INTERRELATIONSHIPS OF PHOSPHORUS, SULFUR, ZINC, BORON AND PLANT POPULATION ON THE YIELD AND LEAF COMPOSITION OF CORN

By

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CORN NUTRITION

AHMAD

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AN ABSTRACT OF THE THESIS OF

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Title: Interrelationships of phosphorus, sulfur, zinc, boron, and plant population on the yield and leaf composition of corn.

A study was conducted in two separate but adjacent field experiments in the Beka'a Plain of Lebanon, in 1965, to explore the interrelationships of P, S, Zn, B and plant population (each varied at five levels) on the yield and leaf composition of corn. A rotatable, central composite, incomplete factorial design was used.

The yields of grain obtained in these experiments were generally high with average values of 12.34 and 11.91 metric tons per hectare in experiments "A" and "B" respectively indicating a considerable potentiality of the area for corn production. The application of P generally increased the grain yield at a low plant population level and high Zn level but decreased it at low levels of plant population and applied Zn. However, the P-Zn interaction tended to disappear at a high plant population level. The Zn-B-population interaction was positive and probably real indicating that grain yields may be enhanced by increasing plant population provided high rates of Zn and B are applied. Stover yields were significantly increased by plant population in experiment "A", however the level of soil Zn tended to influence the effect of population. The S-Zn-B interaction for stover yield was negative showing that the S-B interaction was reversed at low and high levels of Zn.

Leaf composition was significantly affected by various first order and interaction terms. The Phosphate-P concentration of the midribs appears to be a better indicator than that of the leaf blades for the P status of corn plants. The comparison of the sulfate-S concentrations in leaf blades and midribs for the purpose of reflecting the S status of corn plants was inconclusive although both were effective. The total B concentration of the leaf blade was a probable more sensitive test than that of the leaf midrib to determine the B supply to corn plants. Since the corn yields were not much influenced as compared to significant effects on the concentration of the nutrients in leaves no definite "critical levels" could be suggested in these plant parts. Additional work is needed under more controlled conditions.

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I. INTRODUCTION

Corn (Zea mays L.) has been shown to be a very promising crop in the Middle East having a considerable potential as an efficient source of food and feed. Exploratory fertilizer trials by researchers at the American University of Beirut have indicated possible yields of about 15 metric tons per hectare of grain.

A good corn crop has heavy requirements for all the nutrients in their proper proportions. At the same time the soils of the Middle East are generally calcareous and are apt to have low availability of nutrients such as N, P, Zn, and B and responses to N and P have been reported in many studies. Corn has been found to be sensitive to Zn deficiencies which are intensified at high plant populations. Also barrenness of corn at higher planting rates has been related to both B deficiency and excessive population pressure. Increase in corn yields by increasing plant population above 40,000 to 60,000 plants per hectare has been reported in the area provided high rates of Zn and B are applied.

Two irrigated field experiments were conducted at the Agricultural Research and Education Center (AREC) of the American University of Beirut, located in the

Beka'a, Lebanon. The study included four variables, P, Zn, B, and plant population for experiment "A" and four variables, S, Zn, B, and plant population, for experiment "B". A central composite, rotatable, incomplete factorial design was used to study the four variables simultaneously with each at five levels.

The purpose of these experiments was to study the direct effects and the interactions of applied P, S, Zn, and B and plant population on the yield and leaf composition of corn and to investigate the determination of "critical levels" of nutrients in plant tissues such as midribs and leaf blades.

II. REVIEW OF LITERATURE

Because of the great interest in enhancing corn yields, intensive work has been conducted on economic nutrient requirements and optimum planting rates for this crop. The studies on the mineral nutrition of corn in relation to P, S, Zn and B and investigations in plant population have been reviewed with special emphasis on the most recently reported investigations.

Effect of Phosphorus

Response of corn to P varies with soil P content, season and levels of other nutrients in soil. Viets et al. (1954) observed no significant response of corn plants to P application but they found a high positive correlation between total P content of leaves at silking and the yield of corn. Baird (1959) also reported that yield response of corn to P was negligible. Hutton et al. (1956) pointed out that P gave the greatest yield response at the beginning but with the advancement of season the P requirements for maximum yields were decreased.

Raheja et al. (1957) obtained a yield response of 1.53-3.45 pounds of grain per pound of P_2O_5 applied within the range of 40-120 pounds per acre P_2O_5. Reichman *et al*. (1959) observed a decrease of 10 bushels in grain yield and 1090 pounds in forage yield per acre when only P was applied. But, with 80 pounds of N, P additions enhanced yields of both grain and forage. Fulton and Findley (1960) found that grain yield of corn increased with increasing P application on a clay soil. Hubner (1962) reported that application of up to 120 kg P_2O_5 increased fresh weight of corn plants, dry weight of cobs, and starch and invert-sugar contents in the dry matter. Olson *et al*. (1962) pointed out that corn plants responded to applied P in the early stage of growth. They also found that P application to soils containing less than 15 ppm of native P (determined by the Bray number 1 method) increased the corn yield, while P application to soils having more than 15 ppm of native P reduced the yield. Knoll *et al*. (1964) noted an increase in growth, P content, and P uptake in corn plants as a result of increased supply of P in the soil.

Burleson *et al*. (1961) reported that P fertilization caused a reduction in corn yield which was attributed to Zn-deficiency. Soltanpour (1963) in his experiment on corn nutrition on a calcareous clay soil in the Beka'a, North Lebanon, got an increase in grain yield by application of P at low levels of Zn, but at high levels of applied Zn, grain yield decreased with increasing levels of applied P. A mutual antagonism between P and Zn in their uptake and accumulation by corn plants has been reported by many workers (Bingham and Garber, 1960; Ellis _et_ _al_., 1964; Watanabe _et_ _al_., 1965). They have proposed different explanations for the P-Zn antagonisms but definite proposals need considerable more investigation.

Tyner (1946) found highly significant correlation and regression coefficients for relation of yield of corn to percentage of P in the sixth leaf of the plant at the bloom stage. He observed that 0.295 percent P in the sixth leaf was a tentative critical value for P concentration of corn plant. Soofi (1961) in his experiment on corn nutrition on calcareous clay soil, found a significant increase in P concentration of corn leaves as a result of P application. Generally P concentration in the sixth leaf at tasseling, associated with the highest yields, was about 0.25 percent. Findley and Fulton (1964) pointed out that P application increased the P content of corn leaves on the P-deficient Brookston soil but not on the P-rich Brady soil. They obtained no estimate of a critical value of P throughout a wide range of corn yields and associated P percentages. According to Dumenil (1961):

> The critical N or P level is not a point nor narrow range of values but includes a wide range of values depending on how it is defined and on the level of the other nutrients in the leaf.

In his study the N-P nutrient balance was critical only at or near the maximum yield. Gordon et al. (1950), in a fertilizer-spacing experiment with corn, reported that P accumulated in the whole plant throughout the season with the most rapid accumulation occurring at silking time.

Effect of Sulfur

Occurrence of S deficiency in corn is becoming more frequent and extensive, but response to S fertilization varies with soil and other environmental factors. Volk et al. (1945) in their greenhouse studies with fine sand, found large increases in corn yields as a result of S fertilization. Harris et al. (1954), according to Beaton (1966), pointed out that yield of corn was decreased when S application was omitted. McClung et al. (1959) studied the growth response of common pearl millet grown in pot culture to applied S on soils of the central plateau of Brazil. In most soils they used, the maximum dry matter was produced when 20 pounds of S as $CaSO_4$ per 2 million pounds of soil were added. Mikkelsen et al. (1963), mentioned by Beaton (1966), reported that S fertilization accounted for a 23 percent increase in corn yield at Pirassununga and a 28 percent increase at Orlandia, Brazil.

Thomas (1959) reported that the yield and percentage protein content of corn was not affected by applied S. This is in agreement with results of an experiment conducted by Cressman and Davis (1962). Soofi (1961) noted a slight effect of applied S on the grain yield of corn but he found a significant increase in S concentration of corn leaves as a result of S application. High dry forage yield was observed to be associated with an S concentration of corn leaves of about 0.2 percent. Soltanpour (1963) reported that with a high level of P, the grain yield of corn was depressed by addition of high levels of S. On the contrary, application of high levels of S to soil increased the stover yield, especially at low levels of P.

Effect of Zinc

Carlson *et al*. (1961) reported that Zn is the micronutrient element most likely to be deficient for corn especially when top soil has been removed during leveling. Zn application increased grain yield more than forage yields under the conditions of their experiment.

Nearpass (1956) found a logarithmic relationship between Zn concentration in substrate and Zn concentration in the aerial portion of plants grown in ion exchange resin-sand-nutrient cultures. Scharrer and Jung (1958), working with culture solutions, discovered that maize seedlings showed reduced growth, shortened internodes, chlorophyll deficiencies and pigmentation changes in the absence of Zn. They got a linear increase in the Zn concentration in the plant with increasing Zn concentration in the culture solution. Hiatt and Massey (1958) found that corn plants, grown in culture solution with no Zn added, showed very severe deficiency symptoms and contained 18 ppm Zn. Plants in solution with 0.05 ppm added Zn showed mild deficiency symptoms and contained 9 ppm Zn. Plants grown in solution containing 0.14 ppm Zn were apparently normal and contained 16 ppm Zn. They observed a similar relationship in field-grown corn. Thus severe Zn deficiency resulted in higher plant Zn concentration than for nondeficient plants.

Brown _et_ _al_. (1962) observed a response of sweet corn to Zn application on soils containing 0.55 ppm or less dithizone extractable Zn. In general, increasing rates of applied Zn resulted in increased Zn concentration in plants and total uptake by plants. Soltanpour (1963) noted that the grain yield response to Zn application was slight but increasing Zn supply enhanced the Zn concentration in the corn leaves. Fuehring and Soofi (1964), in their experiment with corn grown on a calcareous soil in Lebanon, found that the grain yield was depressed by Zn application, but stover yield was considerably enhanced at all levels of applied Zn. Ellis et al. (1964), in a field experiment on a calcareous Wisner clay loam soil, found that yield of corn was increased from 7504 up to 8680 pounds per acre by an application of 4 pounds of Zn per acre. Ten pounds of applied Zn per acre increased the Zn concentration in the corn tops but no significant increase in corn yield was observed. They further observed that heavy application of P induced Zn deficiency. Their data supported the conclusion that the Zn-P interaction is either at the root surface or within the plant.

