.47	16.2	19.0
4	4	4	4	2	2	115.0	0.14	7.13	2.83	16.0	18.4
2	2	2	2	4	4	85.8	0.14	3.38	2.38	16.3	14.0
4	2	2	2	2	4	102.0	0.17	4.47	3.12	17.5	17.9
2	4	2	2	2	4	87.5	0.10	4.18	2.55	17.5	15.3
4	4	2	2	4	4	107.1	0.14	5.36	2.46	16.0	17.1
2	2	4	2	4	2	85.0	0.11	2.06	2.18	18.0	15.3
4	2	4	2	2	2	94.0	0.18	4.08	2.83	17.7	16.6
2	4	4	2	2	2	98.2	0.11	4.15	2.33	18.0	17.7
4	4	4	2	4	2	110.7	0.14	5.94	2.78	17.1	18.9
2	2	2	4	4	2	92.1	0.12	3.41	2.32	17.1	15.8
4	2	2	4	2	2	98.9	0.18	5.81	3.03	17.0	16.8
2	4	2	4	2	2	101.4	0.13	4.25	2.19	17.3	17.5
4	4	2	4	4	2	92.6	0.14	4.92	2.59	17.1	15.8
2	2	4	4	4	4	89.4	0.15	3.75	2.60	17.4	15.6
4	2	4	4	2	4	96.3	0.17	4.57	2.55	18.1	18.4
2	4	4	4	2	4	94.7	0.11	4.43	2.30	19.1	18.1
4	4	4	4	4	4	93.7	0.14	5.28	2.50	17.0	15.9

Cont. p. 84.

Table 12 continued.

Treatment level						Yield of roots M.tons/Ha.	N in roots %	Yield of tops M.tons/Ha.	N in tops, %	Sucrose %	Yield of sucrose, M.tons/Ha.
N	P	S	Na	K	Mg						
5	3	3	3	3	3	104.4	0.18	6.74	3.11	16.0	16.7
1	3	3	3	3	3	107.7	0.09	5.07	2.04	15.9	17.1
3	5	3	3	3	3	114.6	0.10	4.84	2.33	16.2	18.6
3	1	3	3	3	3	98.5	0.18	4.96	2.45	15.5	15.3
3	3	5	3	3	3	113.2	0.12	3.67	2.50	14.8	16.8
3	3	1	3	3	3	116.5	0.13	4.67	2.41	16.5	19.2
3	3	3	5	3	3	94.5	0.15	4.11	2.28	16.1	15.2
3	3	3	1	3	3	104.7	0.15	6.93	2.75	16.0	16.7
3	3	3	3	5	3	100.8	0.13	4.55	2.15	17.3	17.4
3	3	3	3	1	3	114.0	0.12	4.80	2.51	18.0	20.5
3	3	3	3	3	5	97.2	0.16	4.46	2.35	17.5	17.0
3	3	3	3	3	1	107.2	0.16	5.44	2.61	16.8	18.0
3	3	3	3	3	3	111.5	0.12	5.29	2.48	16.6	18.5
3	3	3	3	3	3	111.0	0.13	5.13	2.36	18.1	20.1
3	3	3	3	3	3	115.6	0.14	6.18	2.53	14.1	16.3
3	3	3	3	3	3	121.5	0.15	6.33	2.28	16.1	19.6
3	3	3	3	3	3	112.3	0.13	5.52	2.45	15.5	17.4
3	3	3	3	3	3	100.8	0.15	4.20	2.18	18.5	18.6
3	3	3	3	3	3	121.0	0.14	3.80	2.37	18.0	21.8
3	3	3	3	3	3	103.3	0.14	4.71	2.52	17.6	18.2
3	3	3	3	3	3	96.2	0.13	4.58	2.38	17.0	16.4
3	3	3	3	3	3	110.0	0.14	4.99	2.29	17.1	18.8

Table 13. Analysis of variance for yield of roots (fresh basis), yield of sucrose, yield of tops (dry basis), sucrose concentration of roots (fresh basis), N concentration of roots (fresh basis) and N concentration of tops (dry basis) as affected by various combinations of levels of N, P, S, Na, K and Mg.

Source	Yield of roots, M.tons / Ha.	Yield of sucrose, M. tons/Ha.	Sucrose in roots, %	Yield of tops, M.tons / Ha.	N in roots, %	N in tops, %
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	4728.5	140.31	61.17	66.55	0.0391	3.990
Block	901.9	0.62	18.80	13.48	0.0001	0.128
Linear	751.3	20.27	3.66	15.69	0.0310	2.162
Quadratic	1720.8	60.89	17.80	18.79	0.0061	1.035
Lack of fit	934.4	35.90	7.50	15.74	0.0014	0.558
Error	420.2	22.63	13.41	2.85	0.0006	0.107
M.S.						
Block	450.9[x]	0.31	9.40[x]	6.74[xx]	0.0000	0.064
Linear	125.2	3.38	0.61	2.61[x]	0.0052[xx]	0.360[xx]
Quadratic	81.9	2.90	0.85	0.89	0.0003	0.049
Lack of fit	55.0	2.11	0.44	0.93	0.0001	0.033
Error	60.0	3.23	1.91	0.41	0.0001	0.015
C.V. %	7.0	9.7	8.2	12.6	6.4	5.2
Equation sufficiency[+], %	72.5	69.3	82.3	68.7	96.4	85.1

---

[x] Statistically significant at the 5% level.

