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

by

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SUGAR BEET NUTRITION

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ABSTRACT

An irrigated field experiment, studying the direct effects and interrelationships of N, P, S, Cl, Na and Zn on the yield and chemical composition of sugar beets, was conducted on a calcareous soil in the Beqa'a Plain of Lebanon in 1964. The yield of beets was relatively high with an average of 107.3 metric tons per hectare indicating a high potentiality of the area for sugar beet production. Applications of N and Na significantly increased the yield of sucrose. The positive effect of Na was decreased by high amounts of S and Cl as indicated by the significantly negative S-Na and Cl-Na interactions. This suggested that $NaNO_3$ was a better source of Na than chloride or sulfate salts. Application of Na counteracted the significantly negative effect of N on sucrose percentage because of the important N-Na positive interaction. Application of N significantly increased the yields of roots and tops, total N in roots and nitrate-N content in petioles. In general, petiole analysis was a better indicator of the fertility level of the soil than leaf blade analysis.

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INTRODUCTION

In Lebanon, the production of sugar beets has been enhanced from 3,000 tons grown on 130 hectares of land in 1958 to 32,000 tons produced on 860 hectares in 1963. The average yield obtained by the local farmers in 1963 was about 3.5 metric tons per hectare whereas under experimental conditions, research workers in Lebanon have obtained more than three times as much. Therefore, much improvement is necessary in fertilizing, irrigation and cultural practices.

A high yielding sugar beet crop is a heavy feeder on all the nutrients, particularly on N, P, Na, S, Mg and various micronutrients. American University of Beirut researchers have found considerable response to nitrogen and phosphorus and sometimes to sodium. Negative interactions of sulfur with nitrogen, phosphorus and sodium have resulted in decreases in yield from sulfur. Chlorine and zinc have been found to be important in sugar beet nutrition and further information is needed.

A central composite, rotatable, incomplete factorial design was used in an irrigated field experiment to study six variables simultaneously with each at five levels. The experiment was conducted at the Agricultural Research and Education Center (AREC) of the American University of Beirut which is located in the Beqa'a Plain of Lebanon.

The purpose of the experiment reported here was to study the direct effects and interrelationships of N, P, S, Cl, Na and Zn on the yields of beets, beet tops and sucrose. Also the chemical composition of sugar beets was studied in order to obtain information regarding the "critical levels" of nutrients in the plant tissues such as petioles and blades.

REVIEW OF LITERATURE

There is a voluminous literature available on the fertilization of sugar beets. A summary of the work that has been done with the five macronutrients, N, P, S, Cl and Na, and one micronutrient, Zn, will be presented.

Effect of nitrogen

Nitrogen is an essential element for the growth of all plant life including sugar beets. During the last two decades, there has been a considerable increase in the rate of application of N fertilizers. Extensive work done by many workers including Adams (4), Ulrich (81), Tolman (77), Haddock (31), Magnitski (54), Boawn (12), Hedlin (36) and Ogden (57) has shown that the effect of N application greatly increased the root and top growth. Baird (8) in studying top-root ratio found that N favored the top growth more than the root growth. The American University workers in the Beqa'a Plain of Lebanon (26, 30, 35 and 55) have also obtained higher yields of roots and tops by N application.

It has been generally observed that the higher rates of nitrogen application increased the tonnage of the roots but associated with this was a decline in the quality of the beets. Many workers (1, 12, 21, 32, 36, 52, 53, 57, 60, 61, 64 and 78) have reported that there was a negative correlation between the sucrose percentage in the beets and nitrogen application. Baver (9) indicated that there was a decrease in sucrose percentage with an increase in nitrogen application and also an increasing concentration of unassimilated nitrogenous compounds in the beet juice. This nitrogen was given the name of "harmful nitrogen" and consisted primarility of amino acids and other related compounds. Dubourg et al. (22) showed that higher amounts of nitrogen fertilizers increased considerably the content of glutamic and other acids resulting in a decrease in the sugar yield per hectare. Tolman and Johnson (77) found a marked and continued decrease in the sucrose percentage as the nitrogen rates were increased in all areas of Utah, Idaho, South Dakota and Washington. They recommended that for most short season areas, 80 - 100 pounds of N per acre would supply the needs of the sugar beet crop. In long season areas and on new lands, the requirement would be higher and might run as high as 200 pounds of N per acre. Adams (4) said that increasing N would lower the juice purity and sugar content. He maintained that the best guide for N requirement could be the previous cropping. The beets which followed two or more years of cereals needed more N than the average. Stout (73) indicated that reduction in the sugar percentage caused by high applications of N was due to the fact that high N stimulated the growth of new leaves late in the season. However an abundant supply of N was needed to get them off to a good start in their early growth. Round _et al_. (66) found that high N nutrition caused impurities that reduced the quality and extraction of sucrose. Nitrogen compounds were highly correlated with nonsugars and ash although different varieties responded somewhat differently to the fertility levels. Adams (1) indicated that excessive N decreased the quality of sugar beets due to high amounts of nitrogenous compounds and as such the processing would be impaired resulting in low sugar extraction in the factory. Goodban _et al_. (29)found that the purity of extracted juice had an inverse relation to the N content of the beets ($r = .97$). In order that the quality be not impaired, the N content of the beets should be less than 0.2% (fresh basis).

Ulrich (81) worked for many years with sugar beets and said that chemical analysis of plant samples could be taken as a criterion for the fertilization program. He found that the critical level of N was 1000 ppm of nitrate N in the petioles of recently matured leaves (dry basis). Yield of roots was not increased further after this critical point had been reached. In order to maintain this level throughout the season, the grower should have a "safe value" of 5000 ppm or higher early in the season. He further pointed out that the critical level was little affected by climate, soil type, management or variety. Krantz _et al_. (46) reported that the nitrate-N concentration should be higher than Ulrich's critical level (1000 ppm, dry basis) in order to obtain the optimum yields. He noted that the nitrate-N of the petioles was closely related to N application and the degree of response. Haddock (31) indicated that there was a close relationship between N fertilization and nitrate-N of the petioles. When nitrate-N of the petioles fell below the critival level (1000 ppm, dry basis), there was a tendency for adverse effect on the yield. However, he (33) found later that there was a significant response to N fertilization when nitrate-N concentration in the petioles was 1500 ppm but when it was 3000 ppm , there was no response. Magnitski (54) pointed out that the critical level of nitrate-N content in the petioles under Moscow conditions was higher than 500 ppm (fresh basis) at the beginning of the season but in the later stages, it was 10 ppm (fresh matter basis). The workers at the American University (30, 35, 55) found that there was a high nitrate-N concentration in the petioles in the early season when all N was applied at planting time but as the season progressed, it was decreased which was in agreement with the findings of Ulrich (80).

Hoff (37) in California in 1958 and 1959 observed that low sugar content and purity were always associated with high nitrate-N concentration in the petioles.

The interaction of N with other elements has been investigated. Dimitrov _et al_. (21) conducted a long term experiment in Sofia (Bulgaria) in which N was applied to sugar beets for eight years at the rate of 60 kilograms per hectare and found that N did not produce economic yield increases unless a basal dressing of P or P and K was also given. Applications of P and K improved quality by decreasing the contents of harmful nitrogenous impurities, especially when high rates of N were applied. Studying the economic importance of the fertilizers, they found that $NaNO_3$ was the most economical N fertilizer followed by NH_4NO_3 and $(NH_4)_2\ SO_4$ was the least. Goodban _et al_. (29) studied the effect of different soils on the growth and composition of sugar beets and observed that in most soils, N applications limited the availability of P and decreased P concentration in the petioles. Alexander _et al_. (7) reporting the results of experiments conducted in Colorado concluded that N and P decreased with the age of leaf while Ca, Mg and Na showed an increase with age. Potassium increased very slightly with age and its contents in the leaf were reduced by the addition of N. Concentrations of P and N in leaf blades increased whereas K, Ca and Na concentrations decreased with increase in N fertilization.

From the above literature, it can be concluded that sugar beets respond to N but the degree of response depends greatly on the soil type, environmental conditions and the crops of previous years. If N is applied in excessive quantities, beet quality, sucrose percentage, juice extraction and yield of sugar are lower. Thus, excess amounts of N become uneconomical in sugar beet production.

Effect of phosphorus

Phosphorus is one of the essential elements necessary for plant growth and development. It is associated with several vital functions in plants and is responsible for several characteristics of plant growth such as utilization of sugar, starch, photosynthesis, etc. (71).

The response of sugar beets to P fertilization (38, 48) varies from field to field and from place to place. Plant species differ materially in their capacities to absorb P from the soil. Fried (25) pointed out that the total amount of P absorbed by crops was greater than 50 pounds P_2O_5 per acre per year. Phosphorus absorption by plants reached a maximum earlier in the growth cycle than did dry matter production. The change in P percentage of plants was influenced by the soil P supply, applied phosphate and relative yield. Tolman (76) pointed out that soils containing less than 5 ppm P_2O_5 (CO_2 soluble) responded to P fertilization but no response was obtained from those soils which contained 50 ppm. Haddock (32) in Utah found that one year residual P fertilizer was as effective in increasing the yield of roots and P content of petioles as applied P and he tentatively supported the use of 25 ppm, of $NaHCO_3$ soluble P as a minimum level of available P for the proper growth of sugar beets on calcareous soils. Carlson _et al_. (18) observed no response of sugar beets to P on three locations where $NaHCO_3$ soluble P_2O_5 was 83 to 89 ppm. Response was observed on one area where the available P_2O_5 was 8.3 ppm. Davis _et al_. (20) pointed out that the plowing down of 200 to 800 pounds P_2O_5 per acre in a calcareous loam (pH 7.5) before planting sugar beets markedly increased the yields and P content of the beets. Yield of gross sugar increased with increasing P but P had no significant effect on sucrose percentage or apparent purity of juice. Russell (67) in England found that root growth was favorably increased with P fertilization but there was no significant effect on sucrose percentage. Dimitrov (21) noted that P fertilization improved the quality of sugar beets by decreasing adverse effects of harmful N. Olsen _et al_. (59) found that in a calcareous soil, calcium metaphosphate was less available than superphosphate in early stages of growth but had about the same availability thereafter. Allos and Macksoud (6) in Lebanon observed that N and P gave highly significant yield increases but no significant variation was found in the sugar percentage. Husseini (39), Hashimi (35), Haddad (30) and Mazaheri (55), under the Beqa'a conditions, reported an increase in beet tonnage due to P fertilization.

Black (11) indicated that P increased the growth of roots more than that of tops. Adams (4) found a similar effect of P fertilization on the yield of tops and roots. Baird (8) concluded that P application slightly decreased the proportion of tops to roots.

Adams (3) found that on the average, spring fertilization gave a higher yield of sugar than fall and plants grew faster in the early season.

It has been proved that uptake and accumulation of P was dependent on the physiological activity of sugar beet plants, their organs and tissues at various stages of growth. Uptake of P was considerably greater in the beginning of plant development, decreasing gradually in later stages (69).

Ulrich (80) indicated that phosphate value of the petioles was lower than for the corresponding blades. He recommended 750 ppm of phosphate-P in the petioles (dry basis) as the "critical level". Saric et al. (69) found that younger leaves contained more P than older ones and leaf blades had higher P concentration than petioles. Davis et al. (20) in Colorado found that high yields of sugar beets required an extractable P content of not less than 0.15 percent in the petioles throughout the growing season. Haddad (30) in Lebanon showed that for relatively high yields, available P in the petioles was 3000 ppm, early in the season and declined to 1650 ppm in the mid season after which little change was observed. Magnitski (54) showed a P critical level around 40 ppm in the petioles (fresh basis) but as the season advanced, this value dropped to 25 ppm after which no significant change was observed.

Many interactions have been observed between P and other elements. George (27) found that N application decreased P content in the plant tissues. Alexander et al. (5) showed that P content of the leaves was significantly decreased by the addition of N but the decrease was gradual. Mazaheri (55) in Lebanon found that K and Mg were depressing to the phosphate concentration in petioles and blades. Russel et al. (68) showed that addition of P fertilizer resulted in higher P and lower K content of beet roots.

From the foregoing literature, it appears that beets respond to P fertilization and the extent of response depends on the soil P supply, applied phosphate, residual P in soil and time of application.

Effect of sulfur

Although S is an essential element for plant growth, knowledge concerning the soil-plant relationships for this element is meager in comparision with other elements (44). The importance of S as a plant nutrient in relation to sugar beets production has not been studied very extensively due to the fact that there is no profound evidence regarding S deficiency in sugar beets. The reason for so few cases of S deficiency in sugar beets may be the indirect supplying of this element from applications of ammonium sulfate, superphosphate, mixed fertilizers, irrigation waters and atmospheric compounds rich in S. Jensen (41) in Denmark while supplying S^{35} as a source of S to different plant species in field experiments found that the plants obtained 22 to 36 percent of their S by direct absorption from the atmosphere. Olsen (58) indicated that over 50 percent of the S in S deficient plants was apparently absorbed directly from atmosphere.

Ulrich (82) said that S deficiencies in sugar beet plants in California appeared in localized areas and could be corrected readily by supplying gypsum to the soil. Gilbert (28) noted that there was a positive response of S fertilization in localized areas of several states in the Pacific North-West of the United States.

Reisenaur and Dickson (63) found a positive interaction between S and N. When either of them was applied singly, the yield of barley was little affected but in combination, the yield was increased. Kalinevich (43) obtained a striking positive interaction between N and S and attributed this to the interchange of sulfate and nitrate processes as a result of similarity in the reduction process of sulfate and nitrate.

Workers in Lebanon (26, 30, 35) found negative interactions of S with N, P and Na thereby indicating that the response of sugar beets to N, P and Na was decreased as the level of S was increased. Freney _et al._ (24) indicated that there was indirect evidence suggesting that a considerable fraction of the soil S was sulfate covalently bonded to the compounds present in the organic matter. Kretschmer _et al._ (47) pointed out that the variation in the S-content of subsoil had little effect on plant content of sulfate or on the absorption of other ions by sugar beets.

Ulrich (81) recommended leaf blades for determination of S rather than petioles because of the wider range in the values of sulfate-S concentrations both in deficient and healthy plants. He estimated the "critical level" for sulfate-S content of the leaf blades to be 250 ppm (dry basis).

Effect of chlorine

Although interest in Cl as an essential element for the growth and development of many crops including sugar beets dated back to 1856 (10), its essentiality had not been proved until Broyer *et al.* (15) obtained conclusive evidence that Cl was an essential element for plants. This discovery threw light on many of the past observations that some fertilizers which gave beneficial results contained Cl. Raleigh (62) found that the addition of chlorides in general gave more consistent increase in the growth of table beets than did Na. Increased yields of beets were obtained when NaCl was added. His results also supported the conclusions drawn by Lipman (51) that Cl was beneficial to the growth of certain plants such as buck-wheat, peas, etc. Wood *et al.* (84) proved that sugar beets were among those crops which appeared to use Cl to some advantage. Broyer *et al.* (15) proved that highly significant increases in yields of sugar beets were obtained when supplied with Cl. Raleigh (62) found that table beets gave optimum growth with 2 to 5 m.e of Cl per liter. Lill et al. (50) proved that the application of common salt to the soil in Michigan for sugar beets had a beneficial effect on the yield of roots which was reflected in many cases as an increase in the calculated sugar production. Buchner et al. (16) in Germany showed by field experiments that the application of Cl increased the yield of sugar beets. Wood et al. (84) indicated that when chloride and sulfate salts of Na, K and ammonium were compared, increased top growth was more apparent from the NH_4Cl treatment. Sirochenk (72) obtained more increases in roots and tops when KCl was used as a source of K.

Hashimi (35) and Haddad (30), in Lebanon, obtained an appreciable increase in beet yields due to Cl application and a slight depressing effect of Cl on the sucrose concentration.

Wood et al. (84) found that a reduction in the percentage of sugar resulted from use of NH_4Cl. Lill et al. (50) indicated that application of common salt apparently had a detrimental effect on the purity coefficient of juice. Such applications were found to increase the total amount of ash and the Na and Cl concentrations in the ash. This would interfere in the refining of sugar resulting in a reduction in the proportion of the sugar that could be extracted.

Kretschmer _et al_. (47) found that increased Cl depressed the N content of sugar beet plants.

Ulrich _et al_. (83) showed that petiole Cl values of 4.9 to 7.9 ueq. and blade Cl values of 3.3 to 5.4 ueq. per gram of dry tissue were indicative of extreme Cl deficiency. Petiole Cl values of 200 ueq. or above and blade (without midrib) Cl values of 50 ueq. or above per gram of dry tissue were indicative of Cl adequacy.

Ulrich _et al_. (81) reported that Cl concentrations in the petioles increased with the age of leaf and ranged from 0.01 to 8.5 percent (dry basis) and estimated the "critical level" of Cl in the petioles to be 0.4 percent (dry basis).

In general Cl tends to increase the yield of roots, tops and sugar, but higher applications of Cl may be detrimental to the sugar percentage and purity coefficient of the juice.

Effect of sodium

The exact role of Na in plant nutrition has been a subject of controversy but its beneficial effect on certain crops has been established. Whether it assisted in the functions of K in metabolic processes of plants or had, in certain plants, functions that it alone best fulfilled is a question yet to be answered (34).

Different crops had different abilities to absorb Na. Lehr (49) showed that applications of Na to sugar beets produced an effect, especially on weakly buffered soils, that might even exceed the reaction to N and K. Consequently Na was regarded as essential for the nutrition of beets. Kaudy _et al_. (45) concluded from field experiments conducted in Wisconsin that yield and quality of sugar beets became markedly more satisfactory when considerable amounts of Na were present in the soil. Sugar beets absorbed large amounts of Na from soil, at times nearly equalling that of K. Sodium was considered essential for maximum growth of sugar beets especially when K in the soil was limited. Truog _et al_. (79) pointed out that Na increased the yield of beets and would partially substitute for K when the latter's supply was limited. Adams (2) reported that when no K was applied, NaCl increased the yield of sugar beets but Na did not replace K in the soil. Black (11) compared the response of $NaNO_3$ and $Ca(NO_3)_2$ as a source of N at three levels of K application and concluded that at all the levels of K, $NaNO_3$ gave higher increases in yield of fodder beets indicating that besides N, Na was also responsible for higher yields. Magnitski (54) showed that the application of $NaNO_3$ to sugar beets decreased K content in the petioles but materially increased Na content and the yield of roots. Thus, Na had a specific effect on the beets that could not be replaced by high K.