Burleson et al. (1961) reported that P fertilization may induce Zn deficiency in corn under certain soil and climatic conditions. Langin et al. (1962) pointed out that Zn concentrations in corn were markedly reduced by modest row applications or heavier mixed application of readily available P fertilizer. Data obtained by Boawn and Leggett (1964) contained evidence for an antagonistic interaction between P and Zn concerning their absorption and accumulation in Russet Burbank potato plants. They found a significant decrease in P concentration and total P uptake as the Zn concentration in the nutrient solution was increased from 0.00625 up to 0.025 ppm.

Viets et al. (1953), in their study of Zn deficiency in corn grown on newly irrigated soils in Central Washington, observed that Zn uptake by corn plants was not reduced by P application. Boawn et al. (1954) also did not observe any Zn deficiency symptoms as a result of P fertilization. However, Bingham et al. (1958) later showed that this was probably due to Zn contamination in the P fertilizer used.

Effect of Boron

Scripture and McHargue (1943) reported that B-deficient alfalfa plants had larger proportions of soluble nitrogen compounds and excess sugars as compared with normal plants. They suggested the possibility of B being involved in protein metabolism. Parks et al. (1944) working with tomatoes grown in sand culture, discovered that the concentration of B in leaflet material was significantly increased with increasing B supply to the plants. They observed a toxic effect on the growth of plants grown in sand culture with excess B supply. Berger and Truog (1949) found a highly significant negative partial correlation between pH and available B in alkaline soils, indicating that the high pH of calcareous (alkaline) soils decreased the B availability to plants.

McIlrath and De Bruyn (1956) working with Siberian millet, reported that both soluble and total B contents of plants increased with the B supply, especially at higher B levels and decreased with increasing Ca supply. Berger et al. (1957), based on the results of their greenhouse and field experiments with corn, reported that B deficiency resulted in blank stalks and barren ears. Further they pointed out that the supply of available B to the corn plants must be continuous. The critical level of B in the upper leaves of corn plant suggested by them was 11 to 13 ppm. Bingham et al. (1958) reported that B availability to citrus plants was reduced by excessive quantities of $Ca(H_2PO_4)_2$applied to soil.

McIlrath et al. (1960) studied the effect of various levels of B ranging from 0 to 200 ppm in the nutrient solution on the uptake of B by setaria plants. They found no significant difference in total dry weight and ash composition among plants grown at non-toxic levels of B. At highly toxic levels the dry weight was reduced while percent ash content was enhanced. Increased B supply resulted in high concentration of B in setaria shoots. Soofi (1961) in his experiment with corn on a calcareous soil found a decrease in grain yield as a result of B application. Application of B increased the B concentration of corn leaves ranging from 10-100 ppm B between the low and high B application levels. The yield of dry forage was the highest at about 30 ppm B. Fuehring (1966) in his study on interaction of Zn and B with plant population found that the B-population interaction was positive and of considerable magnitude, although non-significant at the 5 percent level of probablity. He concluded that this interaction was probably real, and B and plant population levels must be kept in balance and increased simultaneously for maximum yield provided other factors are favorable. Parkash and Subbiah (1965), working with rough lemon seedlings grown in solution cultures, noted that in B-toxic cultures, absorption and accumulation of P^{32} were hampered.

Effect of Plant Population

Kohnke and Miles (1951), using some of the richest land of Indiana, found that the highest yields of corn occurred in the range between 15,000 and 19,000 plants per acre. They observed a consistent decrease in ear weight and suckering with increasing plant population but the percentage of lodged plants increased up to a stand of 20,000 plants per acre. Lang *et al*.

(1956), Pendleton and Seif (1961), and Stickler (1964) reported that increasing plant population above about 20,000 plants per acre resulted in enhanced barrenness and decrease in ear weight. Hybrids which showed a tendency to be multiple-eared at low population rates had the lowest percentage of barren stalks at the highest plant population rates. Average ear weight associated with highest yields was 0.54 pounds (Lang et al., 1956).

Colville and McGill (1962), in their investigations on plant population and method of planting irrigated corn in Nebraska, noted little difference between yields from population of 16,000, 20,000 and 24,000 plants per acre but further population increases over 24,000 plants per acre resulted in decreased yields. Termunde et al. (1963), working in eastern south Dakota found that forage production reached a maximum at 12,000 to 16,000 plants per acre and remained at the maximum if population was increased further. Grain yield reached a maximum at the same level but dropped off drastically if population levels exceeded that optimum.

Prine and Schroder (1964) observed an increase in barrenness of corn plants grown either in uniformly treated buried drums (thereby standardizing root/soil conditions) or in the field as the plant population per acre increased from 6,000 to 12,000 and 12,000 to 18,000 per acre. Since the rate of reduction in yield with increasing plant density was similar for plants grown in drums and field, they concluded that above-soil factors, particularly reduction in light, were responsible for low yields at high plant densities.

Colville et al.(1964) pointed out that highest grain yields were obtained from adapted full season corn hybrids grown at 16,000 to 20,000 plants per acre, but grain yields were slightly depressed at higher populations. Yields of early hybrids increased with increasing plant population and approached linearity within the limits of their experiments. Further they observed that the yield losses associated with planting early as compared to full season hybrids can be recovered by planting at higher plant populations per acre. Yao and Shaw (1964) reported that double planting (28,000 plants per acre) yielded significantly more and used irrigation water more efficiently than single planting (14,000 plants per acre).

Fuehring (1966) in his experiment with corn hybrid Indiana 620 grown on a calcareous clay soil, found positive Zn-population and B-population interactions. He concluded that corn plant populations can be increased to high levels (93,333 plants per hectare) provided high levels of Zn and B are applied to calcareous soils. Robertson et al. (1965) reported that increasing plant population had no significant effect on nutrient composition but increased the yields and uptake and percent recovery of P. Forgeteg (1965) found that the highest yields of maize on medium Chernozem resulted from a plant population of about 40,000 plants per hectare with either one or two plants per sowing position.

Effect of Interaction Among Plant Growth Factors

In this review of the literature, stress has been given to the individual effect of the variables with occasional mention of their interactions. It is intended here to summarize the interaction effect of the variables involved in the present study.

Application of P and Zn have been found to exert mutual antagonistic influences in their uptake and accumulation by corn plants. The application of P has marked depressing effect on the Zn concentration occurring in the corn leaves depending on the soil and climatic conditions, rate and method of application of P and presence of other nutrient elements. The interaction of B with P has been reported but more work is needed to provide support to these results. The positive Zn-population and B-population interactions have indicated that high rates of applied Zn or B depressed the grain yield at low plant populations but enhanced yields at high population rates. However, these interaction effects are variable and depend on the nature and amount of other nutrients present. This indicates that some three-factor interactions may be involved. Very little work has been reported on three-way interactions, however. The present study is designed to include the possible assessment of such third order effects.

III. MATERIALS AND METHODS

A study on the interrelationships of P, S, Zn, B and plant population on yield and leaf composition of corn was conducted in two separate but adjacent field experiments on an irrigated calcareous clay soil in the Beka'a, North Lebanon. Experiment "A" consisted of variables P, Zn, B and plant population, while in experiment "B" the variables were S, Zn, B, and plant population.

A central composite, rotatable, incomplete factorial design, as described by Cochran and Cox (1957, plan 8A.1, pp. 370), was used to study the main effects and the various interactions. Each variable was applied at 5 levels (Table 1) which were coded as -2, -1, 0, +1, +2 and were varied on a logarithmic scale to the base 2 for nutrient variables and on a linear scale for plant population. This design permits calculation, on the basis of the coded values, of the quadratic or partial cubic regression equations which can be used for the characterization of the response surfaces for yield or leaf composition as affected by interaction between different variables. This type of design is especially useful in exploratory experiments where it eliminates the need for a large number of treatments such as required with a complete factorial design.

Table 1. Applied rates of the variables P, S, Zn, and B and plant population in relation to the coded values.

Level	Coded value	Nutrients applied, Kg/ha				Plant population, plants/ ha
		P	S	Zn	B	
1	-2	37	37	11	11	40,000
2	-1	75	75	22	22	53,333
3	0	150	150	45	45	66,666
4	+1	300	300	90	90	80,000
5	+2	600	600	180	180	93,333

Due to the exploratory nature of the experiments, only one replication consisting of 25 treatments was used in each. The treatment in which all the variables were set at the third (coded 0 level) of five applied levels was repeated seven times (Table 3) and the variation within this replicated treatment was used to estimate the experimental error (error 1, Appendix Table 19). Analysis of variance of the collected data was performed and the "F" test was used to determine the significance of first order, quadratic, cubic and lack of fit terms. The significance of the individual regression coefficients was found by the use of the "t" test. Error 2 (Appendix, Table 19) was obtained by pooling sums of squares for error 1 and the lack of fit term and used in determining the significance of regression coefficients when the F-value for the lack of fit term was less than one.

Regression equations of partial cubic form were used in the computation of predicted values of yields and nutrient concentrations in the corn leaves and to characterize the nature of the response surfaces for various interactions between the different variables studied. A generalized form of the partial cubic equation used is given below:

$$\begin{aligned} Y = b_0 &+ b_1x_1 + b_2x_2 + b_3x_3 + b_4x_4 + \\ &b_{11}x_1^2 + b_{22}x_2^2 + b_{33}x_3^2 + b_{44}x_4^2 + \\ &b_{12}x_1x_2 + b_{13}x_1x_3 + b_{14}x_1x_4 + b_{23}x_2x_3 + \\ &b_{24}x_2x_4 + b_{34}x_3x_4 + b_{123}x_1x_2x_3 + \\ &b_{124}x_1x_2x_4 + b_{134}x_1x_3x_4 + b_{234}x_2x_3x_4. \end{aligned}$$

Where y = Quantitative factor measured

b = Regression coefficient for treatment effect

x_1 = coded level of P or S

x_2 = coded level of Zn

x_3 = coded level of B

x_4 = coded level of plant population.

Field Methods

The two experiments were adjacent and treatments were allotted at random to plots of each experiment. Each plot was 5 x 3 m , having 4 rows 75 cm apart. The middle 4 m of the central two rows of each plot were used for leaf sampling and harvest.

The fertilizer carriers applied as sources of nutrient variables under experiment "A" were concentrated super phosphate, zinc chloride and borax for P, Zn, and B respectively. Calcium sulfate and calcium chloride were added to balance the applied S and Cl in all plots. Under experiment "B", carriers used were gypsum, zinc sulfate and borax for S, Zn and B respectively. Extra Zn was equalized by addition of calculated amounts of $Zn(NO_3)_2$. A blanket application of 300 kg per hectare of N as NH_4NO_3 was given to the plots in both experiments and 300 kg per hectare of P as concentrated superphosphate to plots of experiment "B" only.