[xx] Statistically significant at the 1% level.

[+] Percentage of total treatment sum of squares accounted for by the quadratic regression equation.

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

Treatment levels						N in roots, Kg./Ha.	N in tops, Kg./Ha.	Total N uptake Kg./Ha.	Applied N Kg./Ha.
N	P	S	Na	K	Mg				
2	2	2	2	2	2	212	92	304	75
4	2	2	2	4	2	190	147	337	300
2	4	2	2	4	2	90	77	167	75
4	4	2	2	2	2	143	122	265	300
2	2	4	2	2	4	115	120	235	75
4	2	4	2	4	4	204	128	332	300
2	4	4	2	4	4	100	112	212	75
4	4	4	2	2	4	185	118	303	300
2	2	2	4	2	4	115	197	313	75
4	2	2	4	4	4	189	158	347	300
2	4	2	4	4	4	109	71	180	75
4	4	2	4	2	4	126	229	355	300
2	2	4	4	2	2	126	123	249	75
4	2	4	4	4	2	218	149	367	300
2	4	4	4	4	2	110	113	221	75
4	4	4	4	2	2	156	203	359	300
2	2	2	2	4	4	122	80	202	75
4	2	2	2	2	4	171	140	311	300
2	4	2	2	2	4	92	107	199	75
4	4	2	2	4	4	147	132	279	300
2	2	4	2	4	2	98	45	143	75
4	2	4	2	2	2	165	116	281	300
2	4	4	2	2	2	103	97	200	75
4	4	4	2	4	2	158	165	323	300
2	2	2	4	4	2	113	79	192	75
4	2	2	4	2	2	179	176	355	300
2	4	2	4	2	2	134	93	227	75
4	4	2	4	4	2	129	127	256	300
2	2	4	4	4	4	130	98	228	75
4	2	4	4	2	4	168	117	285	300
2	4	4	4	2	4	106	102	208	75
4	4	4	4	4	4	126	132	258	300

Cont. p. 87.

Table 14 continued.

Treatment levels						N in roots, Kg./Ha.	N in tops, Kg./Ha.	Total N uptake Kg./Ha.	Applied N Kg./Ha.
N	P	S	Na	K	Mg				
5	3	3	3	3	3	184	157	341	782
1	3	3	3	3	3	96	103	199	29
3	5	3	3	3	3	118	113	231	150
3	1	3	3	3	3	179	122	301	150
3	3	5	3	3	3	139	92	231	150
3	3	1	3	3	3	149	113	262	150
3	3	3	5	3	3	109	94	203	150
3	3	3	1	3	3	153	191	344	150
3	3	3	3	5	3	134	98	232	150
3	3	3	3	1	3	138	121	259	150
3	3	3	3	3	5	152	105	257	150
3	3	3	3	3	1	176	142	318	150
3	3	3	3	3	3	151	131	282	150
3	3	3	3	3	3	143	121	264	150
3	3	3	3	3	3	165	156	321	150
3	3	3	3	3	3	177	144	321	150
3	3	3	3	3	3	144	135	279	150
3	3	3	3	3	3	154	92	246	150
3	3	3	3	3	3	166	90	256	150
3	3	3	3	3	3	149	119	268	150
3	3	3	3	3	3	174	109	283	150
3	3	3	3	3	3	155	114	269	150

Table 15. Nitrate-N concentration in the petioles (dry basis) at three sampling dates and the seasonal mean as affected by various combinations of levels of N, P, S, Na, K and Mg.

Treatment levels						June 24, ppm.	August 12, ppm.	Sept. 23, ppm.	Mean, ppm.
N	P	S	Na	K	Mg				
2	2	2	2	2	2	832	431	2,756	1,340
4	2	2	2	4	2	9,152	2,089	2,880	4,707
2	4	2	2	4	2	1,169	1,400	316	962
4	4	2	2	2	2	6,466	1,284	622	2,791
2	2	4	2	2	4	3,728	26	2,783	2,179
4	2	4	2	4	4	9,059	1,346	3,447	4,617
2	4	4	2	4	4	11,904	2,692	617	5,071
4	4	4	2	2	4	12,814	1,605	1,337	5,252
2	2	2	4	2	4	1,134	1,356	1,994	1,495
4	2	2	4	4	4	11,971	3,077	5,134	6,727
2	4	2	4	4	4	2,427	578	572	1,192
4	4	2	4	2	4	6,610	4,094	4,588	5,097
2	2	4	4	2	2	1,171	432	1,940	1,181
4	2	4	4	4	2	9,965	2,000	1,785	4,583
2	4	4	4	4	2	6,324	960	1,494	2,926
4	4	4	4	2	2	6,439	4,094	4,775	5,103
2	2	2	2	4	4	958	226	575	586
4	2	2	2	2	4	7,847	133	792	2,924
2	4	2	2	2	4	822	307	1,965	1,031
4	4	2	2	4	4	3,582	1,814	1,892	2,429
2	2	4	2	4	2	690	641	598	643
4	2	4	2	2	2	10,721	322	1,322	4,122
2	4	4	2	2	2	2,422	431	626	1,160
4	4	4	2	4	2	7,338	2,460	873	3,557
2	2	2	4	4	2	1,637	254	1,169	1,020
4	2	2	4	2	2	8,407	1,207	2,495	4,036
2	4	2	4	2	2	797	625	1,453	958
4	4	2	4	4	2	1,238	2,233	2,246	1,906
2	2	4	4	4	4	414	481	1,682	859
4	2	4	4	2	4	696	884	2,185	1,255
2	4	4	4	2	4	424	426	1,875	908
4	4	4	4	4	4	12,022	2,540	1,567	5,376