Lehr (49) put forward the concept of "cationic equilibrium" and concluded that the Na + K + Ca + Mg of roots played a complicated and vital role in plant nutrition. He found that the relative amount of each element was a good indication for the yield. When the yield of sugar beets was plotted against their composition of K, Na and Ca in m.e/100 g it was found that the higher yields were obtained by the monovalent cations, K and Na and relatively high contents of Ca or divalent cations corresponded to low yields. The results of American University workers (26, 30, 35) proved that high yields could be obtained on calcareous soils containing nearly 15 percent $CaCO_3$. Davis _et al_. (20) pointed out that Na might increase the availability of P in soil and so P contents of sugar beets were increased. Finkner (23) indicated that N increased the Na content of beets. Sayer _et al_. (70) maintained that Na in the form of nitrate of soda and NaCl when supplemented with N apparently supplied a definite nutrient need of sugar beets. Applying N without Na did not significantly increase the yield. The workers in Lebanon (26, 30, 35) found positive Na-N and Na-P interactions indicating that along with N and P, Na was also essential for higher yields of sugar beets. Finkner (23) obtained a negative relationship between Na and sucrose content of the roots.

The "critical level" for Na has not been estimated definitely owing to the reason that when Na was present in higher amounts in leaves, symptoms of K deficiency occurred and it became difficult to estimate the required amount of Na in leaves. When K was applied, it only compensated for K deficiency in plants but did not replace the specific influence of Na (54). Magnitski (54) recommended that 0.16 to 0.20 percent (wet basis) of Na + K in the petioles should be considered as the "critical value" for sugar beets.

It has been shown that besides the beneficial effects of applied Na on the yield of sugar beets, contents of other cations such as K, Mg and Ca are decreased. More investigation should be done in order to formulate the relationship between Na and other cations and also to establish the role played by Na in the nutrition of sugar beets.

Effect of zinc

Zinc is one of the elements essential for plant growth. However, the amounts required for normal growth are small and usually plant tissues contain less than 100 ppm (dry basis). The importance of Zn as a plant nutrient has been recognized for approximately 40 years. As quoted by Rosell and Ulrich (65), the effects of Zn on sugar beets were observed in field experiments on soils low in Zn. Its deficiency was noted in commercial crops in localized areas of a few fields in the Delta area of the San Joaquin Valley of California.

Boawn et al. (14) established the fact at Washington that sugar beets apparently caused chemical changes in soil Zn that made it unavailable to the following crops. Exactly how sugar beets changed Zn to make it unavailable is not yet understood. It has been observed that corn following sugar beets sometimes suffered from Zn deficiency.

Tisdale and Nelson (75) showed that plants differed markedly in their abilities to extract Zn from the soil. This could be associated in part with the extensiveness of the root system of the crops.

Thorne (74), in his review, discussed soil pH and P level as factors affecting Zn availability. Several workers have indicated that Zn deficiency was observed most commonly in the pH range of 6.0 to 8.0. It was assumed that at this pH range, an insoluble zinc hydroxide was formed to act as a base or weak acid depending on the pH of the liquid environment. In general, it has been observed that Zn fertilization decreased P, K, Ca and Mg contents of plants. Burleson et al. (17) concluded that P fertilization, under some soil and climatic conditions, induced Zn deficiency in certain crops. It was more pronounced with cold and wet soils during the early part of the growing season when root development was restricted chiefly to the zone of fertilizer placement.

Boawn et al. (12) showed that the total Zn contained in a sugar beet crop yielding 30 tons per acre varied from 0.183 pounds to 0.268 pounds per acre depending on the level of Zn fertilization. When Zn was applied two years previously (16 pounds of Zn per acre) to the soil, there was an increase in Zn content of leaf blades from 20 ppm to slightly over 30 ppm, of total tops from 12 ppm to 22 ppm and of roots from 8 ppm to 12 ppm but these increases in Zn level of the plant did not produce a measurable increase in beet yield.

Nowicki (56) studied the influence of trace elements on the yield, health and sugar content of sugar beets under field conditions and found that the dressing of Zn compounds for two seasons improved sugar quantity in one season and yield in both seasons.

Boawn et al. (13) showed that the growth of sugar beets in Yolo County, California was increased by Zn application. Rosell and Ulrich (65) indicated that Zn concentration in the petioles of sugar beets varied in a unique manner and these concentrations did not provide a well correlated yield concentration curve. They further said that visual symptoms were unique and could be used as a preliminary guide in assessing Zn status of sugar beet plants. Boawn *et al.* (14) published data from a number of experiments showing the levels of Zn in the leaf blades of sugar beets and concluded that 10 ppm Zn in the young, fully developed leaves at mid-season was adequate for average yields.

Rosell and Ulrich (65) said that Zn deficient sugar beet plants had lower root and top weights and in extreme deficiency, a lower sucrose concentration. They maintained that marked accumulation of nitrate in the sugar beet plants also took place, particularily in the blades of the plants. They said that phosphate-P and total P values in the blade tissues of sugar beet plants increased even more sharply at the onset of Zn deficiency than the corresponding nitrate-N values. The sulfate-S concentration increased in Zn deficient plants. The increases in the sulfate paralleled those of nitrate and phosphate. The maximum sulfate-S concentration however, was only about two times that of comparable normal blade tissues in contrast to that of 3 to 5 times for nitrate and 4 to 6 times for phosphate. Thus, Zn deficiency interrupted sulfate metabolism to a lesser extent than that of nitrate or phosphate.

MATERIALS AND METHODS

Experimental design and statistical analysis

The field experimental design was a central composite, rotatable, incomplete factorial (Plan 8A.7, Cochran and Cox, reference 19). Five macronutrients, N, P, S, Cl and Na and one micronutrient, Zn, were included in this design as variables. Each variable was applied at five levels. There were 45 treatments one of which (at the third level of application for all variables) was replicated ten times and distributed at random in order to estimate the experimental error. The field plot contained only one complete replication but the factorial design constituted internal replication. The treatments were distributed at random in three blocks thus making a total of 54 plots (Appendix Table 13). This design makes it possible to study the main effects and the interactions of six elements on the yield, growth and composition of sugar beets with a relatively small number of treatments. Characterization of the response surfaces is permitted by calculation of regression equations in the quadratic form. The form of the quadratic regression equation for six variables is as follows:

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

Where 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 Cl;

x_5= coded level of Na;

x_6= coded level of Zn.

The significance of the magnitude of each individual regression coefficient was found by determining the probability of a true effect using the "t" test. The regression equations were used to determine the nature of the response surface for the interactions that were found to be statistically significant.

Analysis of variance of the collected data was performed and the "F" test was used to find the significance of the first order, quadratic and lack of fit terms. The percentage of equation sufficiency was calculated in order to show how well the quadratic regression equation fitted the actual data collected.

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 of variables were coded according to the form - 2.366, -1, 0, +1 and +2.366 in order to simplify the calculation of the regression equations. The coded 0 rate was an intermediate level. The coded level, -2.366, was assumed to be a possible deficiency rate and +2.366, a possible excess level of the element added.

Table 1. Rate of applications of the macronutrients (N, P, S, Cl, Na) and a micronutrient (Zn).

Level of application	Coded levels	Rate of application, Kg/ha.	
		Macro elements	Micro element
1	-2.366	29	7.25
2	-1	75	18.75
3	0	150	37.50
4	+1	300	75.00
5	+2.366	776	195.00

The carriers used were commercial grades of $NaNO_3$ and NH_4NO_3 for N, concentrated superphosphate for P, concentrated superphosphate, $ZnSO_4$ and $CaSO_4.2H_2O$ for S, NaCl, $CaCl_2$ and $ZnCl_2$ for Cl, NaCl, $NaNO_3$ and $NaHCO_3$ for Na, and $ZnSO_4$ and $ZnCl_2$ for Zn. The amounts of carriers were combined in order to supply the required amount of each element. It was possible to control the levels of all the elements except Ca and since the experimental area was calcareous, it was assumed that the effect of any additional Ca present in the carriers would be negligible.

Field procedure

The experimental area was located at the Agricultural Research and Education Center (AREC) of the American University of Beirut in the Beqa'a Plain of Lebanon. The 54 field plots were each composed of four rows, 50 centimeters apart and 5 meters long. The assignment of the treatments to the different plots was made at random.

The fertilizers for each row of each treatment were weighed into a paper bag, poured into a bucket and thoroughly mixed after which they were applied uniformly at the bottom of furrows. The ridges were then split in order to cover the fertilizers.

Seeds of sugar beets (Beta vulgaris, Kleinwanzleben

E variety) were planted with a Planet Jr. seeder on the ridges above the fertilizers at a depth of about 3 centimeters on March 31, 1964.

Sprinklers were used for irrigation for about the first month after which the furrow method was used.

The beets were thinned between May 7 and May 21 leaving an average of 6 plants per meter.

Leaf hoppers, aphids and powdery mildew were controlled throughout the growing season by spraying with appropriate chemicals.

Petiole samples of ten recently matured leaves, picked at random from the middle two rows of each plot, were taken on June 17, August 5 and September 16. In the August 5 sampling, the leaf blades were separated from the petioles and retained as an additional set of samples. The samples were dried at $70^{0}C$, ground in a Wiley mill and chemically analyzed for the contents of the elements under study.

On November 6, the beets from four meters of the middle two rows of each plot were harvested. Fresh weights of the tops and roots and the number of beets were recorded. Samples of tops and roots were taken for determining the moisture, N and sucrose percentages.

Analysis of petioles

The determination of nitrate-N was done on a water extract by using the phenol-disulfonic acid method in the presence of excess Cl as described by Johnson and Ulrich (42).

Two percent acetic acid soluble phosphate was determined with the chlorostannous - reduced molybdophosphoric blue color method as described by Johnson and Ulrich (42).

The sulfate concentration of the two percent acetic acid extracts (42) was determined by the turbidimetric method as described by Jackson (40). The extract was digested with H_2O_2 to oxidize the organic matter.

The chloride concentration was determined in the water extract by the Mohr method as described by Johnson and Ulrich (42). Activated carbon was used to decolorize the solution.

Potassium and Na were determined in the water extract using a Beckman D.U. flame emission spectrophotometer as described by Jackson (40).

Analysis of the leaf blades

The dried and ground leaf blades of the second set of sampling were predigested with nitric acid for a period of 12 hours after which they were digested with perchloric acid at a temperature of 180 to 200°C according to the procedure given by Jackson (40). The digested samples were washed and filtered with hot water. The determinations of P, S, Na and K in the nitric - perchloric digest were made according to the same methods as described in the petiole analysis. The determination of Mg in the same digest was made by the flame photometer using the procedure described by Jackson (40).

Analysis of the tops and roots

Total N in both root and top samples was determined by the modified Kjeldahl method as described by Jackson (40).

The sucrose concentration in the roots was determined by the A.O.A.C. method (7).

RESULTS AND DISCUSSION

An irrigated field experiment was conducted on a calcareous soil in the Beqa'a Plain of Lebanon to study the interrelationships and direct effects of N, P, S, Cl, Na and Zn, each at five levels, on the yields of roots, tops and sucrose, sucrose percentage in the roots and chemical composition of roots, tops, petioles and leaf blades. A central composite, rotatable, incomplete factorial design (Plan 8A.7, Cochran and Cox, reference 19) was used. The response surfaces were characterized with quadratic regression equations. The magnitude of the individual regression coefficient indicated the relative effect of the variable under study. A positive sign of the regression coefficient of the first order term for an element indicated that the general average effect of that element on the property studied was increasing while a negative sign showed a depressing effect. The magnitude of the regression coefficient for the squared quadratic term denoted the degree of curvature of the response to the variable and its sign indicated whether the response is concave upward, positive or concave downward, negative. The magnitude of the regression coefficient for the interaction quadratic term indicated the amount of the interaction involved. A positive sign for the interaction between two elements indicated that an increase in the level of one variable resulted in a more positive response (or less negative) to the other. If the sign for the regression coefficient for an interaction term was negative, the response to one variable became less positive (or more negative) as the level of other increased. The term "significant" was used to indicate the five percent level of probability while "highly significant" indicated the one percent level.

Results of soil and water analysis

The results of soil analysis (Table 2) as found by Mazaheri (55) showed that the supply of total N in the soil was low (0.13 percent) but the nitrate-N concentration in the top soil was considerable (41 ppm). The available P (Olsen method) was medium. The pH of the soil was 7.8 and the calcium carbonate content was 16.5 percent. The texture analysis revealed that the soil was a silty clay loam.

The irrigation water (Table 2, Hashimi, 35) was of good quality. Approximately 65 kg. of Na, 22 kg. of K, 100 kg. of Mg, 141 kg. of Ca, 113 kg. of Cl 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. Results of chemical analysis of the surface soil for the experimental plots and of the irrigation water.

Soil analysis (55)			Water analysis (35)		
pH ,		7.8	Na,	m.e./liter	0.282
$CaCO_3$,	%	16.5	Ca,	"	0.705
Organic matter,	%	1.9	Mg,	"	0.833
Total N ,	%	0.1344	K ,	"	0.056
Nitrate-N,	ppm	41.0	S ,	"	0.125
Available P,	ppm	15.0	Cl,	"	0.318
Ammonium acetate	Ca	30.4			
Soluble cations	Mg	12.8	Electrical conductivity in m.mho/cm. = 0.155		
m.e. per 100 g.	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 the yield of roots

The yield of roots ranged from 75.8 to 129.0 with an average of 107.3 metric tons per hectare (Appendix Table 13). The equation sufficiency was 78 percent indicating that the quadratic regression equation accounted for most of the treatment variation in the yield (Appendix Table 14).

The combination for the maximum economic yield was determined by a trial and error method. Since the regression equation becomes less accurate near the extremes, it was decided to calculate the combination of the varied elements which could give the maximum yield between the -1 and +1 coded levels. This combination was used in calculating the predicted results throughout the text. Although some combinations were nearly as good, the following combination was chosen because it was most economical with regard to fertilizer cost:

+1 N = 300.00 kg. per hectare
-1 P = 75.00 kg. per hectare
-1 S = 75.00 kg. per hectare
-1 Cl = 75.00 kg. per hectare
+1 Na = 300.00 kg. per hectare
-1 Zn = 18.75 kg. per hectare

The estimated yield was 131.7 metric tons per hectare which was slightly greater than the maximum yield recorded

(129.0 metric tons per hectare, Appendix Table 13).

The highly significant first order effect for N indicated that as the amount of N was increased, the yield of roots was increased (Table 3). The significantly negative squared term for N resulted in the downward curvature at the high rate of application (Figure 1). These results were in agreement with those obtained by Haddad (30), Hashimi (35), Husseini (39) and Mazaheri (55) under similar experimental conditions and with many other workers (4, 12, 36, 52, 54 and 60). Sulfur tended to have a negative first order effect but the positive sign for its squared term indicated that as the rate of application was increased, its negative effect was less pronounced (Figure 1). The positive sign for the first order term for Na (Table 3) indicated that Na tended to increase the yield of roots as its rate of application was increased.

Among the interaction terms, P-Zn and Cl-Zn were significantly positive indicating that increasing levels of P or Cl tended to decrease the negative response to Zn (Figure 2). None of the interactions P-S, P-Cl, S-Cl and S-Zn were statistically significant but P-Cl and S-Cl were of sufficient magnitude to indicate a tendency for yield decrease from Cl as P or S levels were increased. Negative interactions were found between N-Na, S-Na,

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

Term	Roots, M. tons/ha.		Sucrose, M. tons/ha.		Tops, M. tons/ha.		Sucrose, percent	
	b	s_b	b	s_b	b	s_b	b	s_b
Mean	107.30		21.08		5.21		19.69	
N	+4.31^{xx}	±1.18	+0.47^{x}	±0.19	+0.64^{xx}	±0.15	-0.36^{xx}	±0.094
P	+0.16	"	+0.10	"	-0.01	"	+0.10	"
S	-1.20	"	-0.28	"	-0.18	"	+0.02	"
Cl	-0.54	"	-0.13	"	-0.30	"	-0.07	"
Na	+1.80	"	+0.57^{x}	"	+0.10	"	+0.21	"
Zn	-0.07	"	+0.08	"	-0.24	"	+0.01	"
NN	-3.11^{x}	±1.01	-0.62^{xx}	±0.16	-0.13	±0.13	-0.05	±0.080
PP	-1.31	"	-0.31	"	-0.09	"	-0.05	"
SS	+1.09	"	+0.21	"	+0.15	"	-0.01	"
ClCl	-0.40	"	-0.30	"	+0.03	"	-0.21	"
NaNa	+0.64	"	+0.32	"	+0.05	"	+0.19	"
ZnZn	-0.72	"	-0.27	"	+0.06	"	-0.08	"
N-P	+0.85	±1.37	+0.02	±0.22	+0.37	±0.18	-0.16	±0.109
N-S	+0.93	"	+0.15	"	+0.08	"	-0.12	"
N-Cl	-1.13	"	-0.34	"	-0.16	"	-0.07	"
N-Na	-2.74	"	-0.17	"	-0.27	"	+0.32^{x}	"
N-Zn	-2.81	"	-0.65^{x}	"	-0.05	"	-0.02	"
P-S	+1.67	"	+0.40	"	-0.06	"	+0.05	"
P-Cl	+2.30	"	+0.33	"	+0.53^{x}	"	-0.10	"
P-Na	-0.90	"	+0.10	"	0.00	"	+0.23	"
P-Zn	+4.46^{x}	"	+0.92^{xx}	"	+0.30	"	+0.07	"
S-Cl	+2.13	"	+0.21	"	+0.33	"	-0.19	"
S-Na	-2.19	"	-0.63^{x}	"	-0.08	"	-0.16	"
S-Zn	+2.03	"	-0.17	"	+0.20	"	-0.58^{xx}	"
Cl-Na	-2.98	"	-0.66^{x}	"	-0.13	"	-0.05	"
Cl-Zn	+3.53^{x}	"	+0.83^{xx}	"	+0.08	"	+0.16	"
Na-Zn	+0.98	"	+0.11	"	+0.25	"	-0.12	"

^{x} Statistically significant at the 5 percent level.

^{xx} Statistically significant at the 1 percent leve.