The fertilizers for each treatment were mixed and spread by hand in furrows. The fertilizer bands were covered by splitting the furrows and thus leaving ridges above the fertilizer bands. The ridges were packed with a packer and corn seeds of the Indiana 620A variety were planted thickly with a hand planter on the ridges directly above the fertilizer bands on April 15,

1965. The corn seedlings were thinned to the final stands at the 3 or 4 leaf stage. Irrigation was applied weekly first by sprinkling and later by furrow irrigation system after the corn plants were well established.

Two sets of leaf samples were collected, the first on July 2, 1965 (pretasseling stage) and another three weeks later, on July 21, 1965. The leaves were picked at random from the middle 4 m of the two central rows of each plot and composited for leaf analysis. The sixth leaf from the base of the stalk was the one selected at the time of first sampling and the second leaf below the ear at the time of second leaf sampling. Each leaf was split immediately after picking into two parts consisting of (a) the midrib from approximately the lower half of the leaf and (b) the remainder of the leaf. Since the tasseling was not uniform over all the experimental plots, the nutrient concentrations in the corn leaves at the two dates of sampling were averaged and the seasonal mean leaf composition was assumed to approximate the leaf composition at the tasseling stage. Due to the relatively less seasonal variation in the concentrations of the micronutrients(Zn and B), samples collected at first sampling date only were analysed for these elements.

On September 29, 1965, after a 5½ months growth period, the corn was harvested and reported as yield of shelled corn at 15.5 percent moisture and as the air-dry stover.

Analytical Procedures

The leaf samples were first washed with tap water and then rinsed with distilled water to remove possible surface contaminants. After air-drying, samples were dried in a forced ventilation oven at 70°C for two to three days. The blades and the midribs samples were ground in a micro-Wiley mill fitted with a 40 mesh sieve and stored in separate lebelled bottles. The ground plant material was mixed thoroughly and representative subsamples were taken for each analysis.

The phosphate-P and sulfate-S in both the blades and the midribs were extracted with 2 percent acetic acid. The phosphate-P was determined colorimetrically by the ammonium molybdate-stannous chloride method. (Johnson and Ulrich, 1959, pp. 49-52). The sulfate-S was determined turbidimetrically using barium chloride as a precipitant (Jackson, 1958, pp. 265-266). Total B in the blades and the midribs was determined colorimetrically by the curcumin-oxalic acid method after ashing in a muffle furnace (Johnson and Ulrich, 1959, pp. 62-64). Zn in leaf blades was determined on the nitric-perchloric acid digest using an atomic absorption spectrophotometer according to the method described by Allan (1964).

IV. RESULTS AND DISCUSSION

The interrelationships of P, S, Zn, B and plant population on yield and leaf composition of corn were studied in two irrigated field experiments using a rotatable, central composite, incomplete factorial design. This design permits the evaluation of the regression coefficients of different terms in a partial cubic equation which was used in the computation of predicted yields and nutrient concentrations in the corn leaves. A significant regression coefficient of the first order term for a variable involved in the study indicates the overall effect of that particular variable on yield and leaf composition of corn. A positive sign of the first order regression coefficient denotes the positive effect of the respective variable while a negative sign indicates a depressing effect of the variable involved. The magnitude of the regression coefficient of the squared term of each variable determines the rate of increasing or decreasing effect of the particular variable as the level of application is increased. The regression coefficients of the interaction terms indicate the amount of interaction between the two or three variables involved. A positive sign for the quadratic interaction term of two variables denotes that the effect on the yield or nutrient concentration in corn leaves of one of the varied variable become more positive (or less negative) as the level of the second variable is increased. A negative sign for the coefficient indicates that an increase in the level of one variable results in a more negative (or less positive) effect of the other depending on the first order effects and the other interactions. The three-way interactions are more complex and the net effect depends on the magnitude and signs for the coefficients of the first order and second order terms for the three variables involved in the interaction.

The "t" test was applied to determine the significance of individual regression coefficients. In the discussion that follows, the term "significant" will be used for an effect with a probability of 0.95 to 0.99 of being true and "highly significant" will be used for a probability of 0.99 or more of being true. Effects that have regression values greater than the standard error may be discussed as being "probably real."

Results of soil analysis (Table 2) indicated that the soil was calcareous in nature and consequently alkaline in reaction. The organic matter content of 2.1 percent would probably be too low to supply adequate available N to a high yielding irrigated crop. The available P (Olsen method) was "medium". The mechanical analysis revealed that the soil was clay in texture.

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

Soil analysis		Water analysis (Soltanpour, 1963)	
pH,	7.9	Na	0.282 me/l
$CaCO_3$, %	12.8	Ca	0.705 "
Organic matter, % (wet oxidation)	2.1	Mg	0.833
		K	0.056
P, ppm (bicarbonate soluble)	16.5	S	0.125
Soil texture		Cl	0.318
Sand, %	16.4	Electrical Conductivity	0.155 mmhos/cm
Silt, %	27.6		
Clay, %	56.0		

Water analysis (Table 2, Soltanpour, 1963) showed that the irrigation water was of good quality from a salinity point of view. The amount of S added to the soil through the irrigation waster was relatively small compared to the applied rates.

Effect of Variables on Corn Yields

The results of interrelationships of P, S, Zn, B and plant population on yields of grain and stover studied in two separate experiments have been reported here. The relevant data is given in Tables 3-6.

Experiment "A" (Interrelationships of P, Zn, B and plant population):

Grain yields at 15.5 percent moisture varied from 9.69 to 14.43 metric tons per hectare with an average of 12.34 (Table 3) indicating that environmental conditions of the experimental area were very suitable for corn production and that with judicious fertilization and good cultural practices high yields may be obtained. The multiple correlation coefficient (R) between the actual yields of grain and those calculated from the regression equation was 0.658 (highly significant, Table 3) indicating that the partial cubic regression equation used to predict the effect of variables had a fairly close fit to the actual data.

The regression coefficient of the negative P-Zn-Population interaction (Table 4) was larger than the respective standard error indicating a probably real effect. At a low population level and with a low P level, Zn had a depressing effect on grain yield

Table 3. Observed and predicted yields of grain (15.5% moisture) and stover (air-dry weight) as affected by various combinations of coded levels of applied P, Zn, and B and plant population (Pop).

Treatment level				Observed grain yield, m tons/ha	Predicted grain yield, m tons/ha	Observed stover yield, m tons/ha	Predicted stover yield, m tons/ha
P	Zn	B	Pop				
2	2	2	2	12.83	12.35	8.95	8.69
4	2	2	2	9.69	10.66	7.08	8.10
2	4	2	2	11.78	11.20	7.82	8.61
4	4	2	2	11.04	13.55	8.85	8.86
2	2	4	2	13.64	14.12	6.86	7.94
4	2	4	2	11.57	12.14	7.14	7.43
2	4	4	2	11.71	10.72	8.45	8.52
4	4	4	2	11.29	11.75	8.28	9.64
2	2	2	4	14.09	14.28	12.28	12.48
4	2	2	4	12.84	13.12	11.99	11.40
2	4	2	4	14.43	13.16	10.85	10.04
4	4	2	4	11.68	11.86	8.57	9.05
2	2	4	4	11.20	10.99	11.03	10.50
4	2	4	4	9.92	11.16	9.88	10.64
2	4	4	4	13.84	13.52	8.85	9.39
4	4	4	4	12.75	12.52	10.63	10.39
5	3	3	3	13.44	11.92	10.00	8.97
1	3	3	3	11.25	12.82	9.14	8.13
3	5	3	3	10.91	12.51	10.28	9.71
3	1	3	3	14.20	12.65	10.85	10.39
3	3	5	3	12.08	11.56	9.14	7.99
3	3	1	3	11.80	12.37	8.57	8.68
3	3	3	5	12.83	12.88	11.88	12.49
3	3	3	1	11.85	11.85	10.11	8.46
3	3	3	3	11.21	12.39	8.85	9.76
3	3	3	3	11.54	12.39	7.82	9.76
3	3	3	3	12.69	12.39	11.14	9.76
3	3	3	3	10.74	12.39	7.42	9.76
3	3	3	3	11.78	12.39	10.00	9.76
3	3	3	3	14.40	12.39	10.85	9.76
3	3	3	3	14.38	12.39	12.28	9.76
R				0.658		0.750	

Table 4. Regression coefficients (b) and their standard errors (s_b) for yields of grain and stover as affected by various combinations of coded levels of applied P, Zn and B and plant population (Pop).

Coefficient		Grain yield m tons/ha	Stover yield, m tons/ha
Mean	b_0	+ 12.393	+ 9.766
P	b_1	- 0.223	- 0.040
Zn	b_2	- 0.035	- 0.170
B	b_3	- 0.204	- 0.173
Pop	b_4	+ 0.257	+ 1.007*
	s_b	± 0.3037	± 0.3380
P^2	b_{11}	- 0.006	- 0.178
Zn^2	b_{22}	+ 0.047	+ 0.070
B^2	b_{33}	- 0.107	- 0.357 e
Pop^2	b_{44}	- 0.007	+ 0.178
	s_b	± 0.2754	± 0.3065
P-Zn	b_{12}	+ 0.359	+ 0.213
P-B	b_{13}	- 0.001	+ 0.261
P-Pop	b_{14}	- 0.188	- 0.074
Zn-B	b_{23}	+ 0.049	+ 0.346
Zn-Pop	b_{24}	+ 0.222	- 0.602 e
B-Pop	b_{34}	- 0.325	- 0.082
	s_b	± 0.3722	± 0.4142
P-Zn-B	b_{123}	- 0.129	+ 0.097
P-Zn-Pop	b_{124}	- 0.522 e	- 0.096
P-B-Pop	b_{134}	+ 0.202	+ 0.139
Zn-B-Pop	b_{234}	+ 0.738	+ 0.082
	s_b	± 0.3722	± 0.4142

* Significant at 5 percent level.

of corn while at a high P level, Zn generally tended to increase the grain yield (Figure 1). This shows the mutural antagonism between P and Zn reported by many workers (Bingham and Garber, 1960; Watanabe et al., 1965). But at a high population level, the P-Zn interaction tended to disappear (Figure 1).