Cont. p. 89.

Table 15 continued.

Treatment levels N	P	S	Na	K	Mg	June 24, ppm.	August 12, ppm.	Sept. 23, ppm.	Mean, ppm.
5	3	3	3	3	3	12,711	5,424	3,109	7,081
1	3	3	3	3	3	233	1,681	1,468	1,127
3	5	3	3	3	3	1,238	917	1,417	1,191
3	1	3	3	3	3	5,506	961	944	2,470
3	3	5	3	3	3	1,887	967	1,960	1,605
3	3	1	3	3	3	3,143	3,829	1,934	1,484
3	3	3	5	3	3	4,807	2,108	2,780	3,231
3	3	3	1	3	3	4,464	4,225	1,990	3,560
3	3	3	3	5	3	2,780	2,105	945	1,943
3	3	3	3	1	3	3,000	1,554	1,982	2,179
3	3	3	3	3	5	6,387	2,239	939	3,188
3	3	3	3	3	1	5,341	2,346	2,189	3,292
3	3	3	3	3	3	5,083	1,190	3,816	3,363
3	3	3	3	3	3	3,783	668	1,820	2,090
3	3	3	3	3	3	2,306	2,562	1,787	2,218
3	3	3	3	3	3	8,408	1,346	1,311	3,688
3	3	3	3	3	3	3,416	1,498	1,789	2,234
3	3	3	3	3	3	2,838	995	819	1,551
3	3	3	3	3	3	1,154	433	621	736
3	3	3	3	3	3	635	1,434	744	938
3	3	3	3	3	3	3,022	1,520	2,075	2,206
3	3	3	3	3	3	2,966	1,329	1,118	1,804

Table 16. Analysis of variance for nitrate-N, Phosphate-P, Sulfate-S, acid soluble Na and K (seasonal means) concentrations of petioles (dry basis) as affected by various combinations of levels of N, P, S, Na, K and Mg.

Source	Nitrate-N, log.ppm.	Phosphate-P, ppm.	Sulfate-S, %	Na, %	K, %
d.f.					
Total	53	53	53	53	53
Block	2	2	2	2	2
Linear	6	6	6	6	6
Quadratic	21	21	21	21	21
Lack of fit	17	17	17	17	17
Error	7	7	7	7	7
S.S.					
Total	4.305	5,469,406	237,649	5.007	8.609
Block	0.764	558,152	18,549	0.183	0.414
Linear	2.183	1,146,512	162,201	2.355	**3.337**
Quadratic	0.924	2,154,426	36,615	1.150	2.208
Lack of fit	0.242	1,409,150	18,126	1.197	1.051
Error	0.192	201,166	2,158	0.122	1.599
M.S.					
Block	0.382[xx]	279,076[xx]	9,274[xx]	0.092[x]	0.207
Linear	0.364[xx]	191,085[x]	27,034[xx]	0.392[xx]	0.556
Quadratic	0.044	102,592[x]	1,744[x]	0.055	0.105
Lack of fit	0.014	82,891	1,066	0.070[x]	0.062
Error	0.027	28,738	308	0.017	0.228
C.V., %	5.1	10.7	5.8	6.8	11.2
Equation sufficiency[+], %	92.8	70.1	91.6	74.5	84.1

---

[x] Statistically significant at the 5% level.

[xx] Statistically significant at the 1% level.

[+] Percentage of total treatment sum of squares accounted for by the quadratic regression equation.

Table 17. Analysis of variance for nitrate-N and phosphate-P concentrations in the petioles (dry basis) at three sampling dates as affected by various combinations of levels of N, P, S, Na, K and Mg.