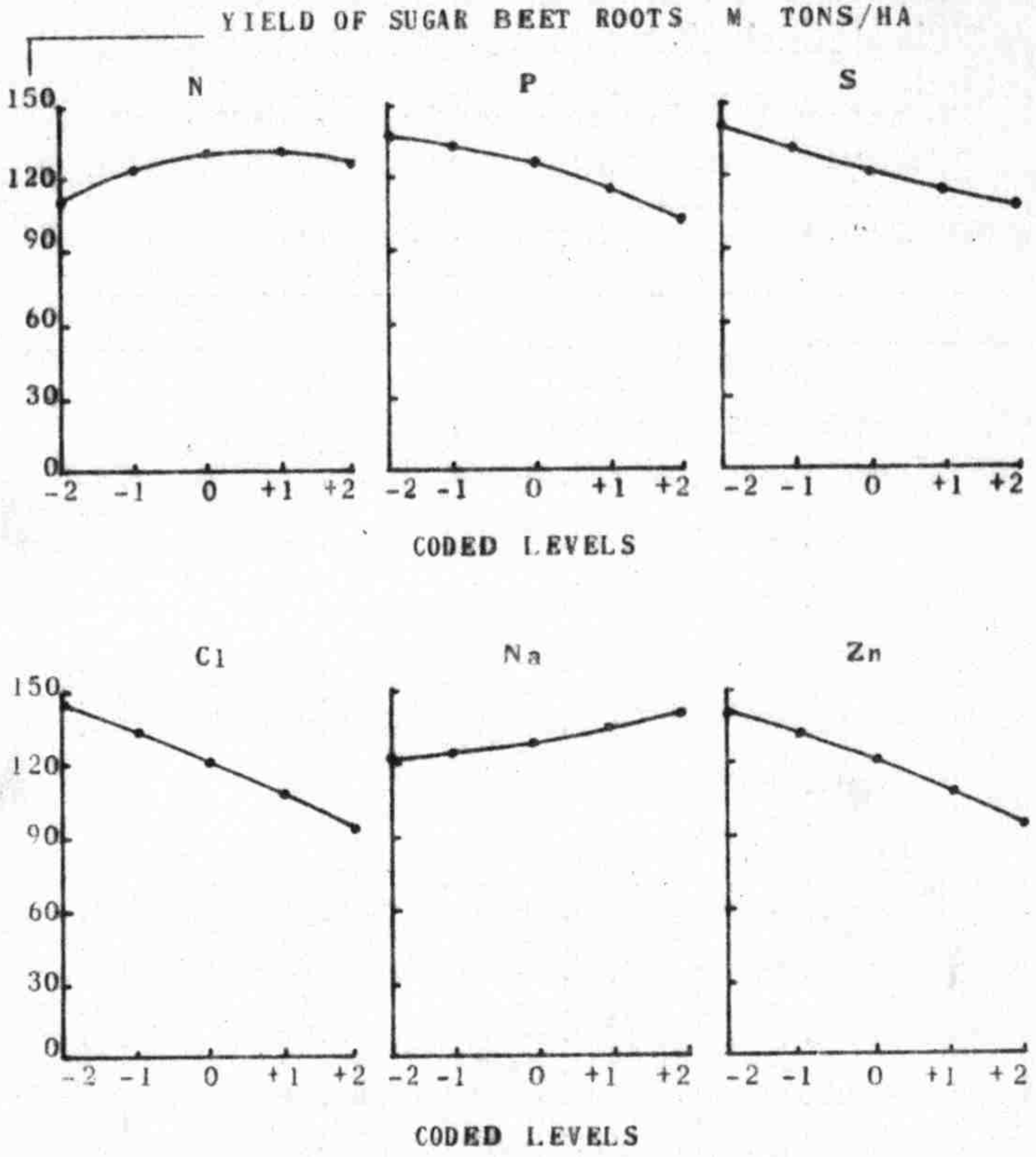

Figure 1. Effect of applied N, P, S, Cl, Na and Zn on the estimated yield of sugar beet roots. Data were calculated from the regression equations. The coded levels of N, P, S, Cl, Na and Zn (when not varied) were held constant at +1, -1, -1, -1, +1 and -1, respectively.

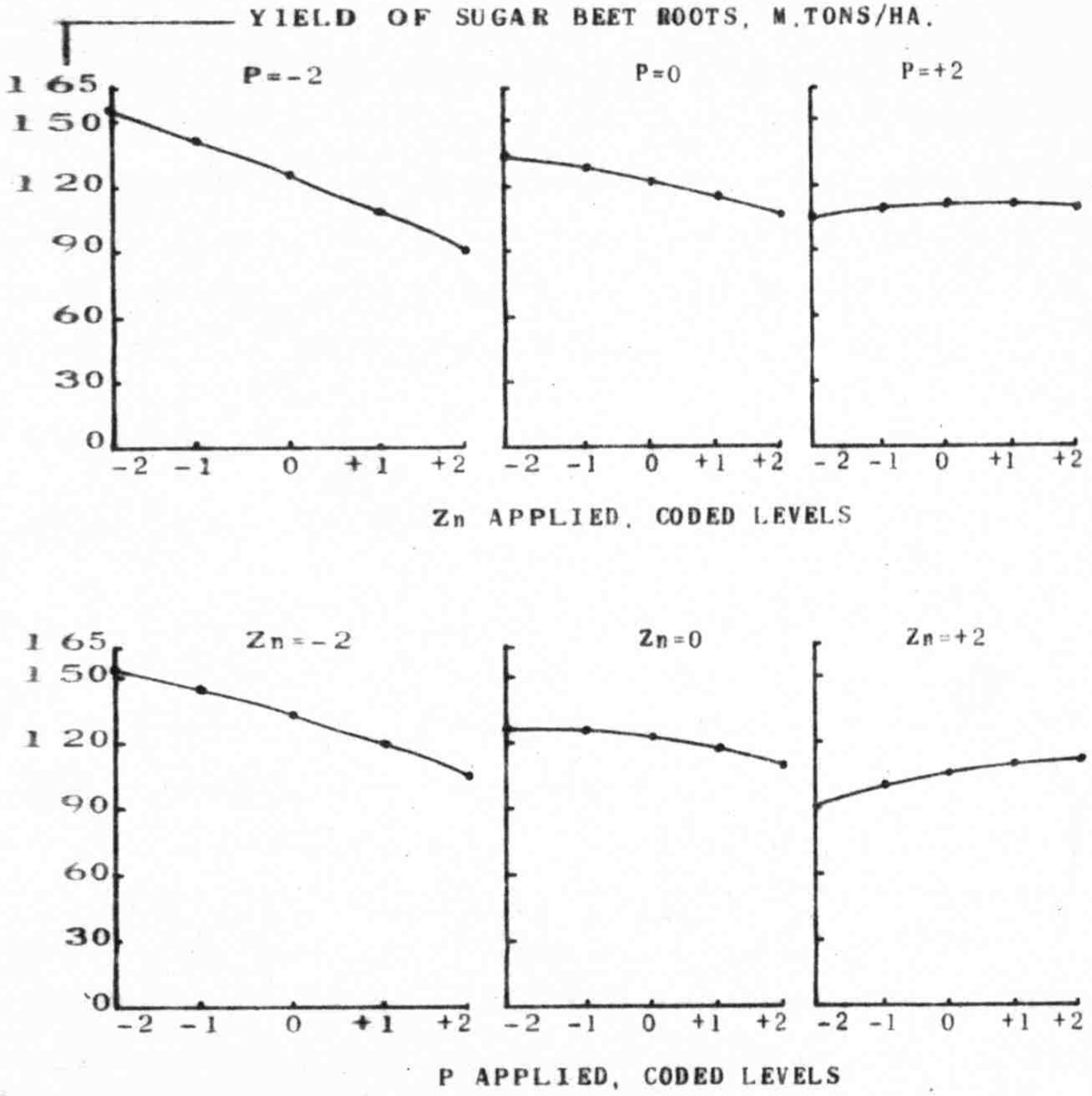

Figure 2. Estimated yield of sugar beet roots as affected by levels of applied Zn at constant levels of P (above) and by levels of applied P at constant levels of Zn (below). The coded levels of application of N, S, Cl and Na were held constant at +1, -1, -1 and +1, respectively.

Cl-Na and N-Zn which were probably real although not statistically significant. These interactions showed that the positive yield response to Na became less as the levels of N, S or Cl were increased.

Thus it is clear that application of N highly significantly increased the yield of roots. Sodium showed a tendency to increase the yield of roots and S tended to be depressing.

Effect of fertilizer treatments on sucrose concentration

The sucrose percentage of roots ranged from 17.6 to 21.3 with an average of 19.7 (Appendix Table 13). A significantly negative first order effect indicated that the application of N decreased the sucrose percentage. Similar findings were found by other American University workers (26, 30, 35, 55) under similar experimental conditions. The positive first order and squared terms of Na indicated that Na tended to increase the sucrose percentage as the rate of application was increased. A significantly positive N-Na interaction (Table 3) showed that as the amount of Na was increased, the negative effect of N on sucrose percentage was reversed and became positive at a high rate of Na application (Figure 3). Although neither S or Zn had individual effects, a highly significant negative S-Zn interaction showed a decrease

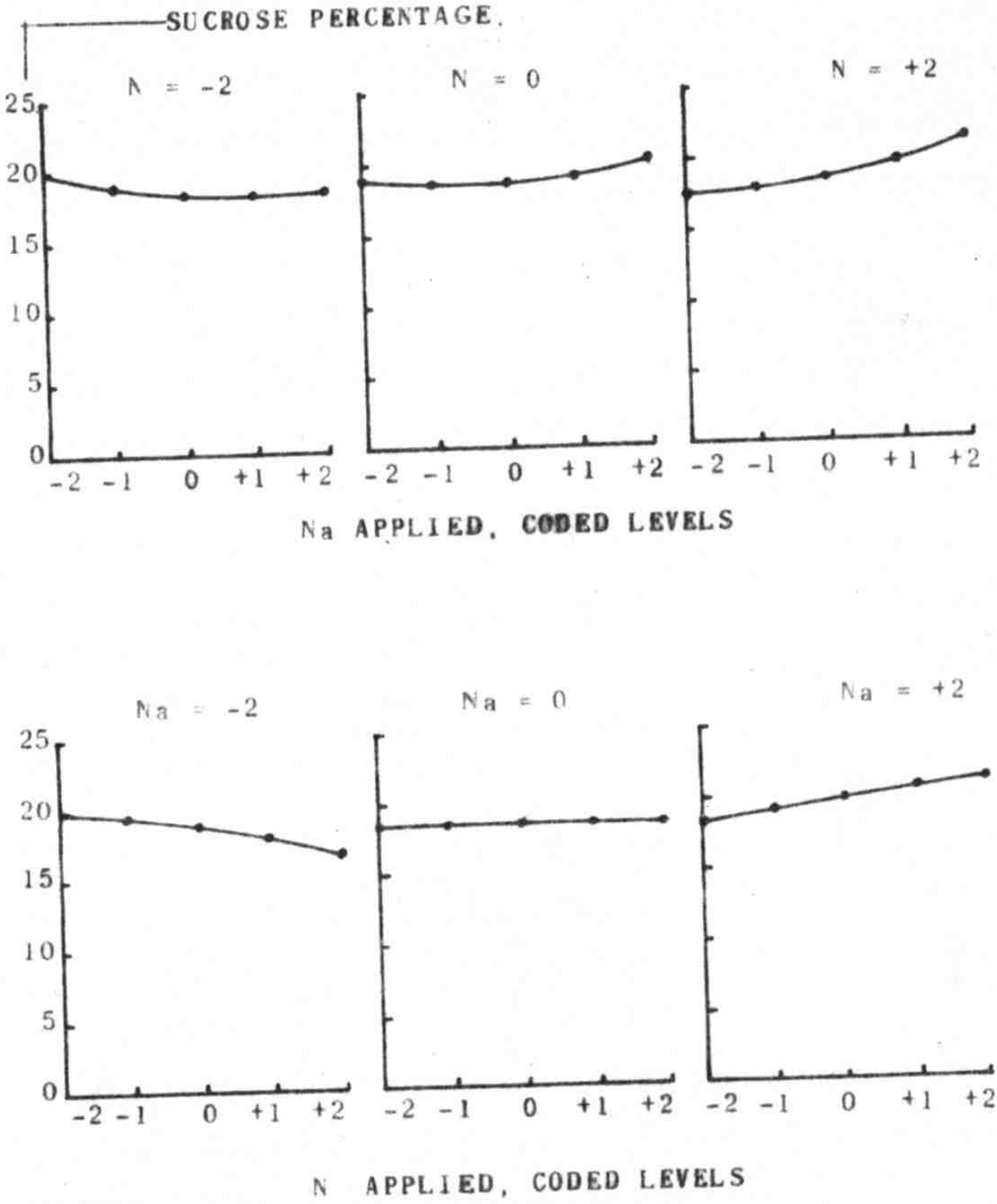

Figure 3. Estimated sucrose percentages as affected by levels of applied Na at constant levels of N (above) and by levels of applied N at constant levels of Na (below). The coded levels of P, S, Cl and Zn were held constant at -1, -1, -1 and -1, respectively.

in sucrose percentage when both were applied at high rates.

In general, application of N highly significantly decreased the sucrose percentage whereas Na had a tendency to increase it.

Effect of fertilizer treatments on the yield of sucrose

The yield of sucrose ranged from 15.6 to 25.8 with an average of 21.1 metric tons per hectare (Appendix Table 13). The significantly positive first order effect of N indicated that N application increased the yield of sucrose but its highly significant negative squared term revealed a decrease in positive response to N at the high rate of application (Table 3). Sodium had a significantly positive first order effect showing an increase in the yield of sucrose and the response tended to increase at a greater rate as the level of application was increased. Sulfur had a tendency to decrease the yield of sucrose.

Among the interaction terms, N-Zn, Cl-Na and S-Na were significantly negative (Table 3). The Cl-Na interaction (Figure 4) showed that the positive effect of Na on the yield of sucrose became less as Cl was increased. The P-Zn and Cl-Zn interactions were highly significantly positive indicating that as the amount of P or Cl was increased, the response to Zn was more positive. The positive P-S interaction showed that increased levels of P

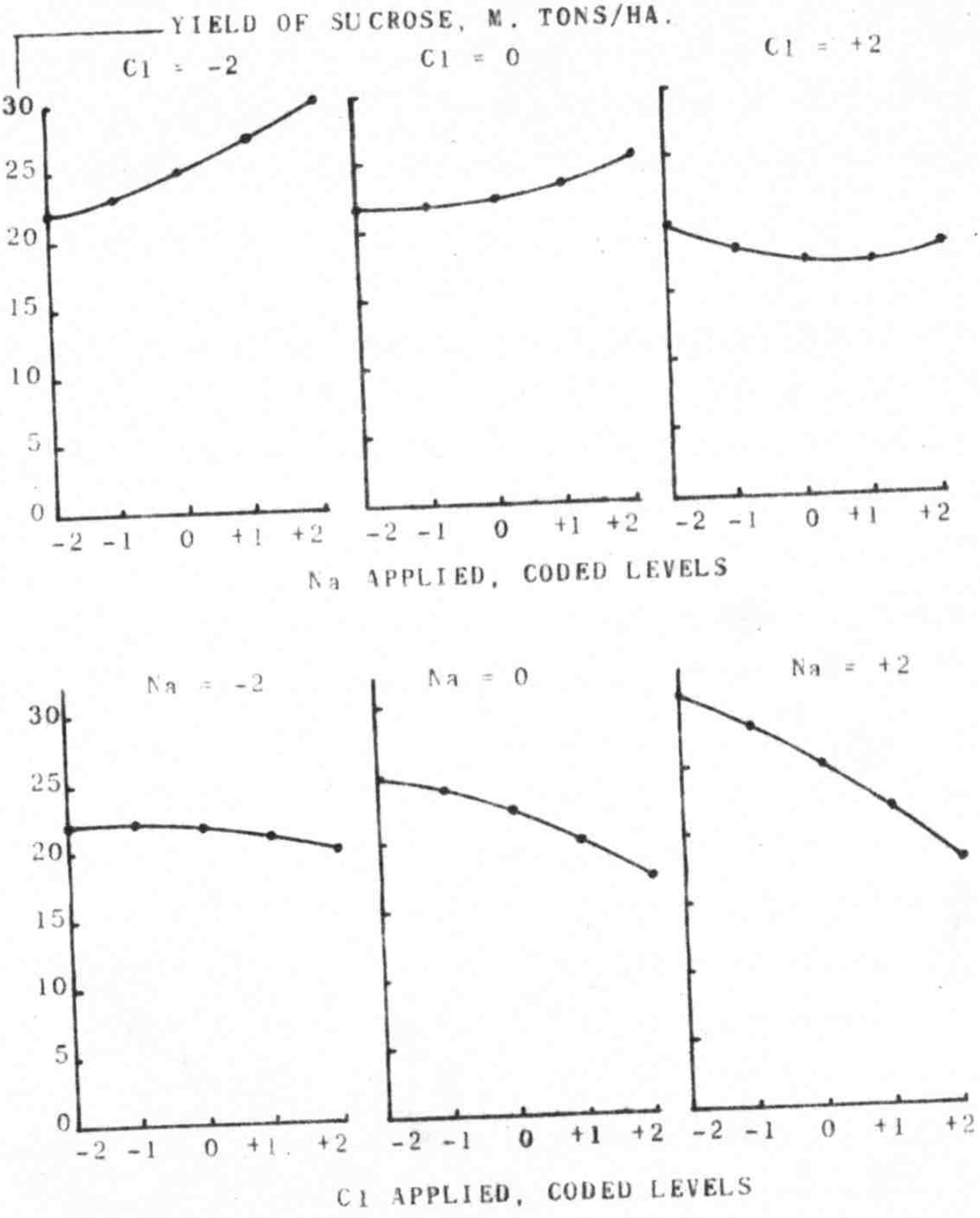

Figure 4. Estimated yield of sucrose as affected by levels of applied Na at constant levels of Cl (above) and by levels of applied Cl at constant levels of Na (below). The coded levels of N, P, S and Zn were held constant at +1, -1, -1 and -1, respectively.

tended to decrease the negative effect of S.

It was concluded that N and Na significantly increased the yield of sucrose whereas S and Cl tended to decrease it.