The overall first order effect of P on the grain yield was negligible (Table 4). This is in agreement with results reported by Viets et al.(1954) and Baird (1959) who found no significant response of corn to P application. However, at a low level of population and with a low level of Zn, the effect of P application on grain yield was negative (Figure 2), But, at a low level of population and a high level of Zn, P application tended to enhance the grain yield. At a high population level, the effect of P was slight at both low and high levels of Zn indicating that the P-Zn interaction tended to disappear. It may be concluded from the preceding discussion that the effects of both P and Zn on grain yield of corn were variable and related to plant population.

The positive Zn-B-population interaction was probably real, although not significant (Table 4). When the level of Zn was low, the predicted effect of B was to enhance the grain yield at a low population level and to depress it at a high population

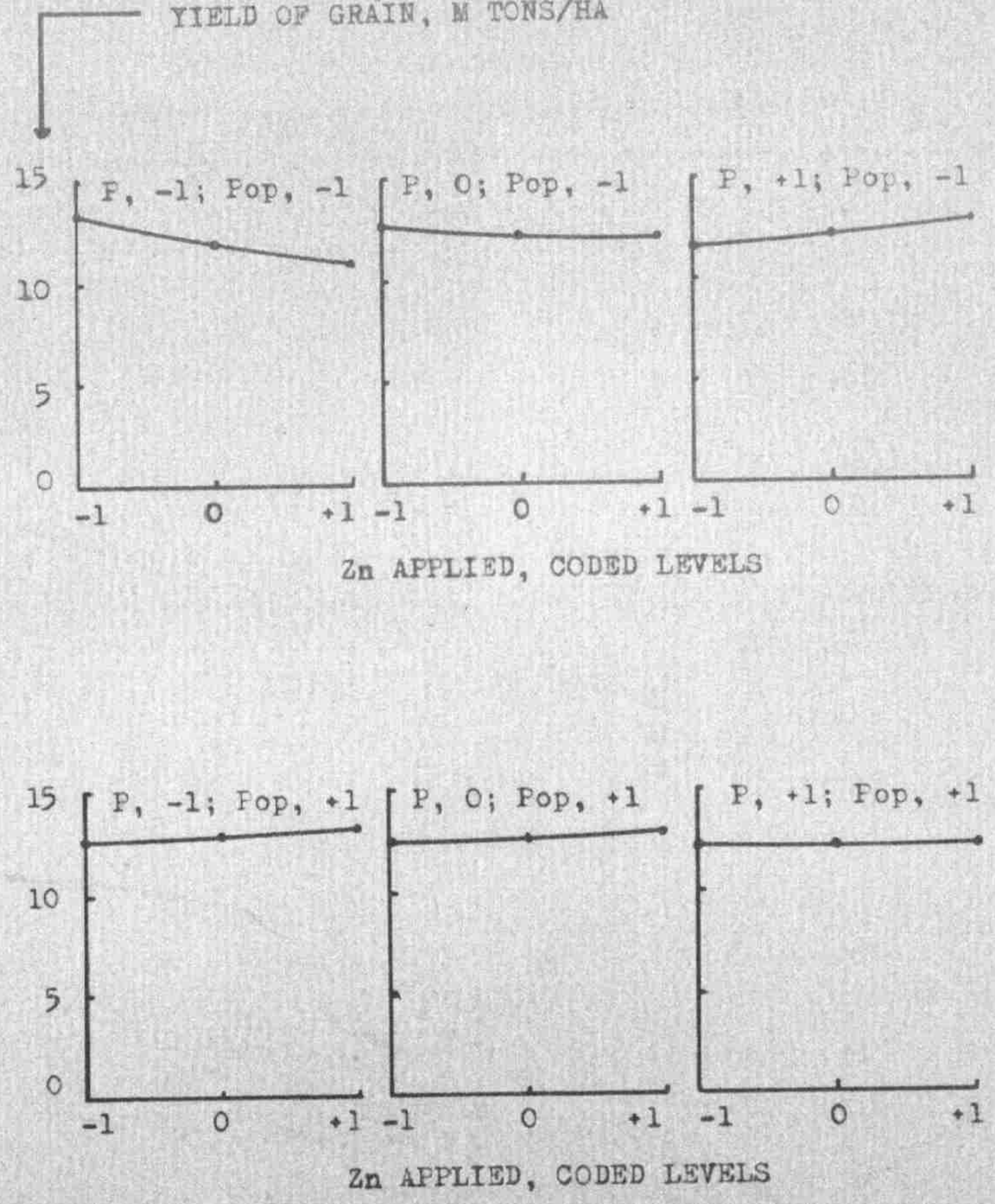

Figure 1. Yield of grain (15.5% moisture) as affected by levels of applied Zn at constant levels of applied P. Plant population (Pop) was held at -1 (above) and +1 (below) and B was held at the 0 coded level.

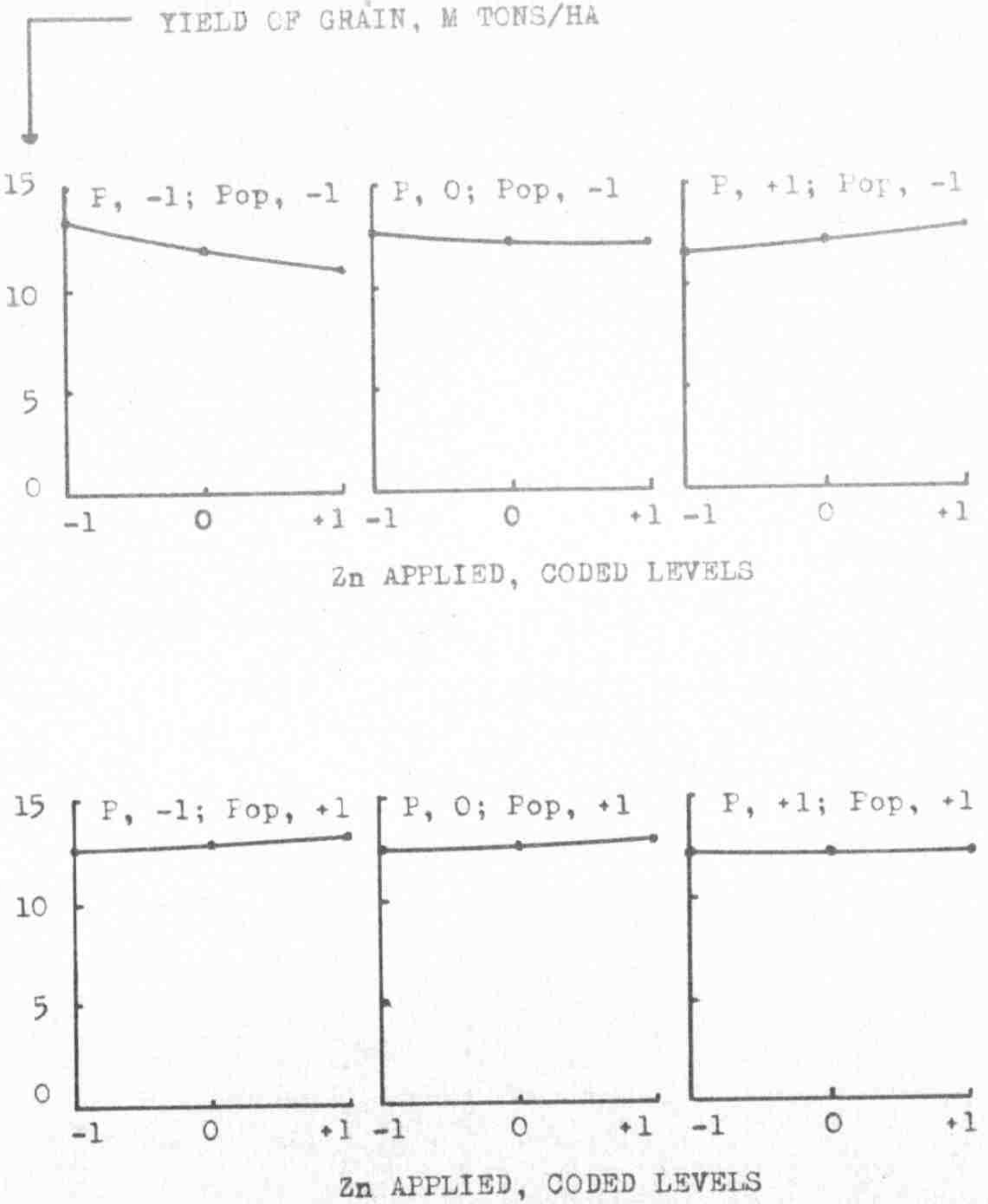

Figure 1. Yield of grain (15.5% moisture) as affected by levels of applied Zn at constant levels of applied P. Plant population (Pop) was held at -1 (above) and +1 (below) and B was held at the 0 coded level.