Source	Nitrate-N, log. ppm.			Phosphate-P, ppm.		
	June 24	August 12	Sept. 23	June 24	August 12	Sept.23
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	10.814	9.520	3.781	7,100,946	3,859,000	4,586,800
Block	1.387	1.631	0.348	5,086	353,426	486,564
Linear	5.195	3.637	1.192	4,357,706	1,092,240	375,379
Quadratic	2.568	2.264	0.968	1,908,367	1,080,140	2,273,280
Lack of fit	1.145	1.627	0.998	801,201	1,174,310	455,993
Error	0.518	0.361	0.276	28,583	158,884	995,584
M.S.						
Block	0.694^{xx}	0.815^{xx}	0.174	2,543	176,713^{x}	243,282
Linear	0.866^{xx}	0.606^{xx}	0.199^{x}	726,284^{xx}	182,040^{xx}	62,563
Quadratic	0.122	0.108	0.046	90,874^{xx}	51,435	108,251
Lack of fit	0.067	0.096	0.059	47,129^{xx}	69,077	26,823
Error	0.074	0.052	0.039	4,083	22,698	142,226
C.V., %	7.9	7.3	6.3	2.8	11.2	33.2
Equation sufficiency^{+}, %	87.1	78.4	68.4	88.5	64.9	85.3

x Statistically significant at the 5% level.

xx Statistically significant at the 1% level.

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

Table 18. Phosphate-P concentration in the petioles (dry basis) at three sampling dates and the seasonal mean as affected by various combination of levels of N, P, S, Na, K and Mg.

Treatment levels						June 24,	August 12,	Sept. 23,	Mean,
N	P	S	Na	K	Mg	ppm.	ppm.	ppm.	ppm.
2	2	2	2	2	2	1855	1369	874	1366
4	2	2	2	4	2	2020	1444	780	1415
2	4	2	2	4	2	2372	1323	1195	1630
4	4	2	2	2	2	2483	1703	849	1678
2	2	4	2	2	4	2105	975	798	1293
4	2	4	2	4	4	2292	1248	949	1496
2	4	4	2	4	4	2644	1474	1373	1830
4	4	4	2	2	4	2713	1693	1024	1810
2	2	2	4	2	4	1827	1342	950	1373
4	2	2	4	4	4	1779	1550	1320	1550
2	4	2	4	4	4	2645	1494	1000	1713
4	4	2	4	2	4	3018	1625	1299	1981
2	2	4	4	2	2	1955	997	875	1276
4	2	4	4	4	2	1886	1493	901	1427
2	4	4	4	4	2	2449	1749	1247	1815
4	4	4	4	2	2	2671	1199	750	1540
2	2	2	2	4	4	2068	1247	525	1280
4	2	2	2	2	4	2513	1169	1164	1615
2	4	2	2	2	4	1872	1420	774	1336
4	4	2	2	4	4	2081	1542	926	1516
2	2	4	2	4	2	2121	1175	849	1382
4	2	4	2	2	2	2206	1151	755	1371
2	4	4	2	2	2	2605	1349	1123	1692
4	4	4	2	4	2	2738	1596	449	1594
2	2	2	4	4	2	2109	846	448	1134
4	2	2	4	2	2	1886	1143	1150	1387
2	4	2	4	2	2	3008	1396	751	1718
4	4	2	4	4	2	2850	1773	950	1858
2	2	4	4	4	4	1667	876	524	1022
4	2	4	4	2	4	1851	1424	676	1317
2	4	4	4	2	4	2572	175	725	1157
4	4	4	4	4	4	2659	1600	1023	1761

Cont. p. 93.

Table 18 continued.

Treatment levels						June 24,	August 12,	Sept. 23,	Mean,
N	P	S	Na	K	Mg	ppm.	ppm.	ppm.	ppm.
5	3	3	3	3	3	2844	1419	698	1654
1	3	3	3	3	3	2450	1472	673	1532
3	5	3	3	3	3	3215	1324	1223	1921
3	1	3	3	3	3	1638	1072	449	1053
3	3	5	3	3	3	2359	1563	1199	1040
3	3	1	3	3	3	1878	1621	1025	1508
3	3	3	5	3	3	2252	1393	1473	1706
3	3	3	1	3	3	2271	1270	1547	1696
3	3	3	3	5	3	1581	1370	897	1283
3	3	3	3	1	3	2446	1325	1025	1599
3	3	3	3	3	5	2087	1124	950	1387
3	3	3	3	3	1	2175	1132	1048	1452
3	3	3	3	3	3	2241	1250	923	1471
3	3	3	3	3	3	2357	1374	949	1559
3	3	3	3	3	3	2361	1724	1971	2017
3	3	3	3	3	3	2275	1323	1299	1632
3	3	3	3	3	3	2197	1196	1125	1506
3	3	3	3	3	3	2339	1244	1273	1619
3	3	3	3	3	3	2278	1101	1072	1484
3	3	3	3	3	3	2351	1223	751	1442
3	3	3	3	3	3	2371	1372	1219	1654
3	3	3	3	3	3	2295	1540	698	1511

Table 19. Sulfate-S concentration in the petioles (dry basis) at three sampling dates and the seasonal mean as affected by various combinations of levels of N, P, S, Na, K and Mg.