Effect of fertilizer treatments on the yield of beet tops

The yield of tops ranged from 2.8 to 7.4 with an average of 5.2 metric tons per hectare (Appendix Table 13). Application of N had a highly significantly positive first order effect (Table 3) showing that the yield of beet tops was increased by N application. Other American University workers (26, 30, 35, 55) also found that N application resulted in high response in yield of beet tops. The very positive effect of N on the top growth probably accounts for its depressive effect on sucrose concentration because of expenditure of carbohydrates for the production of leaves rather than storage in roots. Sulfur, Cl and Zn application tended to decrease the yield of tops.

The P-Cl interaction was significantly positive (Figure 5) meaning that increasing levels of P tended to decrease the negative effect of Cl on the top growth.

Thus, application of N highly significantly increased the top growth and S, Cl and Zn showed a tendency to decrease it.

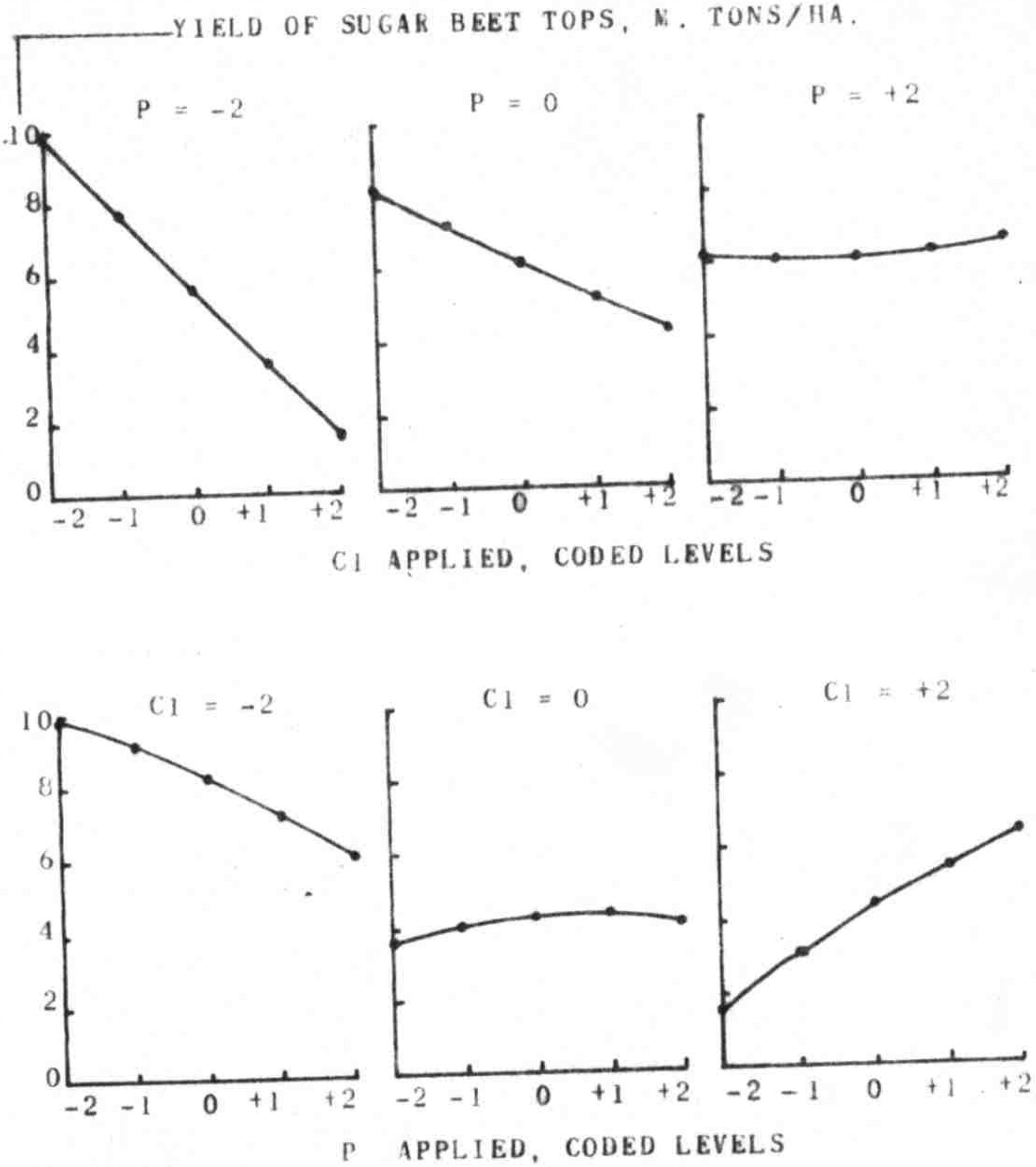

Figure 5. Estimated yield of tops (dry basis) as affected by levels of applied Cl at constant levels of P (above) and by levels of applied P at constant levels of Cl (below). The coded levels of N, S, Na and Zn were held constant at +1, -1, +1 and -1, respectively.

Effect of fertilizer treatments on N concentration in roots

The N concentration of roots (fresh basis) ranged from 0.09 to 0.23 percent with an average of 0.13 percent (Appendix Table 13). The calculated data (Appendix Table 15) showed that about 55 percent of the total N taken up the plants accumulated in the roots.

Nitrogen application increased the N concentration in the roots highly significantly (Table 4). Also, high application of N decreased the sucrose percentage. These results were in agreement with others (1, 9, 22, 66 and 77) who reported that excess N increased the concentration of unwanted nitrogenous compounds in the roots resulting in low recovery of sugar. The N concentration of roots, in this experiment, was mostly below the important 0.2 percent level (Appendix Table 13) above which Goodban _et al_. (29) reported that the purity of the extracted juice was impaired. The significantly positive squared term for N showed that the positive response to N became greater at the higher rates of application. Application of P decreased the N concentration in roots significantly. These results were in agreement with other workers (21, 55) who observed that the quality of sugar beets was improved by P because it helped in reducing the harmful effects of N. A significantly negative

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

Term	N in roots, %		N in tops, %	
	b	s_b	b	s_b
Mean	+0.134		+1.955	
N	+0.029^{xx}	±0.0018	+0.074	± 0.057
P	-0.014^{xx}	"	-0.040	"
S	+0.003	"	+0.208^{xx}	"
Cl	-0.005^{x}	"	-0.458^{xx}	"
Na	+0.003	"	-0.032	"
Zn	-0.003	"	+0.207^{xx}	"
NN	+0.004^{x}	±0.0015	+0.186^{xx}	±0.047
PP	+0.001	"	+0.116^{x}	"
SS	+0.001	"	+0.163^{x}	"
ClCl	+0.005^{x}	"	-0.331^{xx}	"
NaNa	+0.002	"	-0.331^{xx}	"
ZnZn	+0.007^{xx}	"	+0.101	"
N-P	-0.003	±0.0021	-0.014	±0.066
N-S	0.000	"	+0.048	"
N-Cl	-0.004	"	-0.037	"
N-Na	+0.001	"	+0.031	"
N-Zn	-0.002	"	+0.018	"
P-S	+0.002	"	+0.304^{xx}	"
P-Cl	-0.001	"	+0.017	"
P-Na	0.000	"	-0.014	"
P-Zn	0.000	"	-0.252^{xx}	"
S-Cl	-0.006	"	+0.343^{xx}	"
S-Na	+0.003	"	-0.058	"
S-Zn	+0.009^{xx}	"	-0.034	"
Cl-Na	-0.001	"	-0.026	"
Cl-Zn	-0.003	"	+0.397^{xx}	"
Na-Zn	+0.005	"	+0.031	"

x Statistically significant at the 5 percent level.

xx Statistically significant at the 1 percent level.

first order effect of Cl indicated that it decreased the N concentration in roots but its significantly positive squared term showed a decrease in the negative effect of Cl at the higher rates of application.

The significantly positive interactions, S-Zn and Na-Zn, revealed that as the levels of S or Na were increased, the negative effect of Zn on the N concentration in roots decreased (Table 4). The negative sign for the first order effect of Zn showed a tendency for decreasing the N concentration but its highly significantly positive squared term indicated less negative effect at the higher rates of application. The significantly negative S-Cl interaction showed that as the level of Cl application was increased, the positive effect of S was decreased. Chlorine application significantly decreased the N concentration in roots (first order regression coefficient) but its significantly positive squared term indicated a reversal of this effect at a high level of application.

It was concluded that N highly significantly increased the N concentration in roots. Sulfur and Na showed a tendency towards increasing the N concentration while P and Cl significantly decreased the N concentration in roots under the conditions of this experiment.

Effect of fertilizer treatments on N concentration of beet tops

The N percentage of tops (dry basis) had a range of 1.88 to 3.19 with an average of 2.52 (Appendix Table 13). Nitrogen application showed a tendency to increase the N content of tops (Table 4). Its highly significantly positive squared term showed an upward curvature in the positive response to N at the high rate of application.

Highly significant positive interactions were observed between P and S and between S and Cl (Table 4) indicating that as the levels of P and Cl were raised in the soil, the positive effect of S on N concentration of beet tops was increased. Sulfur significantly increased the N content of tops as shown by its first order and squared terms. The highly significantly positive Cl-Zn interaction indicated that increasing levels of Cl increased the positive effect of Zn on the N content of tops. The highly significantly negative first order and squared terms for Cl showed a decrease in the N content of tops as Cl application was increased. The highly significantly negative P-Zn interaction showed that as the level of P was increased, the positive effect of Zn was decreased. Zinc had a highly significant positive effect on the N content of tops.

In general, application of N, S and Zn increased the N concentration of tops whereas Cl decreased it.

Total N uptake by sugar beet plants

The calculated data for total N uptake (Appendix Table 15) showed that the soil had high N supplying power. When the N was supplied at the -1 coded level (75 kg. per hectare), the average total N uptake by the plants was 243 kg. per hectare showing an uptake of N of 168 kg. per hectare from the soil. When N was supplied at the rates of 150, 300 and 776 kg. per hectare, the total N uptake by the plants was 273, 336 and 403 kg. per hectare, respectively, indicating that as the level of N application was increased, the total N uptake was also increased and the proportion of N supplied by the soil was decreased. The experimental area was left fallow the previous year and not irrigated which might account for the favorable supply of N by the soil. The study of Table 2 also showed that the soil had a relatively high level of nitrate-N (41 ppm).

Nitrate-N concentration of petioles

The average seasonal concentration of nitrate-N in the petioles ranged from about 1200 ppm to 8800 ppm (Appendix Table 16). Application of N increased the nitrate-N concentration[x] in the petioles highly significantly at three sampling dates during the growing season (Table 5). However, the effect was greatest at the first sampling date (June 17) and decreased as the season advanced (Figure 6). The plants from the plots which received the three lowest levels of N application had nearly constant nitrate-N concentrations suggesting that the soil was releasing N throughout the growing season. At the 4 and 5 levels of N application, nitrate-N decreased progressively throughout the season.

In general, the effect of other elements was small except for a significantly negative first order effect of Zn on the seasonal mean of nitrate-N concentration of petioles (Table 5). The P-Zn interaction was consistantly negative throughout the season and was significantly negative for the seasonal mean indicating that an increasing level of one increased the negative effect of the other.

Almost all the plots had higher nitrate-N content in the petioles at the third sampling date (Appendix Table 16) than Ulrich's "critical level" of 1000 ppm (81). Also the averages as shown in Figure 6 indicate a probable "critical level" of more than 3000 to 4000 ppm since

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[x] The statistical analysis of petiole nitrate-N content required a conversion of the concentration values in ppm to logarithms in order to counteract the effect of a few extremely high values which overshadowed the effect of all other values.

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, Cl, Na and Zn.

Term	June 17		August 5		September 16		Seasonal mean	
	b	s_b	b	s_b	b	s_b	b	s_b
Mean	+3.674		+3.437		+3.503		+3.574	
N	+.262^{xx}	±.024	+.141^{xx}	±.019	+.116^{x}	±.043	+.182^{xx}	±.017
P	-.014	"	-.037	"	+.030	"	-.010	"
S	+.027	"	-.032	"	-.071	"	-.026	"
Cl	+.038	"	-.012	"	+.011	"	+.014	"
Na	+.012	"	-.008	"	-.020	"	-.008	"
Zn	-.023	"	-.033	"	-.052	"	-.042^{x}	
NN	+.035	±.020	+.031	±.016	-.020	±.037	+.016	±.015
PP	-.067^{x}	"	+.036	"	+.048	"	+.009	"
SS	-.032	"	+.021	"	+.007	"	-.004	"
ClCl	-.003	"	+.021	"	-.038	"	-.005	"
NaNa	-.028	"	+.015	"	-.019	"	-.017	"
ZnZn	+.001	"	+.002	"	+.014	"	+.003	"
N-P	+.023	±.028	+.009	±.022	+.040	±.050	+.012	±.020
N-S	+.032	"	+.018	"	+.019	"	+.037	"
N-Cl	-.024	"	+.006	"	-.052	"	-.027	"
N-Na	-.050	"	+.003	"	+.005	"	-.010	"
N-Zn	-.031	"	-.042	"	+.001	"	-.017	"
P-S	+.008	"	+.053^{x}	"	+.005	"	+.016	"
P-Cl	+.024	"	-.022	"	-.063	"	-.012	"
P-Na	+.010	"	-.016	"	-.025	"	-.008	"
P-Zn	-.061	"	-.037	"	-.060	"	-.050^{x}	"
S-Cl	+.001	"	+.060^{x}	"	-.009	"	+.015	"
S-Na	+.017	"	-.023	"	+.002	"	-.002	"
S-Zn	+.058	"	+.027	"	-.031	"	+.026	"
Cl-Na	+.050	"	+.041	"	+.061	"	+.039	"
Cl-Zn	+.038	"	+.017	" "	-.017	"	+.017	"
Na-Zn	-.017	"	-.029	"	-.034	"	-.021	"

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[x] Statistically significant at the 5 percent level.

[xx] Statistically significant at the 1 percent level.

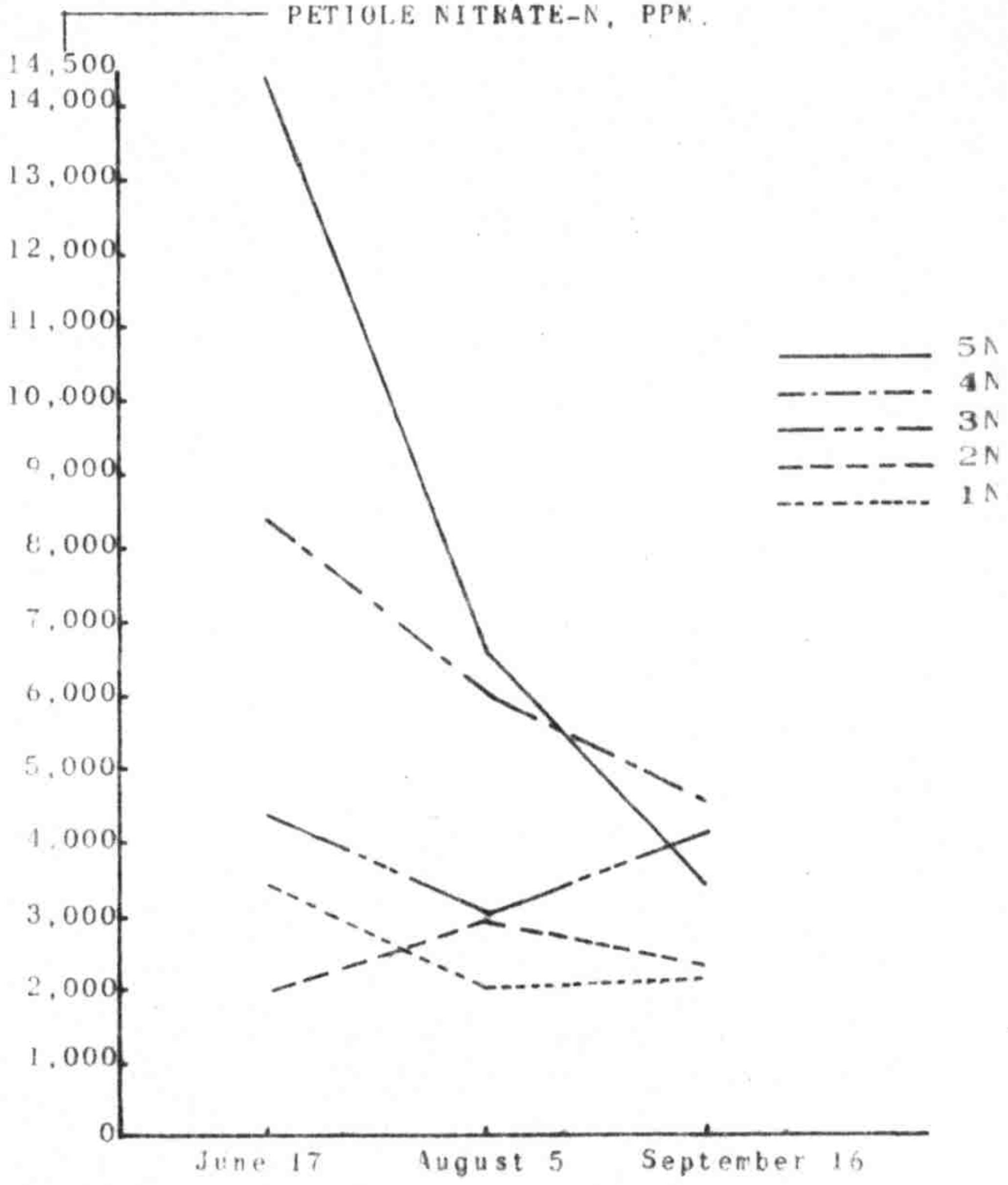

Figure 6. Observed seasonal change in average nitrate-N concentration of petioles (recently mature, dry basis).

the yield response was obtained up to the 4 level of application. The probable reason for the difference is that the yield level obtained here was almost double the yields obtained under Ulrich's California conditions. Similar findings were obtained by other American University workers (30, 35) under similar experimental conditions.

The relatively small effect of other variables on the nitrate-N concentration of petioles as compared to the constant positive effect of N showed that the nitrate-N concentration in the petioles was a good indication for the N supply to the plant as has been shown by Ulrich (81) and American University workers (30, 35, 55).

Phosphate-P concentration of petioles

The average seasonal phosphate-P concentration of petioles had a range of 0.14 to 0.25 percent (Appendix Table 15). The application of P highly significantly increased the phosphate-P content of the petioles during the growing season (Table 6). These results were in agreement with other American University workers (30, 35, 55) under similar experimental conditions.