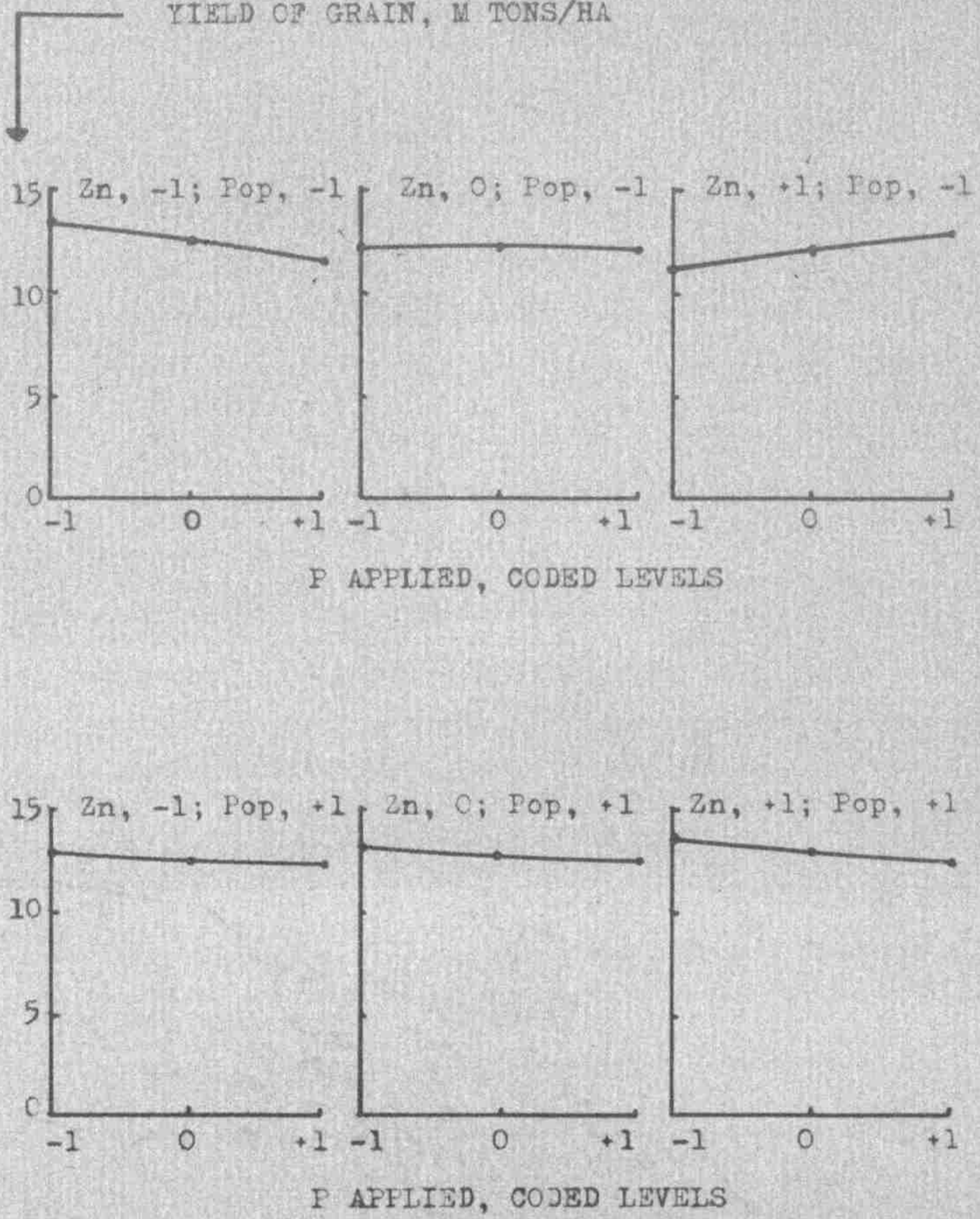

Figure 2. Yield of grain (15.5% moisture) as affected by levels of applied P at constant levels of applied Zn. Population (Pop) was held at -1 (above) and +1 (below) and B was held at the 0 coded level.

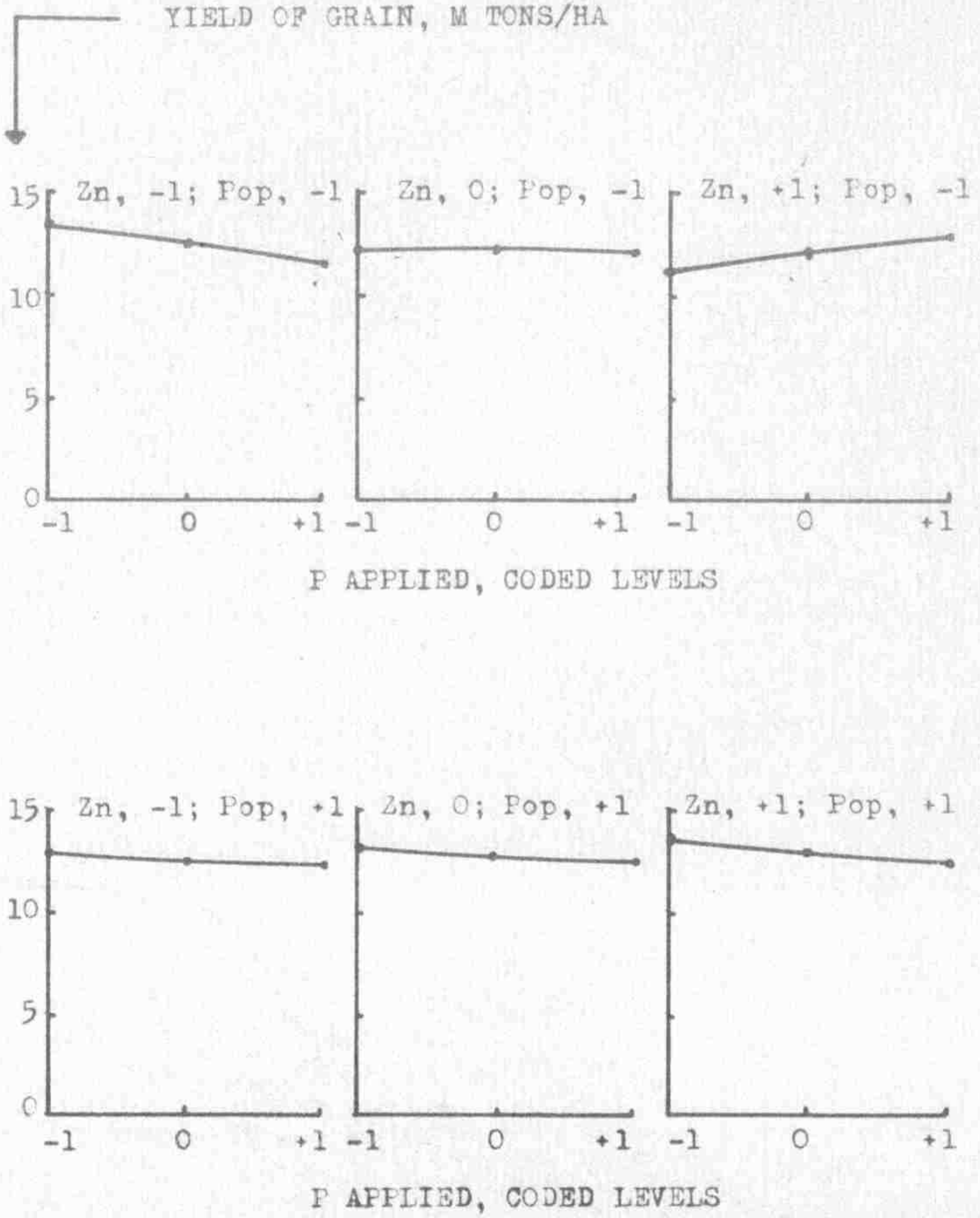

Figure 2. Yield of grain (15.5% moisture) as affected by levels of applied P at constant levels of applied Zn. Population (Pop) was held at -1 (above) and +1 (below) and B was held at the 0 coded level.

level (Figure 3) indicating a negative B-population interaction. But at a high Zn level the B-population interaction was reversed and became positive. The relatively less slope of lines for the positive B-population interaction at a high Zn level (lower set of graphs, Figure 3) resulted in the net negative B-population interaction. Fuehring (1966), under similar conditions, found a positive B-population interaction that was probably real, although not significant, at a medium level of Zn. Thus, the level of Zn tended to influence the interaction between B and plant population.

The effect of population on grain yield of corn was positive at low levels of Zn and B while at a high level of B and a low level of Zn the response of grain yield to plant population was negative (Figure 4). At a high Zn level, response to plant population was slight at a low level of B but more positive at a high B level. This is in support of results reported by Fuehring (1966). He found that corn yields may be enhanced by increasing plant population to levels higher than normally possible provided high rates of Zn and B are applied. Also severe reductions in corn yields have been reported as the result of blank stalks and barren ears caused by lack of B (Berger *et al*., 1957) and high plant population(Termunde

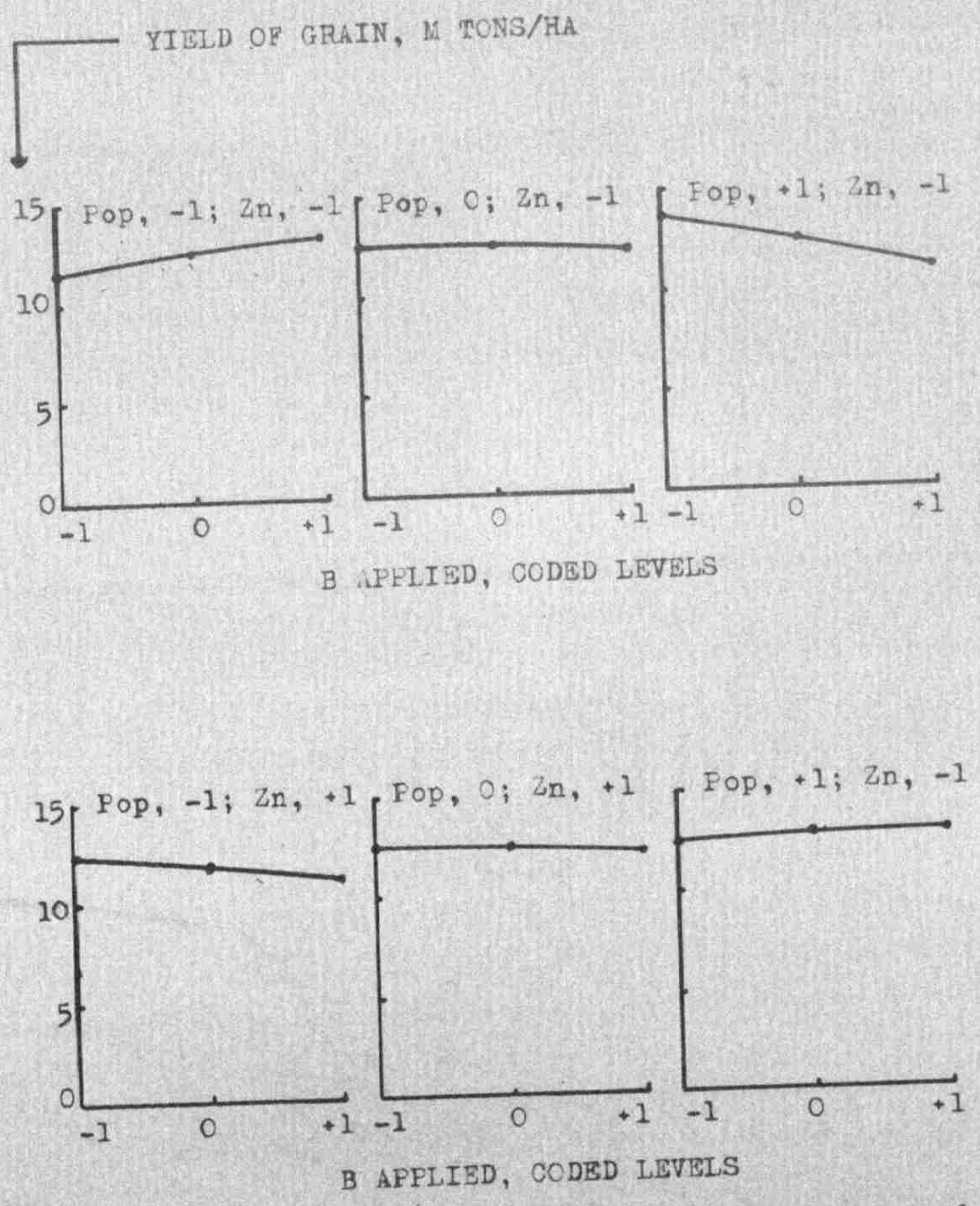

Figure 3. Yield of grain (15.5% moisture) as affected by levels of applied B at constant levels of plant population (Pop). Zn was held at -1 (above) and +1 (below) and P was held at the 0 coded level.