Treatment levels						June 24, ppm.	August 12, ppm.	Sept. 23, ppm.	Mean, ppm.
N	P	S	Na	K	Mg				
2	2	2	2	2	2	155	203	183	180
4	2	2	2	4	2	211	185	219	205
2	4	2	2	4	2	125	231	265	207
4	4	2	2	2	2	109	265	171	182
2	2	4	2	2	4	235	278	356	290
4	2	4	2	4	4	281	315	405	334
2	4	4	2	4	4	297	421	261	326
4	4	4	2	2	4	175	338	388	300
2	2	2	4	2	4	260	192	401	284
4	2	2	4	4	4	210	265	233	236
2	4	2	4	4	4	147	325	197	223
4	4	2	4	2	4	245	261	270	259
2	2	4	4	2	2	315	345	281	314
4	2	4	4	4	2	271	409	533	404
2	4	4	4	4	2	156	291	389	279
4	4	4	4	2	2	261	381	227	290
2	2	2	2	4	4	185	148	351	216
4	2	2	2	2	4	98	252	266	205
2	4	2	2	2	4	237	306	170	238
4	4	2	2	4	4	258	267	182	236
2	2	4	2	4	2	315	371	447	378
4	2	4	2	2	2	247	445	382	358
2	4	4	2	2	2	351	296	538	395
4	4	4	2	4	2	289	363	407	353
2	2	2	4	4	2	230	271	326	275
4	2	2	4	2	2	165	208	156	176
2	4	2	4	2	2	248	282	262	264
4	4	2	4	4	2	306	239	319	288
2	2	4	4	4	4	255	185	611	350
4	2	4	4	2	4	342	470	378	397
2	4	4	4	2	4	398	346	464	403
4	4	4	4	4	4	285	428	420	378

Cont. p. 95.

Table 19 continued.

Treatment levels						June 24, ppm.	August 12, ppm.	Sept. 23, ppm.	Mean, ppm.
N	P	S	Na	K	Mg				
5	3	3	3	3	3	292	360	505	386
1	3	3	3	3	3	411	276	312	333
3	5	3	3	3	3	352	315	423	363
3	1	3	3	3	3	318	407	291	339
3	3	5	3	3	3	406	617	488	504
3	3	1	3	3	3	215	163	232	203
3	3	3	5	3	3	195	276	359	277
3	3	3	1	3	3	214	341	271	275
3	3	3	3	5	3	265	359	412	312
3	3	3	3	1	3	235	265	194	231
3	3	3	3	3	5	191	318	372	294
3	3	3	3	3	1	251	364	403	339
3	3	3	3	3	3	308	214	355	292
3	3	3	3	3	3	259	357	298	305
3	3	3	3	3	3	186	303	322	270
3	3	3	3	3	3	244	281	411	312
3	3	3	3	3	3	285	335	367	329
3	3	3	3	3	3	318	308	277	301
3	3	3	3	3	3	237	263	349	283
3	3	3	3	3	3	196	378	360	313
3	3	3	3	3	3	260	355	292	302
3	3	3	3	3	3	272	286	358	305

Table 20. Analysis of variance for sulfate-S and acetic acid extractable Na concentrations in the petioles (dry basis) at three sampling dates as affected by various combinations of levels of N, P, S, Na, K and Mg.

Source	Sulfate-S, ppm.			Na, %		
	June 24,	August 12	Sept. 23	June 24	August 12	Sept. 23
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	260,456	375,960	558,002	20.512	3.686	6.647
Block	28,182	15,211	23,336	1.638	0.487	0.667
Linear	80,463	205,830	271,852	9.595	1.181	0.844
Quadratic	104,985	62,089	104,046	4.479	1.223	3.326
Lack of fit	30,569	72,961	144,239	3.335	0.708	1.367
Error	16,257	19,867	14,530	1.465	0.086	0.443
M.S.						
Block	14,091[x]	7,605	11,668[x]	0.819	0.244[xx]	0.333[x]
Linear	13,410[x]	34,305[xx]	45,309[xx]	1.599[xx]	0.197[xx]	0.141
Quadratic	4,999	2,957	4,955	0.213	0.058[x]	0.158
Lack of fit	1,798	4,292	8,485[x]	0.196	0.042	0.080
Error	2,322	2,838	2,076	0.209	0.012	0.063
C.V., %	18.8	17.3	13.4	20.4	7.4	12.3
Equation sufficiency[+], %	85.8	78.6	72.5	80.8	77.4	75.3

---

[x] Statistically significant at the 5% level.

[xx] Statistically significant at the 1% level.

[+] Percentage of total treatment sum of squares accounted for by the quadratic regression equation.

Table 21. Acetic acid extractable Na in the petioles (dry basis) at three sampling dates and the seasonal mean as affected by various combinations of levels of N, P, S, Na, K and Mg.