A highly significantly negative first order effect of applied Zn indicated a decrease in the seasonal average phosphate-P content of the petioles. The N-S and S-Na interactions were negative throughout the season and

Table 6. Regression coefficients (b) and their standard errors (s_b) for the phosphate-P concentration of petioles (percent, dry basis) at two sampling dates and the seasonal mean as affected by various combinations of levels of N, P, S, Cl, Na and Zn.

Term	August 5		September 16		Seasonal mean	
	b	s_b	b	s_b	b	s_b
Mean	+0.2024		+0.1647		+0.1838	
N	+0.0053	±0.0033	-0.0033	±0.0043	-0.0020	± 0.0027
P	+0.0126^{xx}	"	+0.0203^{xx}	"	+0.0194^{xx}	"
S	-0.0045	"	+0.0017	"	-0.0044	"
Cl	-0.0024	"	-0.0024	"	+0.0004	"
Na	+0.0068	"	-0.0004	"	+0.0003	"
Zn	-0.0067	"	-0.0068	"	-0.0097^{xx}	"
NN	+0.0006	±0.0028	-0.0041	±0.0037	-0.0023	±0.0023
PP	+0.0002	"	+0.0010	"	0.0000	"
SS	-0.0034	"	-0.0008	"	-0.0028	"
ClCl	+0.0044	"	-0.0080	"	-0.0024	"
NaNa	+0.0018	"	-0.0005	"	+0.0001	"
ZnZn	-0.0001	"	+0.0004	"	-0.0004	"
N-P	+0.0068	±0.0038	-0.0020	±0.0050	+0.0070	±0.0031
N-S	-0.0034	"	-0.0024	"	-0.0075^{x}	"
N-Cl	+0.0024	"	+0.0005	"	+0.0060	"
N-Na	+0.0044	"	+0.0011	"	-0.0018	"
N-Zn	-0.0045	"	+0.0008	"	-0.0064	"
P-S	+0.0021	"	+0.0028	"	+0.0070	"
P-Cl	+0.0010	"	+0.0004	"	-0.0039	"
P-Na	+0.0021	"	-0.0011	"	+0.0050	"
P-Zn	+0.0015	"	-0.0020	"	+0.0043	"
S-Cl	-0.0080	"	+0.0083	"	+0.0047	"
S-Na	-0.0021	"	-0.0040	"	-0.0076^{x}	"
S-Zn	-0.0021	"	+0.0058	"	-0.0027	"
Cl-Na	-0.0005	"	+0.0153^{x}	"	+0.0118^{xx}	"
Cl-Zn	-0.0093^{x}	"	+0.0053	"	+0.0026	"
Na-Zn	-0.0040	"	+0.0045	"	-0.0043	"

^{x} Statistically significant at the 5 percent level.

^{xx} Statistically significant at the 1 percent level.

became significantly negative for the seasonal mean indicating that as the amounts of N and Na were increased, the negative effect of S was increased. The Cl-Na interaction for the seasonal mean phosphate-P was highly significantly positive indicating that when one was applied at a high rate, the other had a more positive effect on the phosphate-P concentration in the petioles. The Cl-Zn interaction was significantly negative at the second sampling date (August 5) but was positive at the September sampling time.

The yield response to P application tended to be negative and the phosphate-P concentrations of the petioles were higher in all cases than the "critical level" of 750 ppm suggested by Ulrich (80). However, the significant effect of P application on P concentration of petioles indicated that the petiole P was a good indicator of P status of the plant.

Sulfate-S concentration of petioles

The recorded data for the seasonal mean sulfate-S concentration of petioles indicated a range of 0.07 to 0.20 percent (Appendix Table 18). These values were in agreement with those reported by other American University workers (30, 35) under similar experimental conditions.

The highly significant positive regression coefficient for the first order term of S (Table 7) indicated that the applied S increased the sulfate-S concentration of petioles throughout the growing season. Its squared term for the seasonal mean was highly significant showing an upward curvature in the positive effect of S on petiole sulfate-S content. The significantly positive first order effect of N on the seasonal mean indicated an increase in the sulfate-S content of the petioles with N application. The N-S interaction was positive throughout the season and became significantly positive for the seasonal mean showing that when both the elements were supplied at high rates, the sulfate-S content of petioles was increased. The P-Na interaction was highly significantly negative indicating a less positive effect of Na with an increase in P application, whereas a highly significantly positive first order effect of Na revealed that the sulfate-S content of petioles was increased with Na application. The S-Zn interaction was significantly positive at the third sampling date and highly significantly positive for the seasonal mean showing that increasing levels of Zn increased the positive effect of S. The negative Cl-Zn interaction was significant for the seasonal mean indicating a decrease in the sulfate-S content of petioles when both were applied at high rates (Table 7).

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

Term	August 5		September 16		Seasonal mean	
	b	s_b	b	s_b	b	s_b
Mean	+0.1188		+0.0974		+0.1031	
N	+0.0037	±0.0054	+0.0057	±0.0031	+0.0047^{x}	±0.0014
P	+0.0043	"	-0.0015	"	+0.0014	"
S	+0.0204^{xx}	"	+0.0169^{xx}	"	+0.0186^{xx}	"
Cl	+0.0019	"	-0.0029	"	-0.0003	"
Na	+0.0076	"	+0.0045	"	+0.0059^{xx}	"
Zn	-0.0017	"	-0.0002	"	-0.0011	"
NN	-0.0009	±0.0046	+0.0011	±0.0026	+0.0010	±0.0012
PP	-0.0055	"	+0.0010	"	-0.0014	"
SS	+0.0106	"	+0.0033	"	+0.0078^{xx}	"
ClCl	+0.0007	"	-0.0026	"	0.0000	"
NaNa	-0.0045	"	+0.0018	"	-0.0005	"
ZnZn	-0.0019	"	-0.0033	"	-0.0017	"
N-P	+0.0012	±0.0062	+0.0024	±0.0036	+0.0016	±0.0016
N-S	+0.0040	"	+0.0053	"	+0.0049^{x}	"
N-Cl	+0.0033	"	-0.0046	"	-0.0008	"
N-Na	+0.0048	"	-0.0017	"	+0.0018	"
N-Zn	-0.0067	"	+0.0007	"	-0.0027	"
P-S	+0.0011	"	+0.0021	"	+0.0014	"
P-Cl	+0.0018	"	-0.0042	"	-0.0009	"
P-Na	-0.0040	"	-0.0084^{x}	"	-0.0063^{xx}	"
P-Zn	-0.0017	"	+0.0011	"	-0.0006	"
S-Cl	+0.0002	"	-0.0035	"	-0.0019	"
S-Na	+0.0017	"	+0.0038	"	+0.0030	"
S-Zn	+0.0042	"	+0.0091^{x}	"	+0.0069^{xx}	"
Cl-Na	0.0000	"	-0.0011	"	-0.0008	"
Cl-Zn	-0.0065	"	-0.0044	"	-0.0056^{x}	"
Na-Zn	-0.0008	"	-0.0020	"	-0.0012	"

^{x} Statistically significant at the 5 percent level.

^{xx} Statistically significant at the 1 percent level.

Sulfur, N and Na increased the sulfate-S content of petioles whereas the influence of other elements was small.

Chlorine concentration of petioles

The seasonal mean concentration of Cl ranged from 1.65 to 3.48 with an average of 2.62 percent (Appendix Table 19). Application of Cl significantly increased the Cl concentration of petioles at the first sampling date but had less effect later (Table 8). The significantly negative first order term of N for the seasonal average indicated a decrease in Cl concentration with N application and this effect became more pronounced as the season advanced. At the first and second sampling dates, a few interactions had significant regression coefficients but the trends were indefinite and none of the interaction terms became significant for the seasonal mean.

The general Cl concentration of petioles was found to be considerably greater than the 0.4 percent (dry basis) in the petioles suggested by Ulrich (81) as a "critical level". Since the sugar beet yields were not greatly affected by application of Cl , no definite effect could be associated with the petiole level of Cl.

The concentration of Cl in the petioles was significantly increased by applied Cl early in the season and

Table 8. Regression coefficients (b) and their standard errors (s_b) for the Cl concentrations of the petioles (percent, dry basis) at three sampling dates and the seasonal mean as affected by the various combinations of levels of N, P, S, Cl, Na and Zn.

Term	June 17		August 5		September 16		Seasonal mean	
	b	s_b	b	s_b	b	s_b	b	s_b
Mean	2.721		2.178		2.952		2.616	
N	-.077	±.076	-.213^{x}	±.081	-.222	±.120	-.179^{x}	±.057
P	+.005	"	-.025	"	-.189	"	-.043	"
S	+.070	"	+.043	"	+.191	"	+.107	"
Cl	+.328^{xx}	"	+.080	"	+.087	"	+.172^{x}	"
Na	+.027	"	+.169	"	+.093	"	+.097	"
Zn	+.022	"	+.145	"	+.177	"	+.123	"
NN	-.032	±.065	+.017	±.069	+.062	±.102	+.017	±.048
PP	+.023	"	+.017	"	+.063	"	+.020	"
SS	+.006	"	-.075	"	-.030	"	-.029	"
ClCl	+.116	"	+.091	"	+.099	"	+.107	"
NaNa	+.060	"	+.091	"	+.007	"	+.057	"
ZnZn	+.006	"	+.053	"	-.064	"	+.002	"
N-P	-.012	±.089	-.082	±.094	-.020	±.139	-.033	±.066
N-S	-.013	"	+.079	"	+.096	"	+.042	"
N-Cl	-.100	"	+.197	"	+.086	"	+.052	"
N-Na	+.052	"	+.010	"	+.149	"	+.064	"
N-Zn	-.114	"	+.011	"	+.044	"	-.029	"
P-S	-.293^{x}	"	+.016	"	+.058	"	-.079	"
P-Cl	-.053	"	+.131	"	-.031	"	+.013	"
P-Na	+.073	"	+.256^{x}	"	-.044	"	+.082	"
P-Zn	+.137	"	+.075	"	+.006	"	+.070	"
S-Cl	+.207	"	-.055	"	+.008	"	+.060	"
S-Na	-.255^{x}	"	-.151	"	-.058	"	-.150	"
S-Zn	-.036	"	+.106	"	+.044	"	+.044	"
Cl-Na	+.012	"	+.092	"	+.004	"	+.036	"
Cl-Zn	-.285^{x}	"	+.016	"	+.008	"	-.077	"
Na-Zn	+.202	"	+.063	"	-.058	"	+.069	"

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[x] Statistically significant at the 5 percent level.

[xx] Statistically significant at the 1 percent level.

was decreased in the later part of the season by application of N.

Potassium concentration of petioles

The seasonal mean of K concentration of the petioles showed a range of 2.55 to 4.20 with an average of 3.02 percent (Appendix Table 20). The seasonal effect of N application was to decrease significantly the K concentration of petioles. Sulfur and Cl had significantly positive first order effects indicating an increase in K concentration from their application (Table 9). Zinc and Na had significantly negative first order effects at the first sampling date showing a decrease in K concentration from their application. However, this effect was not sustained throughout the remainder of the season. Only the N-Zn interaction was appreciable in size and constant throughout the season. It was significantly negative for the seasonal mean indicating that application of Zn increased the negative effect of N application on K concentration of petioles.

It was concluded that application of S or Cl significantly increased the K content in the petioles and N application decreased it.

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

	June 17		August 5		September 16		Seasonal mean	
Term	b	s_b	b	s_b	b	s_b	b	s_b
Mean	+3.426		+ 2.785		+2.837		+ 3.015	
N	+.071	±.065	-.186^{x}	±.043	-.134^{x}	±.042	-.083^{x}	±.033
P	+.063	"	-.085	"	+.011	"	-.004	"
S	+.171^{x}	"	+.126^{x}	"	+.103^{x}	"	+.133^{xx}	"
Cl	+.164^{x}	"	+.011	"	+.116^{x}	"	+.085^{x}	"
Na	-.175^{x}	"	+.036	"	-.078	"	-.072	"
Zn	-.162^{x}	"	+.069	"	+.011	"	-.027	"
NN	+.051	±.055	-.075	±.037	+.145^{xx}	±.036	+.043	±.028
PP	+.047	"	+.140^{x}	"	+.020	"	+.171^{x}	"
SS	+.049	"	+.047	"	-.074	"	+.010	"
ClCl	+.123	"	-.020	"	+.011	"	+.022	"
NaNa	+.058	"	-.011	"	+.167^{x}	"	+.074^{x}	"
ZnZn	+.073	"	-.016	"	+.047	"	+.037	"
N-P	+.100	±.075	-.023	±.051	+.039	±.049	+.038	±.038
N-S	-.043	"	-.024	"	-.025	"	-.031	"
N-Cl	-.021	"	+.151^{x}	"	-.066	"	+.021	"
N-Na	-.159	"	-.179^{xx}	"	+.115	"	-.075	"
N-Zn	-.138	"	-.121^{x}	"	-.013	"	-.091^{x}	"
P-S	-.110	"	+.026	"	.000	"	-.028	"
P-Cl	+.204^{x}	"	+.021	"	-.041	"	+.061	"
P-Na	-.056	"	+.068	"	+.065	"	+.026	"
P-Zn	-.016	"	+.139^{x}	"	-.151^{x}	"	-.009	"
S-Cl	-.063	"	-.104	"	+.002	"	-.055	"
S-Na	-.173	"	+.069	"	+.100	"	-.001	"
S-Zn	-.012	"	+.089	"	-.082	"	-.002	"
Cl-Na	+.123	"	-.065	"	+.016	"	+.024	"
Cl-Zn	+.068	"	-.018	"	+.140^{x}	"	+.063	"
Na-Zn	+.061	"	-.011	"	+.067	"	+.040	"

[x] Statistically significant at the 5 percent level.

[xx] Statistically significant at the 1 percent level.

Sodium concentration of petioles

The seasonal mean Na concentration in the petioles ranged from 0.69 to 1.89 with an average of 1.12 percent (Appendix Table 21). Sodium application increased the uptake of Na significantly throughout the season (Figure 7, Table 10). The first order effect of N was significantly positive at the first sampling date indicating an increase in Na content of petioles with N application. At later sampling dates, the N effect was small. None of the interaction terms were statistically significant in all the three sampling dates.

It was concluded that Na application affected Na concentration positively throughout the season and that N application had a strong positive effect early in the season.

Effect of fertilizer treatments on leaf blade analysis

The total concentrations of P, S, K and Na and Mg were determined in the perchloric acid digests of the leaf blades collected at the second sampling date (August 5). In general, there was little significant effect of the variables on the composition of leaf blades (Tables 11 and 12) except that Na application increased the total Na content and Zn application increased the total Mg content . In this experiment, analysis of petioles

Table 10. Regression coefficients (b) and their standard errors (s_b) for the Na concentration of the petioles (percent, dry basis) at three sampling dates and the seasonal mean as affected by the various combinations of levels of N, P, S, Cl, Na and Zn.

Term	June 17		August 5		September 16		Seasonal mean	
	b	s_b	b	s_b	b	s_b	b	s_b
Mean	+1.492		+0.895		+0.965		+1.117	
N	+.360^{xx}	±.077	-.031	±.031	+.010	±.054	+.110^{x}	±.039
P	-.067	"	+.050	"	-.034	"	-.021	"
S	+.071	"	-.010	"	+.036	"	+.034	"
Cl	+.036	"	-.029	"	+.040	"	+.019	"
Na	+.119	"	+.043	"	+.124^{x}	"	+.093^{x}	"
Zn	+.011	"	+.040	"	+.039	"	+.028	"
NN	-.108	±.066	-.015	±.027	-.010	±.046	-.045	±.034
PP	-.043	"	-.020	"	-.016	"	-.027	"
SS	+.018	"	+.006	"	-.032	"	-.003	"
ClCl	+.027	"	-.036	"	+.049	"	+.013	"
NaNa	+.070	"	+.018	"	+.020	"	+.036	"
ZnZn	-.021	"	+.015	"	-.034	"	-.013	"
N-P	-.027	±.090	-.002	±.036	-.025	±.063	-.021	±.046
N-S	+.070	"	+.007	"	+.039	"	+.042	"
N-Cl	-.063	"	+.047	"	+.005	"	.000	"
N-Na	-.130	"	-.015	"	-.051	"	-.068	"
N-Zn	-.037	"	+.043	"	-.017	"	-.007	"
P-S	-.063	"	+.018	"	-.020	"	-.017	"
P-Cl	+.126	"	-.010	"	+.050	"	+.058	"
P-Na	+.078	"	+.025	"	+.002	"	+.032	"
P-Zn	-.047	"	.000	"	+.015	"	-.014	"
S-Cl	-.024	"	-.055	"	+.023	"	-.023	"
S-Na	+.012	"	+.032	"	-.048	"	+.002	"
S-Zn	-.005	"	+.024	"	+.073	"	+.035	"
Cl-Na	+.141	"	-.013	"	-.085	"	+.017	"
Cl-Zn	+.063	"	+.025	"	-.062	"	+.012	"
Na-Zn	+.084	"	-.016	"	-.023	"	+.011	"

^{x} Statistically significant at the 5 percent level.

^{xx} Statistically significant at the 1 percent level.