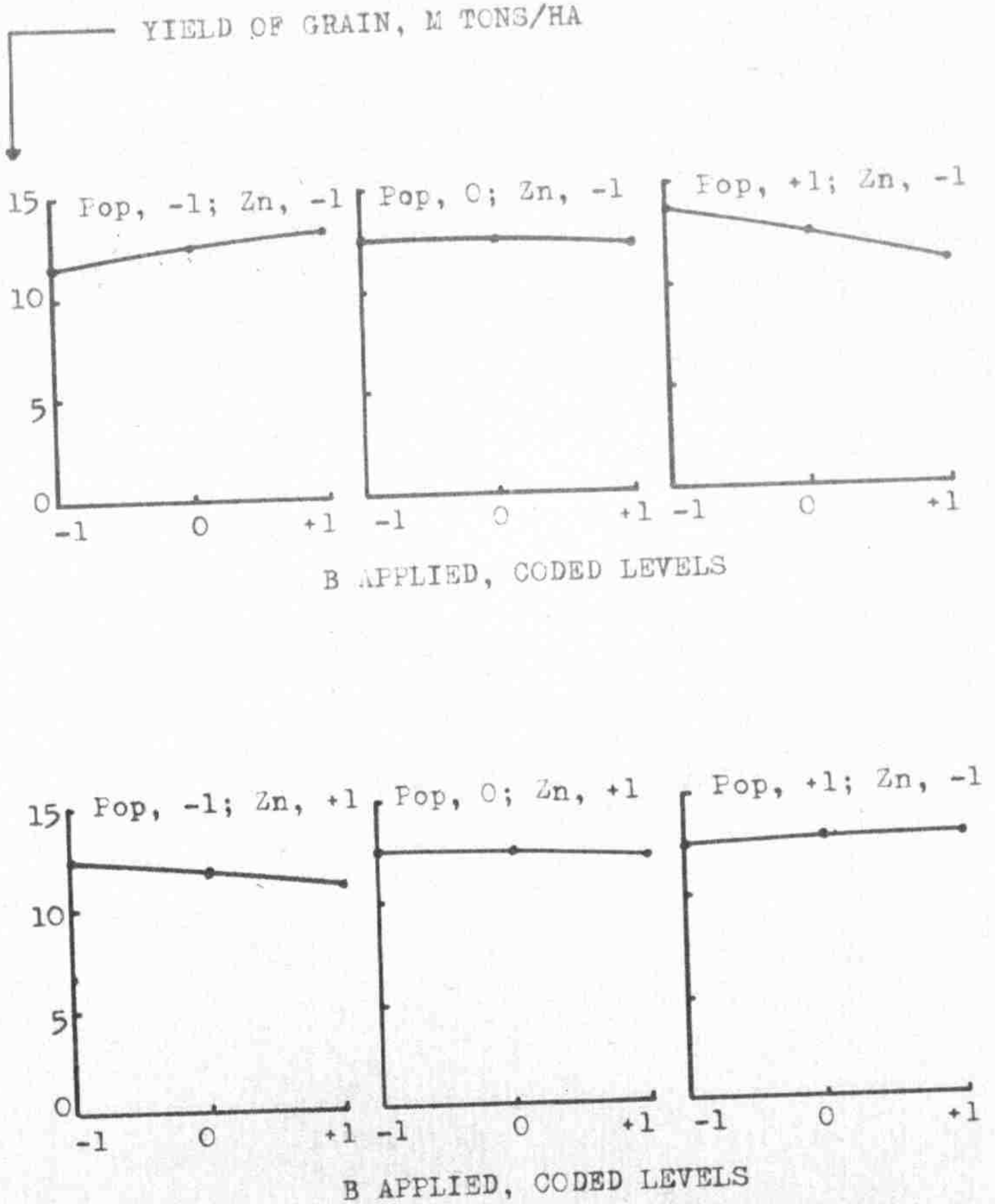

Figure 3. Yield of grain (15.5% moisture) as affected by levels of applied B at constant levels of plant population (Pop). Zn was held at -1 (above) and +1 (below) and P was held at the 0 coded level.

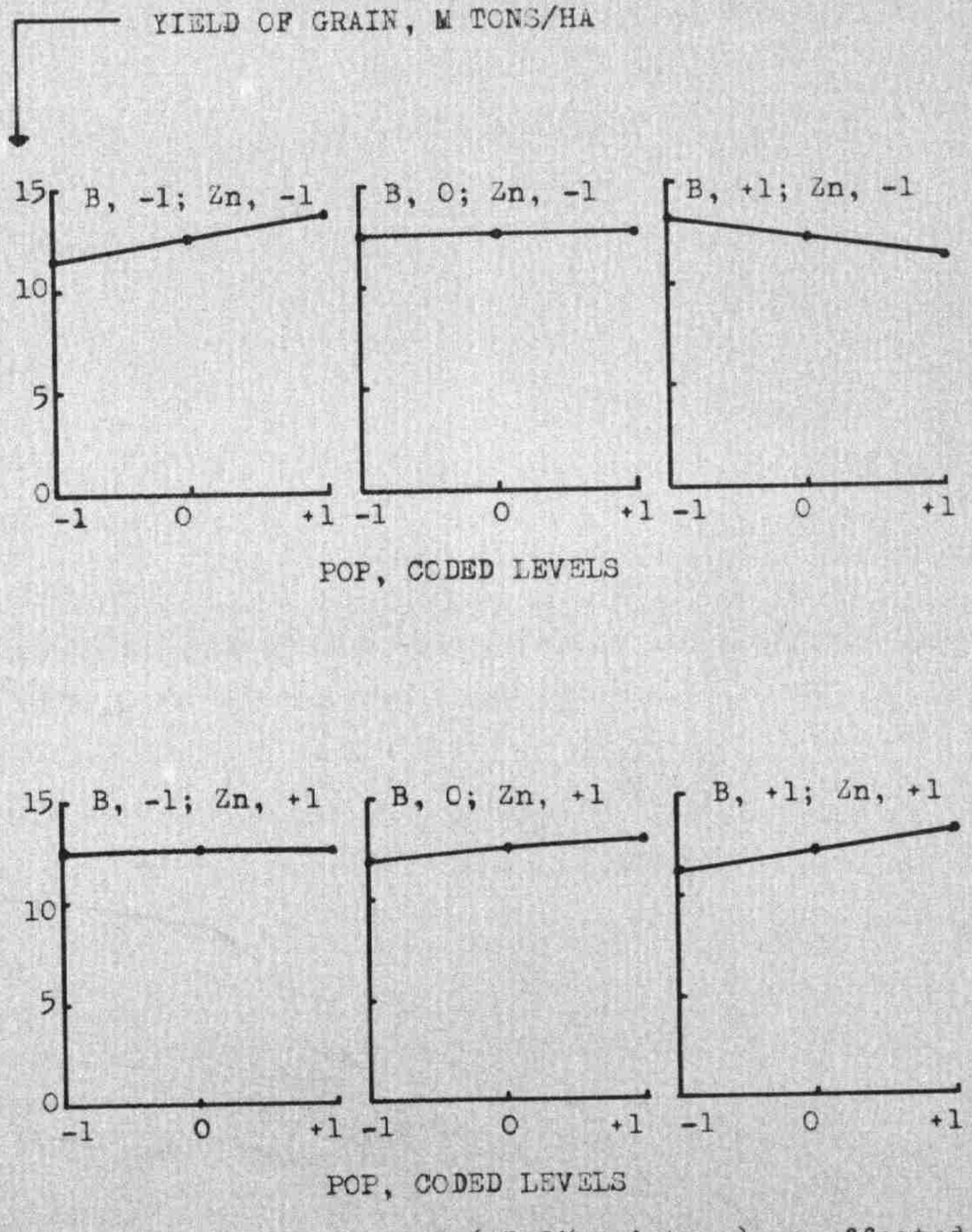

Figure 4. Yield of grain (15.5% moisture) as affected by levels of plant population (Pop) at constant levels of applied B. Zn was held at -1 (above) and +1 (below) and P was held at the 0 coded level.