Treatment levels						June 24,	August 12,	Sept. 23,	Mean,
N	P	S	Na	K	Mg	%	%	%	%
2	2	2	2	2	2	1.63	1.32	1.50	1.48
4	2	2	2	4	2	2.43	1.49	2.31	2.08
2	4	2	2	4	2	0.89	1.50	1.49	1.29
4	4	2	2	2	2	1.77	1.30	2.27	1.78
2	2	4	2	2	4	1.60	1.45	2.09	1.71
4	2	4	2	4	4	2.57	1.45	1.72	1.91
2	4	4	2	4	4	1.45	1.87	1.62	1.65
4	4	4	2	2	4	1.82	1.52	2.37	1.90
2	2	2	4	2	4	2.18	1.43	1.37	1.66
4	2	2	4	4	4	2.93	1.58	1.62	2.04
2	4	2	4	4	4	1.79	1.37	1.57	1.58
4	4	2	4	2	4	3.21	1.68	1.92	2.27
2	2	4	4	2	2	1.45	1.33	1.55	1.44
4	2	4	4	4	2	2.00	1.70	1.33	1.68
2	4	4	4	4	2	2.98	1.71	1.32	2.00
4	4	4	4	2	2	2.64	2.15	2.15	2.31
2	2	2	2	4	4	1.55	1.40	1.97	1.64
4	2	2	2	2	4	2.37	1.54	1.29	1.73
2	4	2	2	2	4	1.15	1.25	1.35	1.25
4	4	2	2	4	4	1.92	1.57	1.90	1.80
2	2	4	2	4	2	0.86	1.08	1.67	1.20
4	2	4	2	2	2	2.11	1.68	1.93	1.91
2	4	4	2	2	2	1.15	1.40	1.92	1.49
4	4	4	2	4	2	1.52	1.35	2.37	1.75
2	2	2	4	4	2	1.75	1.89	2.46	2.03
4	2	2	4	2	2	2.64	1.79	2.05	2.16
2	4	2	4	2	2	1.15	1.63	2.52	1.77
4	4	2	4	4	2	2.20	1.57	2.12	1.96
2	2	4	4	4	4	1.72	1.91	1.97	1.87
4	2	4	4	2	4	2.22	1.70	2.38	2.10
2	4	4	4	2	4	1.22	2.32	2.17	1.90
4	4	4	4	4	4	3.70	1.72	2.45	2.62

Cont. p. 98.

Table 21 continued.

Treatment levels						June 24,	August 12,	Sept. 23,	Mean,
N	P	S	Na	K	Mg	%	%	%	%
5	3	3	3	3	3	2.37	1.95	2.49	2.27
1	3	3	3	3	3	1.02	1.82	2.19	1.68
3	5	3	3	3	3	1.87	1.96	1.77	1.87
3	1	3	3	3	3	2.07	1.65	1.62	1.78
3	3	5	3	3	3	1.52	1.56	1.80	1.63
3	3	1	3	3	3	2.09	1.70	1.83	2.81
3	3	3	5	3	3	2.09	2.49	2.37	2.32
3	3	3	1	3	3	1.62	1.63	1.92	1.72
3	3	3	3	5	3	1.09	1.67	2.49	1.75
3	3	3	3	1	3	1.78	1.40	1.60	1.59
3	3	3	3	3	5	2.24	1.82	1.98	2.01
3	3	3	3	3	1	1.90	1.50	2.15	1.85
3	3	3	3	3	3	2.12	1.41	2.22	1.92
3	3	3	3	3	3	3.06	1.32	2.20	2.23
3	3	3	3	3	3	2.13	1.37	2.02	1.84
3	3	3	3	3	3	3.40	1.46	1.55	2.14
3	3	3	3	3	3	1.82	1.64	2.18	1.88
3	3	3	3	3	3	2.05	1.53	1.77	1.78
3	3	3	3	3	3	2.08	1.35	1.77	1.73
3	3	3	3	3	3	1.55	1.37	2.13	1.68
3	3	3	3	3	3	2.07	1.84	2.30	2.07
3	3	3	3	3	3	2.17	1.65	2.37	2.06

Table 22. Acetic acid extractable K in the petioles (dry basis) at three sampling dates and the seasonal mean as affected by various combinations of levels of N, P, S, Na, K and Mg.

Treatment levels						June 24,	August 12,	Sept. 23,	Mean,
N	P	S	Na	K	Mg	%	%	%	%
2	2	2	2	2	2	3.91	3.63	3.95	3.83
4	2	2	2	4	2	4.20	3.56	3.70	3.85
2	4	2	2	4	2	5.02	5.42	6.72	5.72
4	4	2	2	2	2	4.56	3.51	3.79	3.95
2	2	4	2	2	4	4.75	3.90	4.19	4.28
4	2	4	2	4	4	4.39	4.07	4.20	4.22
2	4	4	2	4	4	4.94	5.05	3.95	4.65
4	4	4	2	2	4	4.74	3.61	3.37	3.91
2	2	2	4	2	4	4.01	4.38	3.75	4.05
4	2	2	4	4	4	4.52	3.50	4.24	4.09
2	4	2	4	4	4	5.25	3.86	3.40	4.17
4	4	2	4	2	4	4.19	3.86	3.27	3.77
2	2	4	4	2	2	5.27	4.26	3.58	4.37
4	2	4	4	4	2	4.44	4.48	3.86	4.26
2	4	4	4	4	2	4.37	5.55	4.04	4.65
4	4	4	4	2	2	4.39	4.85	3.32	4.19
2	2	2	2	4	4	3.90	5.26	4.17	4.44
4	2	2	2	2	4	4.45	3.76	3.36	3.99
2	4	2	2	2	4	4.89	4.01	3.15	4.02
4	4	2	2	4	4	5.05	4.08	2.65	3.96
2	2	4	2	4	2	4.64	5.50	5.29	5.15
4	2	4	2	2	2	3.83	4.03	3.44	3.77
2	4	4	2	2	2	4.12	4.42	3.49	4.01
4	4	4	2	4	2	4.39	4.54	3.09	4.01
2	2	2	4	4	2	4.49	5.23	4.78	4.83
4	2	2	4	2	2	4.48	4.03	3.32	3.94
2	4	2	4	2	2	4.45	4.79	3.95	4.40
4	4	2	4	4	2	4.42	3.87	3.80	4.03
2	2	4	4	4	4	4.04	4.55	3.74	4.11
4	2	4	4	2	4	4.18	3.85	3.20	3.74
2	4	4	4	2	4	3.69	3.98	4.17	3.95
4	4	4	4	4	4	4.11	3.67	2.89	3.56