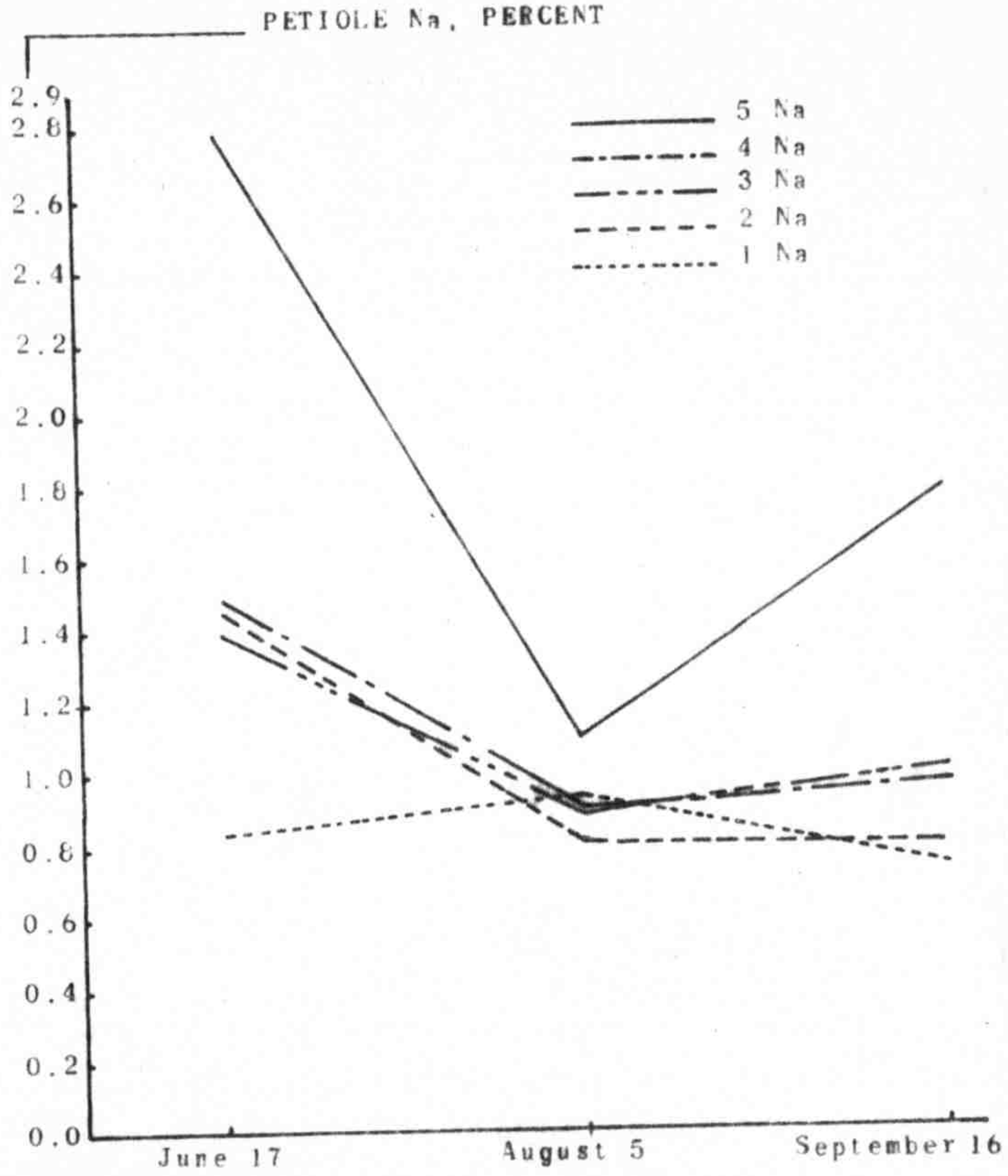

Figure 7. Observed seasonal change in average Na concentration of petioles (recently mature, dry basis).

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

Term	P, percent		S, percent	
	b	s_b	b	s_b
Mean	+0.354		+1.098	
N	+0.023	±0.010	+0.014	±0.027
P	+0.017	"	-0.041	"
S	0.000	"	+0.038	"
Cl	-0.005	"	-0.011	"
Na	-0.012	"	-0.048	"
Zn	-0.019	"	+0.030	"
NN	-0.008	±0.009	+0.008	±0.023
PP	-0.007	"	+0.019	"
SS	+0.010	"	0.000	"
ClCl	+0.004	"	-0.011	"
NaNa	-0.008	"	+0.036	"
ZnZn	-0.006	"	+0.013	"
N-P	+0.003	±0.012	-0.053	±0.032
N-S	-0.011	"	-0.012	"
N-Cl	+0.002	"	-0.015	"
N-Na	+0.002	"	-0.017	"
N-Zn	+0.026	"	-0.069	"
P-S	+0.007	"	-0.019	"
P-Cl	+0.002	"	+0.013	"
P-Na	-0.020	"	-0.021	"
P-Zn	-0.011	"	-0.023	"
S-Cl	+0.016	"	+0.005	"
S-Na	+0.005	"	-0.043	"
S-Zn	+0.016	"	+0.039	"
Cl-Na	-0.007	"	+0.004	"
Cl-Zn	-0.016	"	+0.025	"
Na-Zn	-0.022	"	-0.009	"

Table 12. Regression coefficients (b) and their standard errors (s_b) for the concentrations of total K, Na and Mg in the leaf blades (percent, dry basis) at the second sampling date as affected by various combinations of levels of N, P, S, Cl, Na and Zn.

Term	Percent K		Percent Na		Percent Mg	
	b	s_b	b	s_b	b	s_b
Mean	4.242		1.281		0.413	
N	-0.226	±0.105	-0.036	±0.039	-0.007	±0.028
P	-0.220	"	-0.063	"	-0.044	"
S	+0.056	"	+0.067	"	-0.007	"
Cl	+0.001	"	+0.071	"	+0.024	"
Na	-0.193	"	+0.093^x	"	+0.038	"
Zn	+0.158	"	+0.006	"	+0.076^x	"
NN	+0.065	±0.090	-0.022	±0.033	+0.004	±0.024
PP	-0.051	"	+0.035	"	-0.007	"
SS	-0.028	"	0.000	"	-0.022	"
ClCl	-0.085	"	+0.059	"	-0.034	"
NaNa	+0.112	"	+0.039	"	+0.007	"
ZnZn	+0.077	"	+0.021	"	-0.001	"
N-P	-0.115	±0.122	+0.026	±0.045	+0.041	±0.032
N-S	+0.026	"	-0.026	"	+0.038	"
N-Cl	-0.006	"	-0.057	"	+0.002	"
N-Na	+0.058	"	-0.020	"	-0.040	"
N-Zn	+0.059	"	-0.057	"	-0.041	"
P-S	-0.041	"	-0.026	"	+0.086^x	"
P-Cl	+0.043	"	+0.008	"	+0.001	"
P-Na	+0.078	"	-0.064	"	+0.035	"
P-Zn	-0.036	"	+0.001	"	-0.091^x	"
S-Cl	-0.146	"	+0.026	"	+0.036	"
S-Na	+0.038	"	-0.005	"	+0.040	"
S-Zn	+0.068	"	+0.136^x	"	-0.042	"
Cl-Na	-0.005	"	-0.038	"	+0.004	"
Cl-Zn	+0.083	"	+0.011	"	+0.012	"
Na-Zn	-0.050	"	-0.059	"	+0.035	"

x Statistically significant at the 5 percent level.

appeared to result in more significant differences than the total analysis of leaf blade tissues.

SUMMARY AND CONCLUSIONS

An irrigated field experiment was conducted on a calcareous soil in the Beqa'a Plain of Lebanon, in 1964, to evaluate the individual effects and interactions of N, P, S, Cl, Na and Zn on the yield and chemical composition of sugar beets. A central composite, rotatable, incomplete factorial design involving six variables was used. The rates of fertilizers were from 29 to 776 kg. per hectare for the macronutrients and from 7.25 to 195 kg. per hectare for Zn (Table 1). There were 45 treatments one of which (at third level of application for all variables) was replicated ten times and distributed at random within three blocks in order to estimate the experimental error. Quadratic regression equations were employed for determining the nature of the response surfaces for some of the important interactions.

Seeds of sugar beets were planted on March 31, 1964 and the beets were harvested on November 6, 1964. During the growing season, petiole samples of recently matured leaves were taken at three stages.

Statistical analyses for yields and concentrations of nutrients in the petioles and leaves were made on an IBM 1620 computer. The equation sufficiency was generally high indicating that the quadratic regression equation accounted for most of the treatment variability.

Application of N significantly increased the yields of roots, sucrose and tops and total N in roots and tops but had detrimental effect on sucrose percentage. The positive effect of N on the yield of sucrose was decreased by Zn application as indicated by significantly negative N-Zn interaction. The significantly positive N-Na interaction showed a decrease in the negative effect of N on sucrose percentage by application of Na.

Sodium application increased the yield of sucrose and sucrose percentage significantly and tended to increase the yield of roots. Its positive effect on the yield of sucrose was decreased by high rates of S and Cl applications as indicated by the significantly negative S-Na and Cl-Na interactions indicating that a source of Na other than the chloride or sulfate salts should be used.

The remaining variables, P, S, Cl, and Zn showed a tendency to decrease the yields of roots, sucrose and tops. The significantly positive P-Zn and Cl-Zn interactions indicated that high levels of P or Cl decreased the negative effect of Zn on the yield of roots and sucrose.

The concentrations of nutrients in the petioles were directly affected by application of the variables. There was little significant effect of the variables on leaf blade composition.

In general, it was concluded that N and Na were the fertilizers that were most needed for sugar beets under the conditions of this experiment. Large negative interactions of Na with Cl and S suggested the use of $NaNO_3$ rather than NaCl or Na_2SO_4 as a carrier of Na. The important positive interaction of P and Zn warranted further investigation. Petiole analysis was effective for following the nutritional status. However, the high yields obtained here appeared to require higher levels than those given by Ulrich for California conditions.

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APPENDICES

Table 13. Yield of roots (fresh basis, N and sucrose concentration of roots (fresh basis), yield of tops (dry basis), N concentration in tops (dry basis) and yield of sucrose as affected by various combinations of levels of N, P, S, Cl, Na and Zn.

Treatment level						Yield of roots	N in roots,	Suc-rose,	Yield of tops	N in tops,	Yield of sucrose,
N	P	S	Cl	Na	Zn	M.tons/Ha.	%	%	M.tons/Ha.	%	M.tons/Ha.
2	2	2	2	2	2	103.7	0.15	18.6	7.4	2.35	19.3
4	2	2	2	4	2	116.5	0.21	20.1	6.3	2.99	23.4
2	4	2	2	4	2	98.5	0.10	20.9	4.7	2.10	20.6
4	4	2	2	2	2	113.1	0.19	17.5	7.9	2.47	19.8
2	2	4	2	2	4	83.0	0.15	20.1	3.5	2.01	16.7
4	2	4	2	4	4	101.5	0.23	18.5	7.0	2.53	18.8
2	4	4	2	4	4	107.0	0.16	18.9	4.3	2.08	20.2
4	4	4	2	2	4	106.0	0.19	18.4	5.9	2.49	19.5
2	2	2	4	2	4	97.4	0.13	20.3	3.8	2.57	20.4
4	2	2	4	4	4	99.2	0.17	20.7	3.8	2.43	20.5
2	4	2	4	4	4	110.8	0.11	21.0	4.9	1.98	23.3
4	4	2	4	2	4	104.3	0.15	17.8	6.3	2.69	18.6
2	2	4	4	2	2	94.9	0.13	20.3	5.0	2.39	19.3
4	2	4	4	4	2	96.3	0.20	18.2	4.3	2.67	17.5
2	4	4	4	4	2	75.8	0.11	21.3	3.1	2.51	16.1
4	4	4	4	2	2	105.6	0.13	19.1	6.5	2.89	20.2
2	2	2	2	4	4	117.3	0.16	18.6	6.9	2.53	22.2
4	2	2	2	2	4	105.1	0.19	18.3	7.1	3.05	19.2
2	4	2	2	2	4	89.6	0.09	21.5	4.0	2.69	19.3
4	4	2	2	4	4	105.0	0.17	20.7	6.7	2.45	21.7
2	2	4	2	4	2	107.7	0.13	20.6	5.7	2.33	22.2
4	2	4	2	2	2	114.5	0.21	19.8	7.6	3.03	22.7
2	4	4	2	2	2	78.9	0.14	20.9	2.9	2.48	16.5
4	4	4	2	4	2	99.2	0.19	21.5	4.7	2.91	21.3
2	2	2	4	4	2	102.6	0.15	18.9	5.0	2.60	19.4
4	2	2	4	2	2	104.7	0.22	19.3	5.5	3.19	20.2
2	4	2	4	2	2	84.5	0.15	18.9	3.7	2.38	16.0
4	4	2	4	4	2	98.7	0.17	18.8	6.7	2.63	18.6
2	2	4	4	4	4	96.3	0.15	18.6	4.2	2.58	17.9
4	2	4	4	2	4	108.6	0.20	17.3	5.3	2.95	18.8
2	4	4	4	2	4	129.0	0.12	19.3	6.2	2.19	24.9
4	4	4	4	4	4	112.8	0.17	19.0	6.2	2.65	21.4

Cont. p. 82.

Table 13 continued.

Treatment level						Yield of roots	N in roots,	Sucrose,	Yield of tops	N in tops,	Yield of sucrose
N	P	S	Cl	Na	Zn	M.tons/Ha.	%	%	M.tons/Ha.	%	M.tons/Ha.
5	3	3	3	3	3	108.9	0.22	19.1	5.2	3.14	20.8
1	3	3	3	3	3	78.5	0.06	19.4	3.0	1.88	15.6
3	5	3	3	3	3	111.7	0.09	18.8	5.0	2.09	21.0
3	1	3	3	3	3	95.8	0.15	19.7	3.7	2.61	18.9
3	3	5	3	3	3	113.4	0.13	19.5	5.8	2.48	22.1
3	3	1	3	3	3	121.0	0.12	19.5	5.6	2.35	23.6
3	3	3	5	3	3	109.2	0.14	19.2	4.8	2.51	21.0
3	3	3	1	3	3	108.5	0.15	17.5	5.2	2.56	19.0
3	3	3	3	5	3	126.4	0.15	20.4	6.9	2.38	25.8
3	3	3	3	1	3	103.0	0.11	20.6	3.4	2.43	21.2
3	3	3	3	3	5	91.3	0.14	20.5	3.2	2.52	18.7
3	3	3	3	3	1	122.8	0.17	17.6	7.2	2.71	21.6
3	3	3	3	3	3	103.8	0.13	18.3	3.7	2.49	19.0
3	3	3	3	3	3	107.0	0.14	19.5	4.7	2.38	20.9
3	3	3	3	3	3	106.8	0.13	19.1	6.0	2.51	20.4
3	3	3	3	3	3	91.8	0.15	20.3	3.1	2.48	18.6
3	3	3	3	3	3	112.5	0.12	19.4	5.4	2.28	21.8
3	3	3	3	3	3	116.1	0.14	19.6	6.7	2.39	22.8
3	3	3	3	3	3	103.4	0.13	19.9	5.6	2.24	20.6
3	3	3	3	3	3	111.2	0.15	19.7	6.3	2.55	21.9
3	3	3	3	3	3	99.0	0.12	20.8	4.7	2.31	20.6
3	3	3	3	3	3	117.9	0.14	20.0	6.2	2.47	23.6

Table 14. 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) as affected by various combinations of levels of N, P, S, Cl, Na and Zn.

Source	Yield of roots, M.tons /Ha.	Yield of sucrose M. tons/Ha.	Yield of tops, M tons / Ha.	Sucrose in roots, %	N in roots, %	N in tops, %
d.f.						
Total	53	53	53	53	53	53
Block	2	2	2	2	2	2
First order	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	7034.6	253.9	96.7	65.2	0.6700	70.6223
Block	364.1	15.1	4.0	0.3	0.0045	2.8217
First order	1017.1	28.3	26.0	8.0	0.0456	13.1296
Quadratic	3585.5	158.1	31.3	30.7	0.0117	32.7836
Lack of fit	1648.5	41.9	28.3	23.6	0.0043	20.9087
Error	419.3	10.6	7.1	2.7	0.0009	0.9787
M.S.						
Block	182.06	7.54	2.02	0.13	0.00223	1.4108
First order	169.52	4.71	4.34^{x}	1.33	0.00759^{xx}	2.1883^{xx}
Quadratic	170.74^{x}	7.53^{xx}	1.49	1.46^{xx}	0.00055^{xx}	1.5611^{xx}
Lack of fit	96.97	2.46	1.66	1.39^{x}	0.00025	1.2299^{xx}
Error	59.91	1.51	1.01	0.38	0.00014	0.1398
C.V. %	7.2	5.8	19.2	3.1	8.7	19.1
Equation sufficiency+, %	77.8	83.3	69.0	62.1	85.7	68.9

[x] Statistically significant at the 5 percent level.

[xx] Statistically significant at the 1 percent level.

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

Table 15. Total N uptake by plants in relation to applied N as affected by various combinations of levels of N, P, S, Cl, Na and Zn.

Treatment levels						N in roots, Kg./Ha.	N in tops, Kg./Ha.	Total N uptake Kg./Ha.	Applied N Kg./Ha.
N	P	S	Cl	Na	Zn				
2	2	2	2	2	2	156	174	330	75
4	2	2	2	4	2	245	188	433	300
2	4	2	2	4	2	99	99	198	75
4	4	2	2	2	2	215	195	410	300
2	2	4	2	2	4	125	70	195	75
4	2	4	2	4	4	234	177	411	300
2	4	4	2	4	4	171	89	260	75
4	4	4	2	2	4	201	147	348	300
2	2	2	4	2	4	127	98	225	75
4	2	2	4	4	4	169	92	261	300
2	4	2	4	4	4	122	97	219	75
4	4	2	4	2	4	157	170	327	300
2	2	4	4	2	2	123	120	243	75
4	2	4	4	4	2	193	115	308	300
2	4	4	4	4	2	83	78	161	75
4	4	4	4	2	2	137	188	325	300
2	2	2	2	4	4	188	175	363	75
4	2	2	2	2	4	200	217	417	300
2	4	2	2	2	4	81	108	189	75
4	4	2	2	4	4	179	164	343	300
2	2	4	2	4	2	140	133	273	75
4	2	4	2	2	2	241	230	471	300
2	4	4	2	2	2	111	72	183	75
4	4	4	2	4	2	189	137	326	300
2	2	2	4	4	2	154	130	284	75
4	2	2	4	2	2	230	170	400	300
2	4	2	4	2	2	127	88	215	75
4	4	2	4	4	2	168	176	344	300
2	2	4	4	4	4	145	108	253	75
4	2	4	4	2	4	217	156	373	300
2	4	4	4	2	4	155	136	291	75
4	4	4	4	4	4	192	164	356	300

Cont. p. 85.

Table 15 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	Cl	Na	Zn				
5	3	3	3	3	3	240	163	403	776
1	3	3	3	3	3	47	56	103	29
3	5	3	3	3	3	101	105	206	150
3	1	3	3	3	3	144	97	241	150
3	3	5	3	3	3	147	144	291	150
3	3	1	3	3	3	145	132	277	150
3	3	3	5	3	3	153	121	274	150
3	3	3	1	3	3	163	133	296	150
3	3	3	3	5	3	190	164	354	150
3	3	3	3	1	3	113	83	196	150
3	3	3	3	3	5	128	81	209	150
3	3	3	3	3	1	209	195	404	150
3	3	3	3	3	3	135	92	227	150
3	3	3	3	3	3	150	112	262	150
3	3	3	3	3	3	139	151	290	150
3	3	3	3	3	3	138	77	215	150
3	3	3	3	3	3	135	123	258	150
3	3	3	3	3	3	163	160	323	150
3	3	3	3	3	3	134	125	259	150
3	3	3	3	3	3	167	161	328	150
3	3	3	3	3	3	119	109	228	150
3	3	3	3	3	3	165	153	318	150

Table 16. 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, Cl, Na and Zn.