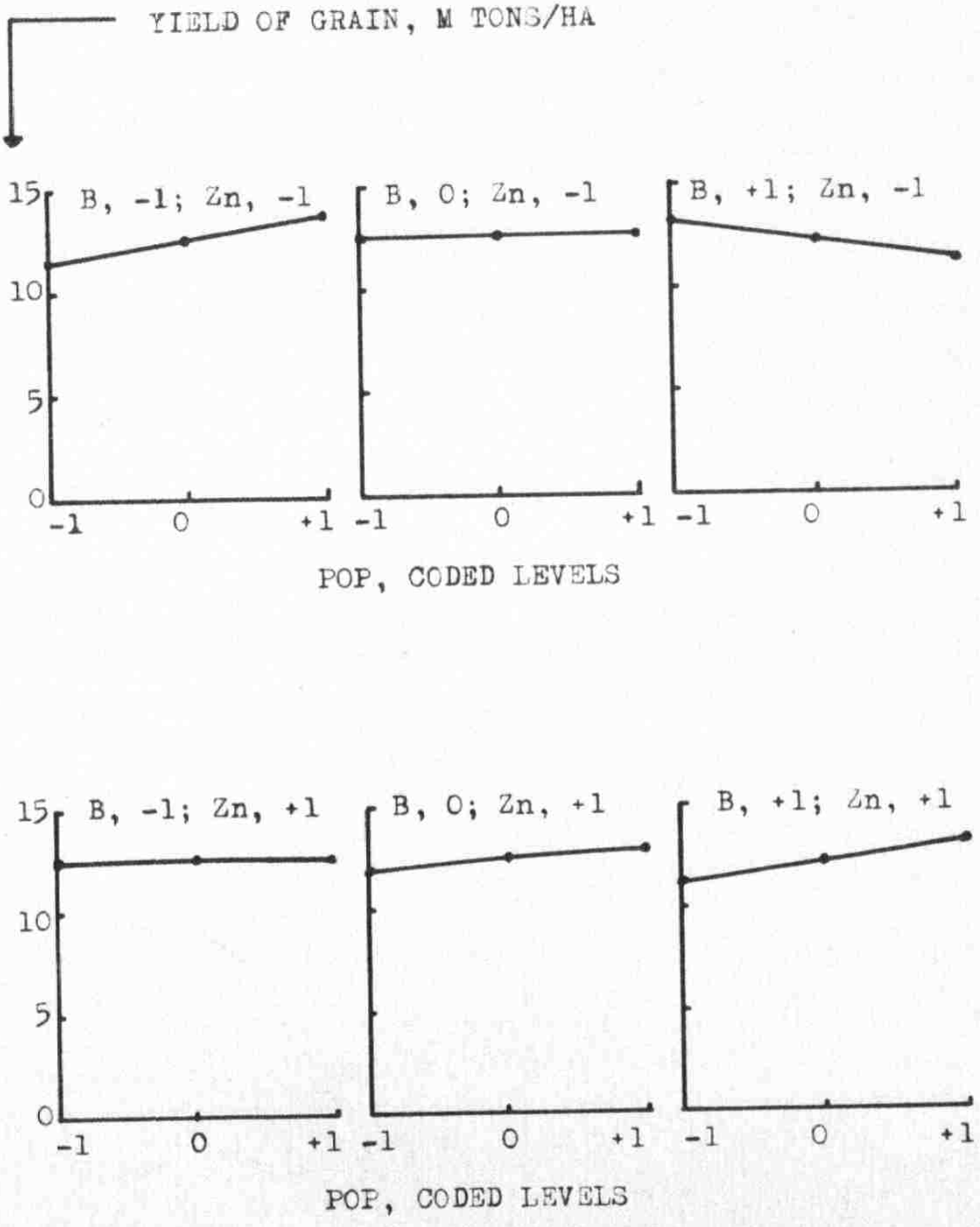

Figure 4. Yield of grain (15.5% moisture) as affected by levels of plant population (Pop) at constant levels of applied B. Zn was held at -1 (above) and +1 (below) and P was held at the 0 coded level.

et al., 1963).

Stover yields (air dried) ranged from 6.86 to 12.28 metric tons per hectare with an average yield for all 31 plots of 9.54 (Table 3). The multiple correlation coefficient (R) between the actual and calculated stover yields was 0.750 indicating a fairly close fit of the regression equation to the actual data. The first order effect of plant population on the stover yield was significantly positive (Table 4). The negative Zn-population interaction was probably real (although not significant) indicating that at a low level of plant population, Zn tended to increase the stover yield. This is in agreement with results reported by Fuehring and Soofi (1964) who were working at a relatively low plant population level. They found that the forage yield was enhanced at all levels of applied Zn. However, in this study Zn decreased the stover yield at a high level of population as indicated by the probably real negative Zn-population interaction. This shows that the significantly positive first order effect of plant population on stover yield depends on the level of soil Zn.

Experiment "B" (Interrelationships of S, Zn, B and population:

Grain yields at 15.5 percent moisture ranged from 6.40 to 15.08 metric tons per hectare with an average of 11.91 for all 31 plots (Table 5). The analysis of variance (Appendix table 20) indicated a relatively high coefficient of variation (19.99%), which was due to one exceptionally low yield from one of the seven plots (Table 5) where the same treatment combination was repeated. This resulted in relatively large values of "t" and consequently less assurance that the observed differences were real.

The first order effect of B application on grain yield was negative although not significant (Table 6). This confirms the tendency for a negative first order effect of B in the average results of five experiments conducted under similar experimental conditions at Agricultural Research and Education Center of American University of Beirut (unpublished report). The first order regression coefficient for population was also negative (probably real) indicating a tendency for decrease in grain yield at high plant population rates as reported by other workers (Lang <u>et</u> <u>al</u>., 1956; Pendleton and Seif, 1961; Stickler, 1964). The Zn-B interaction was positive and probably real indicating that the positive effect of one on grain yield was increased at a high application level of other.

The S-Zn-population interaction (Table 6)

Table 5. Observed and predicted yields of grain (15.5% moisture) and stover (air-dry weight) as affected by various combinations of coded levels of applied S, Zn, and B and plant population (Pop).

Treatment level S	Zn	B	Pop	Observed grain yield, m tons/ha	Predicted grain yield, m tons/ha	Observed stover yield, m tons/ha	Predicted stover yield, m tons/ha
2	2	2	2	14.34	13.21	11.43	11.89
4	2	2	2	14.11	14.16	8.57	9.10
2	4	2	2	11.36	11.21	9.42	10.08
4	4	2	2	14.27	14.76	11.14	11.79
2	2	4	2	11.85	11.12	7.42	7.57
4	2	4	2	11.25	11.16	8.85	8.99
2	4	4	2	12.87	12.58	9.14	9.40
4	4	4	2	11.54	12.43	7.71	8.05
2	2	2	4	12.75	12.79	8.28	8.57
4	2	2	4	12.29	12.96	7.88	8.16
2	4	2	4	11.04	11.51	7.42	7.82
4	4	2	4	8.34	9.99	9.99	10.47
2	2	4	4	9.80	9.69	8.00	7.89
4	2	4	4	10.22	11.30	9.14	9.11
2	4	4	4	12.28	13.15	10.40	10.50
4	4	4	4	8.77	10.28	7.42	7.50
5	3	3	3	14.69	12.21	10.57	9.92
1	3	3	3	10.60	11.77	10.57	10.05
3	5	3	3	15.08	13.01	11.71	10.81
3	1	3	3	12.37	13.13	10.00	9.73
3	3	5	3	10.76	9.84	7.42	7.53
3	3	1	3	12.46	12.06	10.03	9.74
3	3	3	5	13.39	10.95	7.14	6.98
3	3	3	1	12.05	13.18	9.71	8.70
3	3	3	3	13.22	11.52	9.42	9.58
3	3	3	3	11.89	11.52	8.28	9.58
3	3	3	3	12.16	11.52	10.00	9.58
3	3	3	3	12.02	11.52	12.56	9.58
3	3	3	3	13.04	11.52	7.71	9.58
3	3	3	3	11.89	11.52	9.42	9.58
3	3	3	3	6.40	11.52	9.70	9.58
R				0.636		0.822	

Table 6. Regression coefficients (b) and their standard errors (s_b) for yields of grain and stover as affected by various combinations of coded levels of applied S, Zn and B and plant population (Pop).

Coefficient		Grain yield, m tons/ha	Stover yield m tons/ha
Mean	b_0	+ 11.517	+ 9.584
S	b_1	+ 0.112	- 0.034
Zn	b_2	- 0.030	+ 0.270
B	b_3	- 0.555	- 0.553
Pop	b_4	- 0.559	- 0.429
	s_b	± 0.4698	± 0.2688
S^2	b_{11}	+ 0.118	+ 0.100
Zn^2	b_{22}	+ 0.388	+ 0.171
B^2	b_{33}	- 0.141	- 0.237
Pop	b_{44}	+ 0.137	- 0.437
	s_b	± 0.4261	± 0.2438
S-Zn	b_{12}	- 0.235	+ 0.036
S-B	b_{13}	- 0.284	- 0.179
S-Pop	b_{14}	- 0.488	+ 0.092
Zn-B	b_{23}	+ 0.676	- 0.034
Zn-Pop	b_{24}	- 0.195	+ 0.049
B-Pop	b_{34}	+ 0.201	+ 0.552
	s_b	± 0.5758	± 0.3294
S-Zn-B	b_{123}	- 0.348	- 0.908*
S-Zn-Pop	b_{124}	- 0.536	- 0.179
S-B-Pop	b_{134}	+ 0.292	- 0.322
Zn-B-Pop	b_{234}	+ 0.160	- 0.037
	s_b	± 0.5758	± 0.3294

* Significant at 5 percent level.

was negative and the largest of the three-way interactions. The regression coefficient of this interaction was almost equal to standard error indicating a probability of being a real effect. When S was at a low level, the effect of population was very small (Figure 5). However, at a high S level, plant population generally decreased the grain yield particularly at a high level of Zn.

Response of grain yield to Zn application was negligible at low levels of S (Figure 6). However, at a high S level, the effect of Zn application was positive at a low plant population level and negative at a high population level indicating a negative Zn-population interaction. It was concluded that the effect of Zn and population were variable tending to be influenced by different levels of S and more work is needed with regard to the causes responsible.

Stover yields (air dry) obtained in this experiment had a range of 7.14 to 12.56 metric tons per hectare with an average of 9.27 (Table 5). The first order effect of B application on stover yield was negative and probably real (Table 6). This is in agreement with the results reported by Fuehring (1966) who, working under similar experimental conditions, found that the first order effect of B was negative although not significant. Response to population was