Cont. p. 100.

Table 22 continued.

Treatment levels						June 24,	August 12,	Sept. 23,	Mean,
N	P	S	Na	K	Mg	%	%	%	%
5	3	3	3	3	3	5.74	3.73	2.79	4.09
1	3	3	3	3	3	4.84	4.94	3.64	4.48
3	5	3	3	3	3	5.10	4.05	3.22	4.12
3	1	3	3	3	3	4.41	4.11	3.94	4.15
3	3	5	3	3	3	4.55	4.12	4.67	4.44
3	3	1	3	3	3	4.18	4.46	4.40	4.35
3	3	3	5	3	3	4.29	3.54	3.42	3.75
3	3	3	1	3	3	5.23	4.20	4.07	4.50
3	3	3	3	5	3	4.80	4.18	4.24	4.41
3	3	3	3	1	3	4.76	4.13	3.85	4.25
3	3	3	3	3	5	4.99	3.80	3.85	4.21
3	3	3	3	3	1	4.49	4.58	4.92	4.66
3	3	3	3	3	3	3.99	4.07	5.49	4.52
3	3	3	3	3	3	4.44	4.55	5.50	4.83
3	3	3	3	3	3	4.09	3.70	3.74	3.84
3	3	3	3	3	3	4.23	4.04	4.67	4.31
3	3	3	3	3	3	3.79	4.04	3.90	3.91
3	3	3	3	3	3	3.81	4.03	3.59	3.81
3	3	3	3	3	3	3.75	4.38	6.11	4.75
3	3	3	3	3	3	3.76	3.99	3.90	3.88
3	3	3	3	3	3	3.84	3.74	4.34	3.97
3	3	3	3	3	3	4.43	5.79	4.66	4.96

Table 23. Analysis of variance for acetic acid extractable K concentrations in the petioles (%, dry basis) at three sampling dates as affected by various combinations of levels of N, P, S, Na, K and Mg.

Source	June 24	August 12	Sept. 23
d.f.			
Total	53	53	53
Block	2	2	2
Linear	6	6	6
Quadratic	21	21	21
Lack of fit	17	17	17
Error	7	7	7
S.S.			
Total	11.057	17.124	33.068
Block	1.950	0.117	1.147
Linear	1.021	7.184	8.456
Quadratic	5.742	5.002	13.020
Lack of fit	2.055	2.233	4.219
Error	0.290	2.566	6.226
M.S.			
Block	0.975[xx]	0.058	0.573
Linear	0.170[x]	1.197	1.409
Quadratic	0.273[xx]	0.239	0.620
Lack of fit	0.121	0.131	0.248
Error	0.041	0.367	0.889
C.V., %	5.1	14.3	20.5
Equation sufficiency[+], %	76.7	84.5	83.7

---

[x] Statistically significant at the 5% level.

[xx] Statistically significant at the 1% level.

[+] Percentage of total treatment sum of squares accounted for by the quadratic regression equation.

Table 24. Total N, P, S, Na, K and Mg concentrations in the leaf blades (dry basis) of the second sampling, as affected by various combinations of levels of N, P, S, Na, K and Mg.