Treatment levels						June 17, ppm.	August 5, ppm.	September 16, ppm.	Seasonal mean, ppm.
N	P	S	Cl	Na	Zn				
2	2	2	2	2	2	2,135	4,018	1,758	2,637
4	2	2	2	4	2	4,738	10,490	2,172	5,800
2	4	2	2	4	2	1,942	5,483	1,875	3,100
4	4	2	2	2	2	10,499	7,711	7,791	8,667
2	2	4	2	2	4	2,139	3,180	2,184	2,501
4	2	4	2	4	4	9,997	3,314	1,869	5,060
2	4	4	2	4	4	1,431	1,519	1,253	1,401
4	4	4	2	2	4	8,212	9,789	6,599	8,200
2	2	2	4	2	4	2,127	4,216	3,356	3,233
4	2	2	4	4	4	4,819	6,478	5,803	5,700
2	4	2	4	4	4	1,631	2,722	2,061	2,138
4	4	2	4	2	4	7,629	3,096	5,382	5,369
2	2	4	4	2	2	1,125	2,862	2,274	2,087
4	2	4	4	4	2	6,323	9,965	6,611	7,633
2	4	4	4	4	2	2,218	1,911	1,964	2,031
4	4	4	4	2	2	5,715	5,868	3,222	4,935
2	2	2	2	4	4	2,818	4,411	2,494	3,241
4	2	2	2	2	4	9,791	9,118	7,491	8,800
2	4	2	2	2	4	1,209	2,029	2,090	1,776
4	4	2	2	4	4	2,989	2,363	3,912	3,088
2	2	4	2	4	2	1,218	1,536	870	1,208
4	2	4	2	2	2	12,968	3,108	3,124	6,400
2	4	4	2	2	2	1,741	2,645	2,481	2,789
4	4	4	2	4	2	10,179	4,525	7,295	7,333
2	2	2	4	4	2	2,635	2,119	3,964	2,906
4	2	2	4	2	2	6,883	6,091	2,413	5,129
2	4	2	4	2	2	1,410	1,756	4,790	2,652
4	4	2	4	4	2	11,389	5,360	2,745	6,498
2	2	4	4	4	4	4,718	3,618	1,864	3,400
4	2	4	4	2	4	11,797	3,785	3,549	6,377
2	4	4	4	2	4	2,641	2,614	1,771	2,342
4	4	4	4	4	4	10,098	4,924	2,489	5,837

Cont. p. 87.

Table 16 continued.

Treatment levels						June 17, ppm.	August 5, ppm.	September 16, ppm.	Seasonal mean, ppm.
N	P	S	Cl	Na	Zn				
5	3	3	3	3	3	14,387	6,565	3,387	8,113
1	3	3	3	3	3	3,434	2,007	2,101	2,514
3	5	3	3	3	3	2,138	3,588	8,575	4,767
3	1	3	3	3	3	1,726	4,112	4,761	3,533
3	3	5	3	3	3	3,091	3,064	1,909	2,688
3	3	1	3	3	3	2,909	3,319	7,392	4,540
3	3	3	5	3	3	7,386	2,821	1,601	3,936
3	3	3	1	3	3	2,517	3,605	2,782	2,968
3	3	3	3	5	3	4,381	3,018	3,182	3,527
3	3	3	3	1	3	2,214	2,910	2,289	2,471
3	3	3	3	3	5	2,208	1,588	1,403	1,733
3	3	3	3	3	1	9,322	3,897	12,104	8,441
3	3	3	3	3	3	4,813	2,893	1,288	2,998
3	3	3	3	3	3	2,961	2,808	5,292	3,687
3	3	3	3	3	3	6,394	2,457	6,101	4,984
3	3	3	3	3	3	3,118	3,515	4,884	3,839
3	3	3	3	3	3	4,315	4,122	2,384	3,607
3	3	3	3	3	3	4,288	2,179	4,333	3,600
3	3	3	3	3	3	10,017	2,603	5,896	6,172
3	3	3	3	3	3	4,851	2,030	1,600	2,872
3	3	3	3	3	3	4,269	2,028	3,504	3,267
3	3	3	3	3	3	5,076	3,784	1,400	3,420

Table 17. Phosphate-P concentration in the petioles (dry basis) at two sampling dates and the seasonal mean as affected by various combinations of levels of N, P, S, Cl, Na and Zn.

Treatment levels						August 5, %	September 16, %	Seasonal mean, %
N	P	S	Cl	Na	Zn			
2	2	2	2	2	2	0.20	0.14	0.17
4	2	2	2	4	2	0.21	0.10	0.16
2	4	2	2	4	2	0.20	0.15	0.18
4	4	2	2	2	2	0.21	0.22	0.22
2	2	4	2	2	4	0.19	0.12	0.16
4	2	4	2	4	4	0.19	0.08	0.14
2	4	4	2	4	4	0.22	0.11	0.17
4	4	4	2	2	4	0.23	0.17	0.20
2	2	2	4	2	4	0.21	0.09	0.15
4	2	2	4	4	4	0.19	0.13	0.16
2	4	2	4	4	4	0.18	0.19	0.19
4	4	2	4	2	4	0.24	0.10	0.17
2	2	4	4	2	2	0.19	0.11	0.15
4	2	4	4	4	2	0.19	0.13	0.16
2	4	4	4	4	2	0.23	0.17	0.20
4	4	4	4	2	2	0.22	0.13	0.18
2	2	2	2	4	4	0.21	0.16	0.19
4	2	2	2	2	4	0.17	0.17	0.17
2	4	2	2	2	4	0.22	0.18	0.20
4	4	2	2	4	4	0.25	0.17	0.21
2	2	4	2	4	2	0.19	0.13	0.16
4	2	4	2	2	2	0.21	0.13	0.17
2	4	4	2	2	2	0.21	0.23	0.22
4	4	4	2	4	2	0.23	0.15	0.19
2	2	2	4	4	2	0.21	0.14	0.18
4	2	2	4	2	2	0.22	0.16	0.19
2	4	2	4	2	2	0.20	0.19	0.20
4	4	2	4	4	2	0.30	0.20	0.25
2	2	4	4	4	4	0.15	0.15	0.15
4	2	4	4	2	4	0.15	0.16	0.16
2	4	4	4	2	4	0.19	0.22	0.21
4	4	4	4	4	4	0.19	0.23	0.21

Cont. p. 89.

Table 17 continued.

Treatment levels						August 5, %	September 16, %	Seasonal mean, %
N	P	S	Cl	Na	Zn			
5	3	3	3	3	3	0.21	0.12	0.17
1	3	3	3	3	3	0.20	0.16	0.18
3	5	3	3	3	3	0.23	0.21	0.22
3	1	3	3	3	3	0.18	0.13	0.16
3	3	5	3	3	3	0.20	0.19	0.19
3	3	1	3	3	3	0.17	0.13	0.15
3	3	3	5	3	3	0.22	0.08	0.15
3	3	3	1	3	3	0.24	0.16	0.20
3	3	3	3	5	3	0.25	0.18	0.22
3	3	3	3	1	3	0.17	0.14	0.16
3	3	3	3	3	5	0.20	0.11	0.16
3	3	3	3	3	1	0.21	0.22	0.22
3	3	3	3	3	3	0.20	0.17	0.19
3	3	3	3	3	3	0.21	0.19	0.20
3	3	3	3	3	3	0.20	0.19	0.20
3	3	3	3	3	3	0.20	0.15	0.18
3	3	3	3	3	3	0.25	0.21	0.23
3	3	3	3	3	3	0.21	0.14	0.18
3	3	3	3	3	3	0.20	0.21	0.21
3	3	3	3	3	3	0.21	0.19	0.20
3	3	3	3	3	3	0.15	0.12	0.14
3	3	3	3	3	3	0.20	0.09	0.14

Table 18. Sulfate-S concentration in the petioles (dry basis) at two sampling dates and the seasonal mean as affected by various combinations of levels of N, P, S, Cl, Na and Zn.

Treatment levels						August 5, %	September 16, %	Seasonal mean, %
N	P	S	Cl	Na	Zn			
2	2	2	2	2	2	0.10	0.07	0.09
4	2	2	2	4	2	0.13	0.10	0.12
2	4	2	2	4	2	0.11	0.08	0.10
4	4	2	2	2	2	0.11	0.11	0.11
2	2	4	2	2	4	0.14	0.10	0.12
4	2	4	2	4	4	0.16	0.13	0.15
2	4	4	2	4	4	0.16	0.12	0.14
4	4	4	2	2	4	0.16	0.19	0.18
2	2	2	4	2	4	0.10	0.09	0.10
4	2	2	4	4	4	0.10	0.07	0.09
2	4	2	4	4	4	0.10	0.06	0.08
4	4	2	4	2	4	0.11	0.06	0.09
2	2	4	4	2	2	0.11	0.10	0.11
4	2	4	4	4	2	0.20	0.12	0.16
2	4	4	4	4	2	0.15	0.11	0.13
4	4	4	4	2	2	0.16	0.12	0.14
2	2	2	2	4	4	0.12	0.08	0.10
4	2	2	2	2	4	0.07	0.06	0.07
2	4	2	2	2	4	0.09	0.09	0.09
4	4	2	2	4	4	0.10	0.07	0.09
2	2	4	2	4	2	0.10	0.13	0.12
4	2	4	2	2	2	0.11	0.10	0.11
2	4	4	2	2	2	0.13	0.10	0.12
4	4	4	2	4	2	0.15	0.12	0.14
2	2	2	4	4	2	0.08	0.10	0.09
4	2	2	4	2	2	0.10	0.10	0.10
2	4	2	4	2	2	0.13	0.13	0.13
4	4	2	4	4	2	0.15	0.08	0.12
2	2	4	4	4	4	0.13	0.12	0.13
4	2	4	4	2	4	0.11	0.11	0.11
2	4	4	4	2	4	0.13	0.11	0.12
4	4	4	4	4	4	0.15	0.12	0.14

Cont. p. 91.

Table 18 continued.

Treatment levels						August 5, %	September 16, %	Seasonal mean, %
N	P	S	Cl	Na	Zn			
5	3	3	3	3	3	0.09	0.14	0.12
1	3	3	3	3	3	0.11	0.06	0.09
3	5	3	3	3	3	0.07	0.07	0.07
3	1	3	3	3	3	0.08	0.13	0.11
3	3	5	3	3	3	0.24	0.15	0.20
3	3	1	3	3	3	0.10	0.08	0.09
3	3	3	5	3	3	0.12	0.06	0.09
3	3	3	1	3	3	0.10	0.10	0.10
3	3	3	3	5	3	0.10	0.15	0.13
3	3	3	3	1	3	0.06	0.06	0.06
3	3	3	3	3	5	0.10	0.09	0.10
3	3	3	3	3	1	0.09	0.06	0.08
3	3	3	3	3	3	0.08	0.08	0.08
3	3	3	3	3	3	0.12	0.07	0.10
3	3	3	3	3	3	0.11	0.06	0.09
3	3	3	3	3	3	0.09	0.10	0.10
3	3	3	3	3	3	0.12	0.13	0.13
3	3	3	3	3	3	0.12	0.11	0.12
3	3	3	3	3	3	0.10	0.12	0.11
3	3	3	3	3	3	0.11	0.09	0.10
3	3	3	3	3	3	0.13	0.08	0.11
3	3	3	3	3	3	0.11	0.14	0.13

Table 19. Chlorine 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, Cl, Na and Zn.

Treatment levels						June 17, %	August 5, %	September 16, %	Seasonal mean, %
N	P	S	Cl	Na	Zn				
2	2	2	2	2	2	1.23	3.10	3.72	2.68
4	2	2	2	4	2	1.85	1.24	3.10	2.06
2	4	2	2	4	2	2.27	2.68	3.10	2.68
4	4	2	2	2	2	2.27	1.45	1.24	1.65
2	2	4	2	2	4	2.68	3.30	4.13	3.37
4	2	4	2	4	4	2.07	2.07	3.51	2.55
2	4	4	2	4	4	2.67	3.91	3.31	3.30
4	4	4	2	2	4	2.07	1.65	3.06	2.26
2	2	2	4	2	4	1.86	2.27	3.31	2.48
4	2	2	4	4	4	2.69	2.89	3.10	2.89
2	4	2	4	4	4	2.89	3.72	3.30	3.30
4	4	2	4	2	4	1.86	1.86	2.27	2.06
2	2	4	4	2	2	4.14	2.27	3.10	3.17
4	2	4	4	4	2	2.89	1.65	3.30	2.61
2	4	4	4	4	2	2.89	2.27	3.10	2.75
4	4	4	4	2	2	3.10	2.27	2.90	2.76
2	2	2	2	4	4	3.31	2.27	3.10	2.89
4	2	2	2	2	4	2.07	2.07	2.27	2.14
2	4	2	2	2	4	3.93	2.48	3.31	3.24
4	4	2	2	4	4	4.69	1.99	2.69	3.12
2	2	4	2	4	2	2.07	2.07	3.31	2.48
4	2	4	2	2	2	4.05	2.27	2.07	2.80
2	4	4	2	2	2	1.86	1.87	3.51	2.41
4	4	4	2	4	2	1.86	1.45	2.89	2.07
2	2	2	4	4	2	3.31	2.68	3.31	3.10
4	2	2	4	2	2	2.89	1.48	2.27	2.21
2	4	2	4	2	2	3.72	2.07	2.68	2.82
4	4	2	4	4	2	3.72	2.68	2.07	2.82
2	2	4	4	4	4	3.72	1.65	3.92	3.30
4	2	4	4	2	4	3.31	2.90	3.31	3.17
2	4	4	4	2	4	3.72	3.10	3.31	3.48
4	4	4	4	4	4	3.51	3.10	2.89	3.13

Cont. p. 93.

Table 19 continued.

Treatment levels						June 17, %	August 5, %	September 16, %	Seasonal mean, %
N	P	S	Cl	Na	Zn				
5	3	3	3	3	3	2.27	2.27	3.72	2.72
1	3	3	3	3	3	3.10	2.48	3.30	2.96
3	5	3	3	3	3	2.89	1.65	2.89	2.48
3	1	3	3	3	3	3.10	3.10	4.14	3.24
3	3	5	3	3	3	3.10	2.07	3.31	2.83
3	3	1	3	3	3	2.69	1.65	2.68	2.34
3	3	3	5	3	3	4.55	2.89	4.55	4.00
3	3	3	1	3	3	2.48	2.69	2.89	2.69
3	3	3	3	5	3	3.10	3.93	3.31	3.45
3	3	3	3	1	3	3.30	1.65	3.10	2.68
3	3	3	3	3	5	2.48	2.27	3.34	2.70
3	3	3	3	3	1	3.31	2.89	2.27	2.82
3	3	3	3	3	3	2.27	1.65	3.51	2.48
3	3	3	3	3	3	2.48	1.86	2.07	2.14
3	3	3	3	3	3	3.31	2.27	1.65	2.41
3	3	3	3	3	3	2.89	2.27	3.10	2.75
3	3	3	3	3	3	2.69	2.27	3.71	2.89
3	3	3	3	3	3	2.69	3.10	2.48	2.76
3	3	3	3	3	3	2.27	2.69	2.07	2.34
3	3	3	3	3	3	3.10	1.65	3.10	2.62
3	3	3	3	3	3	2.07	1.44	3.31	2.27
3	3	3	3	3	3	3.31	2.49	4.34	3.38

Table 20. Potassium 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, Cl, Na and Zn.

Treatment levels						June 17, %	August 5, %	September 16, %	Seasonal mean, %
N	P	S	Cl	Na	Zn				
2	2	2	2	2	2	3.30	2.43	3.55	3.09
4	2	2	2	4	2	2.68	2.55	2.42	2.55
2	4	2	2	4	2	2.63	2.67	2.75	2.68
4	4	2	2	2	2	4.85	2.55	2.95	3.45
2	2	4	2	2	4	3.75	3.20	3.10	3.35
4	2	4	2	4	4	3.35	2.03	2.80	2.73
2	4	4	2	4	4	3.20	5.15	2.80	3.72
4	4	4	2	2	4	3.30	2.42	2.85	2.86
2	2	2	4	2	4	2.95	2.75	4.30	3.33
4	2	2	4	4	4	3.10	2.43	3.00	2.84
2	4	2	4	4	4	3.35	2.55	3.30	3.07
4	4	2	4	2	4	4.60	3.33	2.90	3.61
2	2	4	4	2	2	3.95	2.80	3.38	3.38
4	2	4	4	4	2	3.63	2.75	3.20	3.19
2	4	4	4	4	2	3.90	2.50	3.85	3.42
4	4	4	4	2	2	4.10	2.55	3.10	3.25
2	2	2	2	4	4	4.55	3.30	2.67	3.51
4	2	2	2	2	4	3.38	2.78	2.53	2.90
2	4	2	2	2	4	3.10	2.90	2.63	2.88
4	4	2	2	4	4	3.10	1.98	2.98	2.69
2	2	4	2	4	2	3.63	3.25	3.00	3.29
4	2	4	2	2	2	6.15	3.60	2.85	4.20
2	4	4	2	2	2	4.33	2.41	3.90	3.55
4	4	4	2	4	2	3.70	2.63	3.30	3.21
2	2	2	4	4	2	4.45	3.37	2.15	3.32
4	2	2	4	2	2	3.63	2.68	2.80	3.04
2	4	2	4	2	2	3.75	3.05	3.55	3.45
4	4	2	4	4	2	5.10	2.75	2.95	3.60
2	2	4	4	4	4	3.70	2.90	4.05	3.55
4	2	4	4	2	4	4.45	3.20	3.20	3.62
2	4	4	4	2	4	5.10	3.05	3.38	3.84
4	4	4	4	4	4	3.90	3.35	2.98	3.41

Cont. p. 95.

Table 20 continued.