Treatment levels N	P	S	Na	K	Mg	Total P, ppm.	Total S, %	Total Na, %	Total K, %	Total Mg, %
2	2	2	2	2	2	1897	0.65	1.92	5.52	1.29
4	2	2	2	4	2	2101	0.64	2.41	4.75	0.92
2	4	2	2	4	2	1938	0.81	2.26	5.74	1.54
4	4	2	2	2	2	2027	0.80	2.12	5.07	0.92
2	2	4	2	2	4	1716	0.80	2.60	4.85	0.90
4	2	4	2	4	4	2183	0.74	2.12	4.75	1.30
2	4	4	2	4	4	1770	1.05	2.46	4.92	1.82
4	4	4	2	2	4	2168	0.61	1.80	4.15	1.00
2	2	2	4	2	4	1959	0.79	2.22	4.50	1.62
4	2	2	4	4	4	2167	0.81	2.22	4.40	1.52
2	4	2	4	4	4	1746	0.75	2.57	4.83	1.56
4	4	2	4	2	4	2451	0.84	2.34	4.04	1.00
2	2	4	4	2	2	1761	0.73	2.24	5.53	1.40
4	2	4	4	4	2	1999	0.82	2.44	5.00	1.30
2	4	4	4	4	2	2122	0.72	2.24	4.55	1.38
4	4	4	4	2	2	1609	1.39	3.50	4.25	1.93
2	2	2	2	4	4	1789	0.99	2.34	5.90	1.54
4	2	2	2	2	4	2074	0.85	2.34	4.25	1.32
2	4	2	2	2	4	1987	0.72	2.62	7.39	1.61
4	4	2	2	4	4	2290	0.82	2.26	4.75	1.36
2	2	4	2	4	2	1759	1.04	2.44	6.35	1.75
4	2	4	2	2	2	1940	0.70	2.20	5.10	1.40
2	4	4	2	2	2	1729	0.94	2.54	5.75	1.80
4	4	4	2	4	2	2554	0.78	1.81	4.97	1.19
2	2	2	4	4	2	1654	1.14	2.44	5.00	1.40
4	2	2	4	2	2	1864	0.82	1.78	5.16	1.26
2	4	2	4	2	2	2364	0.71	2.44	4.12	1.12
4	4	2	4	4	2	2457	0.79	2.26	4.45	1.26
2	2	4	4	4	4	1561	0.86	2.92	5.01	1.61
4	2	4	4	2	4	1052	0.77	2.70	4.11	1.74
2	4	4	4	2	4	1492	1.12	3.08	5.71	2.16
4	4	4	4	4	4	2009	0.92	2.24	4.40	1.66

Cont. p. 103.

Table 24 continued.

Treatment levels						Total P,	Total S,	Total Na,	Total K,	Total Mg,
N	P	S	Na	K	Mg	ppm.	%	%	%	%
5	3	3	3	3	3	2275	0.65	2.48	3.95	1.90
1	3	3	3	3	3	2348	0.64	2.44	3.75	1.18
3	5	3	3	3	3	2188	0.82	2.84	3.95	1.44
3	1	3	3	3	3	1488	0.17	2.04	3.25	1.30
3	3	5	3	3	3	2174	0.61	1.80	4.45	1.30
3	3	1	3	3	3	2371	0.70	2.10	5.43	1.10
3	3	3	5	3	3	2200	1.06	3.40	5.25	1.80
3	3	3	1	3	3	2414	0.79	1.93	4.78	1.26
3	3	3	3	5	3	2046	0.66	1.85	4.84	1.41
3	3	3	3	1	3	1947	0.79	2.10	4.45	1.76
3	3	3	3	3	5	2048	0.61	2.70	3.70	2.29
3	3	3	3	3	1	2088	0.83	2.74	4.33	1.39
3	3	3	3	3	3	1850	0.85	2.48	4.35	1.64
3	3	3	3	3	3	1901	0.87	3.01	4.30	1.25
3	3	3	3	3	3	2700	0.66	2.16	4.80	0.70
3	3	3	3	3	3	2102	0.85	1.95	5.15	1.30
3	3	3	3	3	3	1950	0.86	2.98	5.65	1.30
3	3	3	3	3	3	2075	0.76	2.60	5.75	1.40
3	3	3	3	3	3	2001	0.81	2.94	6.85	1.90
3	3	3	3	3	3	1825	0.76	2.60	5.35	1.30
3	3	3	3	3	3	1851	0.97	3.05	6.10	1.44
3	3	3	3	3	3	1850	0.82	2.60	6.45	1.10

Table 25. Analysis of variance for total P, S, Na, K, and Mg (second sampling) concentrations of leaf blades (dry basis) as affected by various combinations of levels of N, P, S, Na, K and Mg.

Source	P, ppm.	S, %	Na, %	K, %	Mg, %
d.f.					
Total	53	53	53	53	53
Block	2	2	2	2	2
Linear	6	6	6	6	6
Quadratic	21	21	21	21	21
Lack of fit	17	17	17	17	17
Error	7	7	7	7	7
S.S.					
Total	4,653,000	1.570	8.299	35.050	5.365
Block	243,750	0.198	0.156	4.599	0.406
Linear	1,451,580	0.206	1.709	5.371	1.066
Quadratic	1,673,710	0.603	3.495	12.267	1.545
Lack of fit	794,462	0.563	2.069	10.977	1.588
Error	489,498	0.048	0.870	1.836	0.759
M.S.					
Block	121,875	0.077[x]	0.078	2.299[x]	0.203
Linear	241,930	0.034[x]	0.285	0.895	0.178
Quadratic	79,700	0.029[x]	0.166	0.584	0.074
Lack of fit	46,733	0.033[x]	0.122	0.646	0.093
Error	69,928	0.006	0.124	0.262	0.108
C.V., %	13.1	20.8	13.4	9.4	23.8
Equation sufficiency[+], %	79.7	58.9	71.5	61.6	62.2

[x] Statistically significant at the 5% level

[+] Percentage of total treatment sum of squares accounted for by the quadratic regression equation.