Treatment levels						June 17, %	August 5, %	September 16, %	Seasonal mean, %
N	P	S	Cl	Na	Zn				
5	3	3	3	3	3	3.62	1.60	3.75	2.99
1	3	3	3	3	3	3.75	3.01	3.85	3.54
3	5	3	3	3	3	3.95	2.77	2.95	3.22
3	1	3	3	3	3	3.38	4.25	3.25	3.63
3	3	5	3	3	3	4.05	3.35	2.60	3.33
3	3	1	3	3	3	3.30	2.63	2.55	2.83
3	3	3	5	3	3	4.00	2.68	3.05	3.24
3	3	3	1	3	3	3.58	2.55	3.05	3.06
3	3	3	3	5	3	3.55	2.90	3.80	3.42
3	3	3	3	1	3	3.90	2.43	4.05	3.46
3	3	3	3	3	5	3.37	2.68	3.40	3.15
3	3	3	3	3	1	4.25	2.60	3.10	3.32
3	3	3	3	3	3	2.50	3.00	2.63	2.71
3	3	3	3	3	3	3.63	2.90	3.55	3.36
3	3	3	3	3	3	3.75	2.50	3.10	3.12
3	3	3	3	3	3	3.05	3.00	2.80	2.95
3	3	3	3	3	3	3.63	2.80	2.62	3.02
3	3	3	3	3	3	3.20	2.75	2.75	2.90
3	3	3	3	3	3	3.85	3.00	2.78	3.21
3	3	3	3	3	3	3.35	2.63	2.67	2.88
3	3	3	3	3	3	3.55	2.25	2.80	2.87
3	3	3	3	3	3	3.75	3.06	2.53	3.11

Table 21. Sodium 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, Cl, Na and Zn.

Treatment levels						June 17, %	August 5, %	September 16, %	Seasonal mean, %
N	P	S	Cl	Na	Zn				
2	2	2	2	2	2	0.75	0.85	0.73	0.78
4	2	2	2	4	2	0.95	0.46	1.37	0.93
2	4	2	2	4	2	1.00	1.22	1.18	1.13
4	4	2	2	2	2	1.77	0.55	0.30	0.87
2	2	4	2	2	4	0.92	0.72	1.05	0.90
4	2	4	2	4	4	2.05	0.80	1.48	1.44
2	4	4	2	4	4	0.85	1.28	1.10	1.08
4	4	4	2	2	4	1.55	1.05	0.75	1.12
2	2	2	4	2	4	0.80	0.95	0.70	0.82
4	2	2	4	4	4	1.95	0.90	0.35	1.07
2	4	2	4	4	4	1.05	0.88	1.02	0.98
4	4	2	4	2	4	1.70	1.20	0.90	1.27
2	2	4	4	2	2	0.83	0.48	0.75	0.69
4	2	4	4	4	2	1.65	0.57	0.97	1.06
2	4	4	4	4	2	0.85	0.80	0.83	0.83
4	4	4	4	2	2	1.35	0.35	1.28	0.99
2	2	2	2	4	4	1.63	1.10	0.92	1.22
4	2	2	2	2	4	2.65	0.85	0.80	1.43
2	4	2	2	2	4	0.75	0.93	0.63	0.77
4	4	2	2	4	4	1.33	0.93	0.95	0.96
2	2	4	2	4	2	0.98	0.83	0.78	0.86
4	2	4	2	2	2	3.58	0.68	0.73	1.66
2	4	4	2	2	2	0.60	0.95	0.65	0.73
4	4	4	2	4	2	1.78	0.90	0.65	1.11
2	2	2	4	4	2	1.15	0.75	1.18	1.03
4	2	2	4	2	2	1.70	0.73	0.92	1.12
2	4	2	4	2	2	1.00	0.95	0.62	0.86
4	4	2	4	4	2	2.13	1.00	0.83	1.32
2	2	4	4	4	4	1.78	0.92	1.12	1.27
4	2	4	4	2	4	1.90	0.73	1.08	1.24
2	4	4	4	2	4	1.30	0.98	0.75	1.01
4	4	4	4	4	4	2.53	1.08	0.78	1.46

Cont. p. 97.

Table 21 continued.

Treatment levels						June 17, %	August 5, %	September 16, %	Seasonal mean, %
N	P	S	Cl	Na	Zn				
5	3	3	3	3	3	1.07	0.93	1.15	1.05
1	3	3	3	3	3	0.55	0.73	1.02	0.77
3	5	3	3	3	3	1.35	0.68	1.10	1.04
3	1	3	3	3	3	1.00	0.93	1.00	0.98
3	3	5	3	3	3	1.70	1.10	1.00	1.27
3	3	1	3	3	3	1.33	0.80	0.92	1.02
3	3	3	5	3	3	1.78	0.63	1.78	1.40
3	3	3	1	3	3	1.35	0.80	1.05	1.07
3	3	3	3	5	3	2.78	1.10	1.78	1.89
3	3	3	3	1	3	0.83	0.93	0.73	0.83
3	3	3	3	3	5	0.83	0.68	1.18	0.90
3	3	3	3	3	1	1.76	1.32	0.72	1.27
3	3	3	3	3	3	1.20	0.95	1.10	1.08
3	3	3	3	3	3	0.85	0.60	0.75	0.73
3	3	3	3	3	3	1.63	0.93	0.73	1.10
3	3	3	3	3	3	0.78	1.05	0.68	0.84
3	3	3	3	3	3	1.95	1.00	1.22	1.39
3	3	3	3	3	3	1.33	1.15	0.75	1.08
3	3	3	3	3	3	2.25	0.60	1.15	1.33
3	3	3	3	3	3	1.28	0.88	0.67	0.94
3	3	3	3	3	3	1.28	0.97	0.70	0.98
3	3	3	3	3	3	2.43	0.80	1.75	1.66

Table 22. Analysis of variance for nitrate-N and Cl concentrations in the petioles (dry basis) at three sampling dates as affected by various combinations of levels of N, P, S, Cl, Na and Zn.

Source	Nitrate-N, log.of ppm.			Cl, %		
	June 17,	Aug.5,	Sept.16,	June 17,	Aug.5,	Sept.16
d.f.						
Total	53	53	53	53	53	53
Block	2	2	2	2	2	2
First order	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	5.1051	2.3555	3.3585	28.6996	21.9538	22.3217
Block	0.0917	0.1499	0.0016	3.9331	0.0803	1.8432
First order	3.0860	1.0123	0.9731	5.3009	4.4808	7.3086
Quadratic	1.1590	0.7799	1.0405	13.0197	7.6471	3.2696
Lack of fit	0.5961	0.3062	0.7786	4.6967	7.7567	5.5627
Error	0.1723	0.1072	0.5646	1.7492	1.9890	4.3377
M.S.						
Block	0.0459	0.0750	0.00082	1.9665	0.0401	0.9216
First order	0.5143[xx]	0.1687[xx]	0.16219	0.8835	0.7468	1.2181
Quadratic	0.0552	0.0371	0.04955	0.6199	0.3642	0.1557
Lack of fit	0.0351	0.0180	0.04580	0.2763	0.4563	0.3272
Error	0.0246	0.0153	0.08066	0.2499	0.2841	0.6197
C.V., %	4.3	3.6	8.1	18.5	24.6	26.8
Equation[+] sufficiency, %	87.7	85.4	72.1	79.6	64.2	65.4

[xx] Statistically significant at the 1 percent level.

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

Table 23. Analysis of variance for phosphate-P and sulfate-S concentrations in the petioles (dry basis) at two sampling dates as affected by various combinations of levels of N, P, S, Cl, Na and Zn.

Source	Phosphate-P, %		Sulfate-S, %	
	August 5,	September 16,	August 5,	September 16,
d.f.				
Total	53	53	53	53
Block	2	2	2	2
First order	6	6	6	6
Quadratic	21	21	21	21
Lack of fit	17	17	17	17
Error	7	7	7	7
S.S.				
Total	0.03892	0.08572	0.06440	0.04390
Block	0.00036	0.01401	0.00199	0.00051
First order	0.01315	0.02070	0.02217	0.01508
Quadratic	0.01193	0.01872	0.01659	0.01141
Lack of fit	0.01027	0.02670	0.01498	0.01407
Error	0.00321	0.00559	0.00866	0.00282
M.S.				
Block	0.00018	0.00701	0.00100	0.00025
First order	0.00219[x]	0.00345[x]	0.00370	0.00251[x]
Quadratic	0.00057	0.00089	0.00079	0.00054
Lack of fit	0.00060	0.00157	0.00088	0.00083
Error	0.00046	0.00080	0.00124	0.00040
C.V., %	10.6	17.1	29.4	20.6
Equation[+] sufficiency, %	71.0	59.6	72.1	65.3

[x] Statistically significant at the 5 percent level.

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

Table 24. Analysis of variance for K and Na concentrations in the petioles (dry basis) at three sampling dates as affected by various combinations of levels of N, P, S, Cl, Na and Zn.

Source	K, %			Na, %		
	June 17,	Aug.5,	Sept. 16,	June 17,	Aug.5,	Sept.16
d.f.						
Total	53	53	53	53	53	53
Block	2	2	2	2	2	2
First order	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	23.3078	14.9765	11.5855	20.4512	2.2729	5.0541
Block	2.7486	0.2232	0.3805	2.0838	0.0508	0.6882
First order	5.2595	2.7559	2.0818	6.6853	0.3357	0.9098
Quadratic	7.1435	5.8139	6.2999	4.0655	0.5145	1.2335
Lack of fit	6.8889	5.6142	2.2830	5.8222	1.0800	1.3293
Error	1.2674	0.5694	0.5404	1.7944	0.2918	0.8934
M.S.						
Block	1.3743	0.1116	0.1903	1.0419	0.0254	0.3441
First order	0.8766^{x}	0.4593^{x}	0.3470^{x}	1.1142^{xx}	0.0560	0.1516
Quadratic	0.3402	0.2769^{x}	0.3000^{xx}	0.1936	0.0245	0.0587
Lack of fit	0.4052	0.3303^{xx}	0.1343	0.3425	0.0635	0.0782
Error	0.1811	0.0813	0.0772	0.2563	0.0417	0.1276
C.V., %	12.4	10.3	9.8	33.8	22.9	37.6
Equation^{+} sufficiency,%	63.4	60.6	78.5	65.1	46.4	61.7

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^{x} Statistically significant at the 5 percent level.

^{xx} Statistically significant at the 1 percent level.

$^{+}$ Percentage of total treatment sum of squares accounted for by the quadratic regression equation.

Table 25. Analysis of variance for nitrate-N, phosphate-P, sulfate-S, Cl, K and Na (seasonal means) concentrations in the petioles (dry basis) as affected by various combinations of levels of N, P, S, Cl, Na and Zn.

Source	Nitrate-N, log of ppm.	Phosphate-P, %	Sulfate-S, %	Cl, %	K, %	Na, %
d.f.						
Total	53	53	53	53	53	53
Block	2	2	2	2	2	2
First order	6	6	6	6	6	6
Quadratic	21	21	21	21	21	21
Lack of fit	17	17	17	17	17	17
Error	7	7	7	7	7	7
S.S.						
Total	2.3957	0.06663	0.03549	31.9188	34.7051	7.6933
Block	0.0040	0.00643	0.00064	0.6525	1.1296	0.0537
First order	1.5587	0.02142	0.01754	2.4634	0.8762	0.4231
Quadratic	0.4624	0.01891	0.00985	9.7455	13.8278	2.5488
Lack of fit	0.2842	0.01772	0.00689	12.5431	12.2376	2.5600
Error	0.0865	0.00220	0.00058	6.5144	6.6339	2.1077
M.S.						
Block	0.0020	0.00321	0.000320	0.3263	0.5648	0.0269
First order	0.2598^{xx}	0.00357^{xx}	0.002924^{xx}	0.4106	0.1460	0.0705
Quadratic	0.0220	0.00090^{x}	0.000470^{xx}	0.4641	0.6585	0.1213
Lack of fit	0.0167	0.00104^{x}	0.000410^{xx}	0.7378	0.7197	0.1506
Error	0.0124	0.00031	0.000083	0.9306	0.9477	0.3011
C.V., %	68.3	42.9	47.1	50.8	46.5	74.4
Equation^{+} sufficiency, %	77.8	36.1	55.6	50.0	54.7	53.6

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[x] Statistically significant at the 5 percent level.

[xx] Statistically significant at the 1 percent level.

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

Table 26. Total P, S, K, Na and Mg concentrations in the leaf blades (dry basis) of the second sampling as affected by various combinations of levels of N, P, S, Cl, Na and Zn.

Treatment levels						Total P,	Total S,	Total K,	Total Na,	Total Mg,
N	P	S	Cl	Na	Zn	%	%	%	%	%
2	2	2	2	2	2	0.28	1.04	4.75	1.19	0.30
4	2	2	2	4	2	0.39	1.27	4.65	1.34	0.17
2	4	2	2	4	2	0.38	1.03	4.14	1.64	0.18
4	4	2	2	2	2	0.42	1.15	3.10	1.34	0.17
2	2	4	2	2	4	0.23	1.12	5.84	1.41	0.33
4	2	4	2	4	4	0.34	1.34	4.47	1.82	0.19
2	4	4	2	4	4	0.26	1.10	4.16	1.70	0.55
4	4	4	2	2	4	0.48	1.27	4.00	1.28	0.20
2	2	2	4	2	4	0.26	1.17	5.31	1.25	1.00
4	2	2	4	4	4	0.26	1.11	4.16	1.24	0.52
2	4	2	4	4	4	0.31	1.06	4.43	1.14	0.33
4	4	2	4	2	4	0.41	0.87	4.36	1.38	0.17
2	2	4	4	2	2	0.31	1.00	3.88	1.27	0.18
4	2	4	4	4	2	0.30	1.12	3.79	1.35	0.30
2	4	4	4	4	2	0.47	1.10	4.52	1.38	0.32
4	4	4	4	2	2	0.34	1.08	3.96	1.12	0.49
2	2	2	2	4	4	0.33	1.23	3.43	1.57	0.99
4	2	2	2	2	4	0.32	1.05	4.14	1.12	0.85
2	4	2	2	2	4	0.36	1.15	4.48	1.30	0.17
4	4	2	2	4	4	0.35	0.93	4.06	1.26	0.24
2	2	4	2	4	2	0.31	1.14	4.46	1.44	0.20
4	2	4	2	2	2	0.34	1.52	4.68	1.31	0.32
2	4	4	2	2	2	0.38	1.16	4.79	0.89	0.23
4	4	4	2	4	2	0.30	0.94	3.75	1.45	0.37
2	2	2	4	4	2	0.29	0.87	4.38	1.90	0.30
4	2	2	4	2	2	0.33	1.22	4.60	1.12	0.22
2	4	2	4	2	2	0.41	0.94	5.05	1.20	0.30
4	4	2	4	4	2	0.44	1.36	3.19	1.67	0.19
2	2	4	4	4	4	0.24	1.40	4.95	2.16	0.84
4	2	4	4	2	4	0.35	1.45	5.06	1.36	0.50
2	4	4	4	2	4	0.36	1.50	4.02	2.31	0.20
4	4	4	4	4	4	0.36	0.86	4.01	1.36	0.69

Cont. p. 103.

Table 26 continued.

Treatment levels						Total P,	Total S,	Total K,	Total Na,	Total Mg,
N	P	S	Cl	Na	Zn	%	%	%	%	%
5	3	3	3	3	3	0.37	1.22	3.95	1.30	0.50
1	3	3	3	3	3	0.30	1.18	5.28	1.01	0.28
3	5	3	3	3	3	0.32	1.22	3.34	0.99	0.44
3	1	3	3	3	3	0.37	1.31	4.59	1.96	0.22
3	3	5	3	3	3	0.40	1.16	4.16	1.47	0.23
3	3	1	3	3	3	0.47	1.15	4.03	1.08	0.27
3	3	3	5	3	3	0.42	1.07	3.62	2.02	0.17
3	3	3	1	3	3	0.38	1.12	3.93	1.20	0.19
3	3	3	3	5	3	0.35	1.10	4.27	1.59	0.60
3	3	3	3	1	3	0.32	1.62	5.48	1.40	0.23
3	3	3	3	3	5	0.34	1.36	5.46	1.01	0.31
3	3	3	3	3	1	0.36	1.09	3.90	1.78	0.42
3	3	3	3	3	3	0.38	1.54	5.36	1.83	0.24
3	3	3	3	3	3	0.43	1.08	4.05	1.26	0.20
3	3	3	3	3	3	0.29	0.96	3.53	1.23	0.45
3	3	3	3	3	3	0.38	1.04	4.31	1.24	0.20
3	3	3	3	3	3	0.34	1.01	4.22	1.53	0.55
3	3	3	3	3	3	0.46	0.99	3.38	1.12	0.19
3	3	3	3	3	3	0.33	1.17	4.65	1.11	0.39
3	3	3	3	3	3	0.31	1.04	4.73	1.19	0.78
3	3	3	3	3	3	0.25	1.11	4.53	0.96	0.59
3	3	3	3	3	3	0.36	1.00	3.65	1.35	0.58

Table 27. Analysis of variance for total S, P, K, Na, and Mg (second sampling) concentrations in the leaf blades (dry basis) as affected by various combinations of levels of N, P, S, Cl, Na and Zn.

Source	Total P, %	Total S, %	Total K, %	Total Na, %	Total Mg, %
d.f.					
Total	53	53	53	53	53
Block	2	2	2	2	2
First order	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	1.5800	0.3068	19.6775	5.0445	2.5292
Block	0.0423	0.0056	0.0182	0.0298	0.1045
First order	0.2887	0.0587	7.1155	1.0130	0.4220
Quadratic	0.5680	0.1074	4.4626	1.6165	1.0450
Lack of fit	0.4544	0.1047	4.7608	1.9330	0.7237
Error	0.2265	0.0305	3.3204	0.4522	0.2341
M.S.					
Block	0.0212	0.0028	0.0091	0.0149	0.0522
First order	0.0481	0.0098	1.1859	0.1688	0.0703
Quadratic	0.0271	0.0051	0.2125	0.0770	0.0498
Lack of fit	0.0267	0.0062	0.2801	0.1137	0.0426
Error	0.0324	0.0044	0.4745	0.0646	0.0334
C.V., %	16.5	18.8	16.2	19.8	43.9
Equation[+] sufficiency, %	64.3	60.7	83.1	91.0	68.2

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