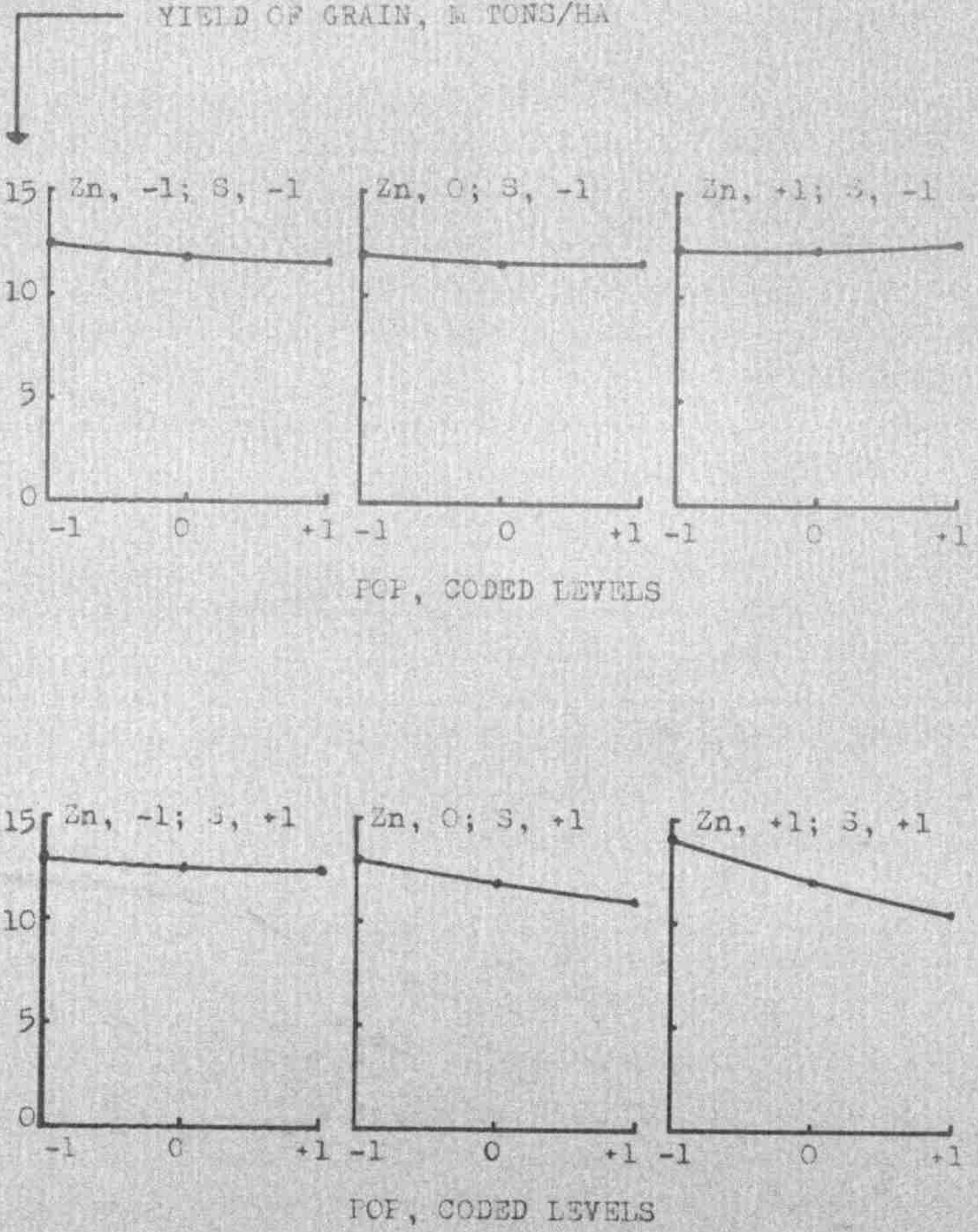

Figure 5. Yield of grain (15.5% moisture) as affected by levels of plant population at constant levels of applied Zn. S was held at -1 (above) and +1 (below) and B was held at the 0 coded level.

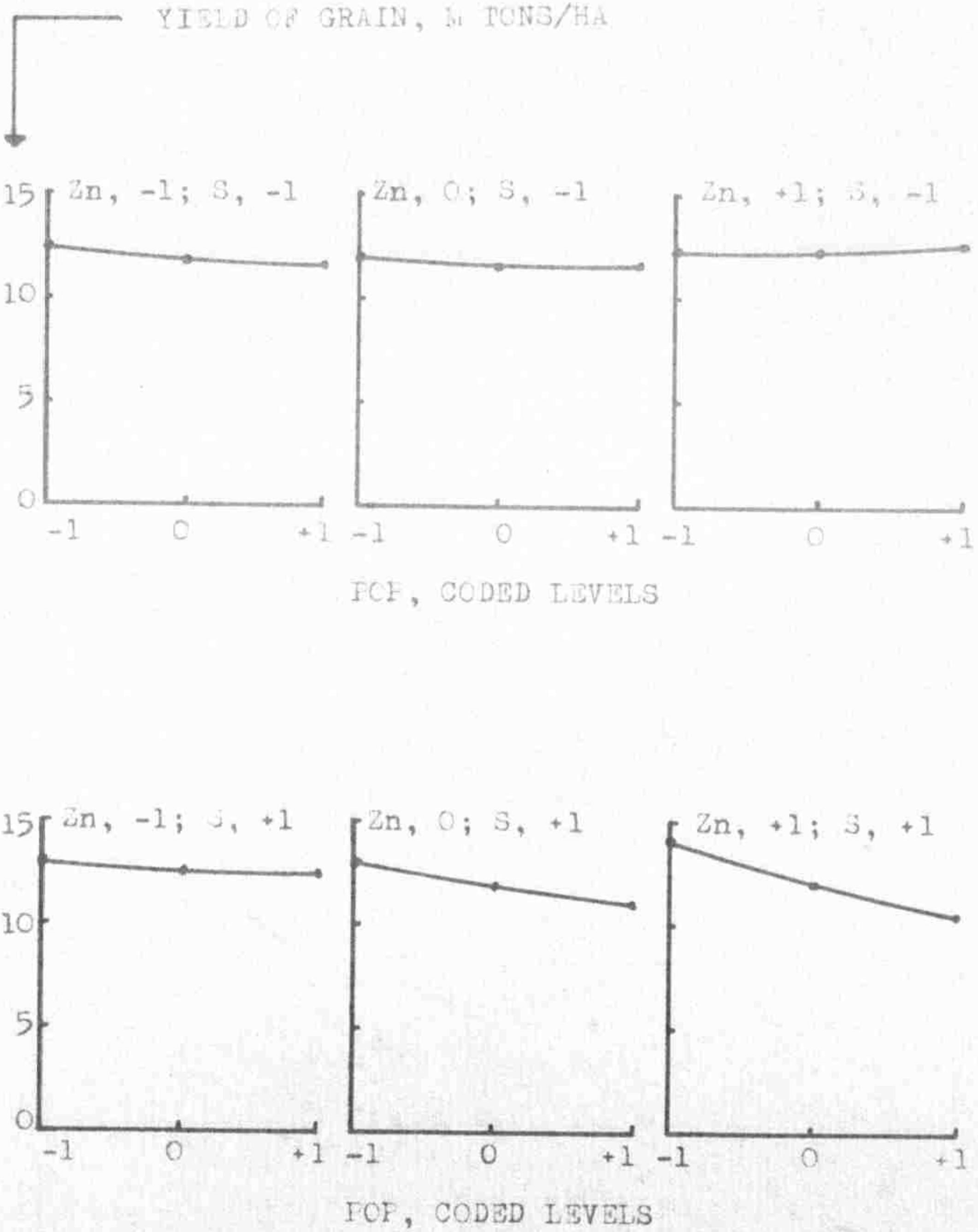

Figure 5. Yield of grain (15.5% moisture) as affected by levels of plant population at constant levels of applied Zn. S was held at -1 (above) and +1 (below) and B was held at the 0 coded level.

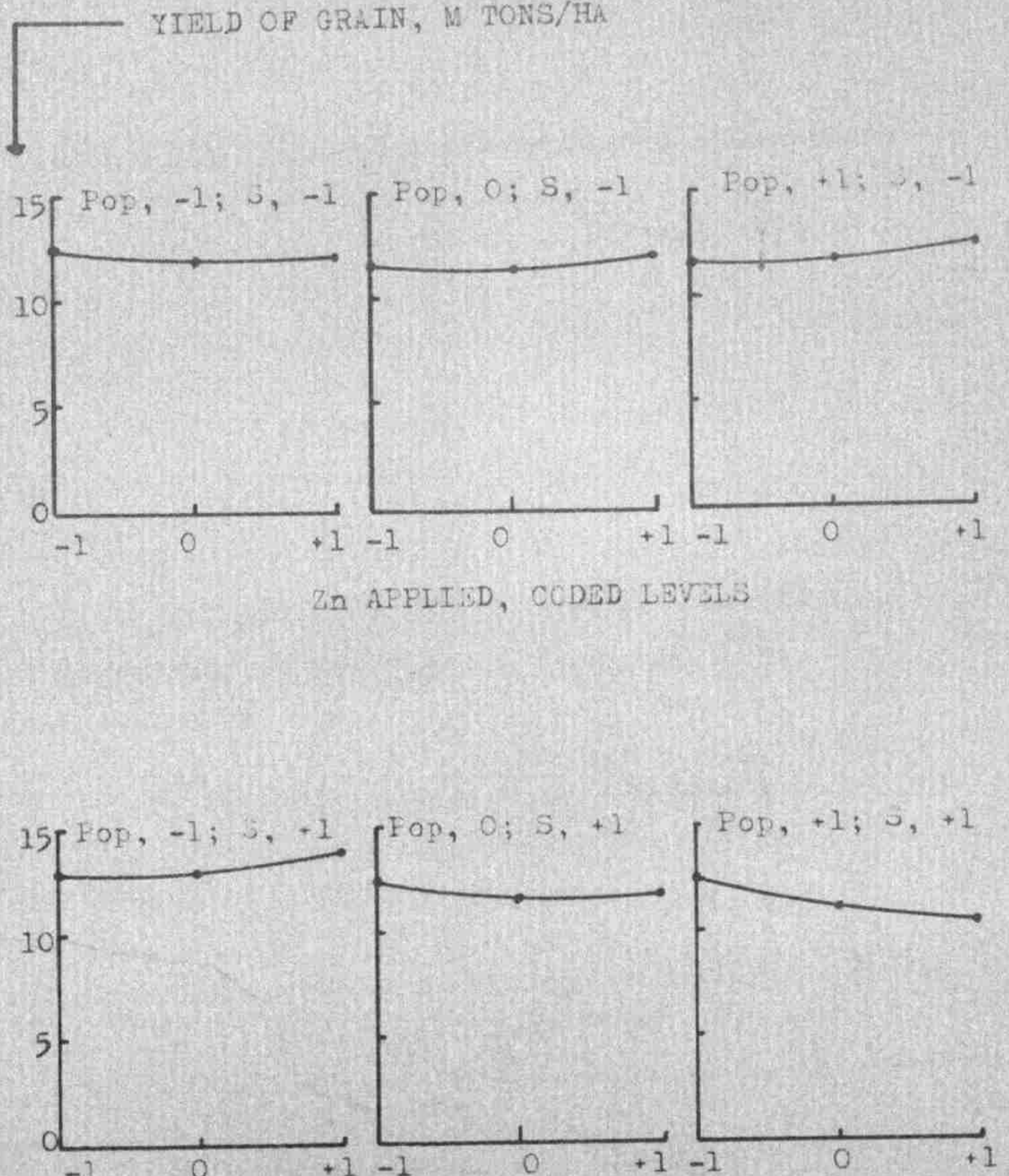

Figure 6. Yield of grain (15.5% moisture) as affected by levels of applied Zn at constant levels of plant population (Pop), S was held at -1 (above) and +1 (below) and B was held at the 0 coded level.

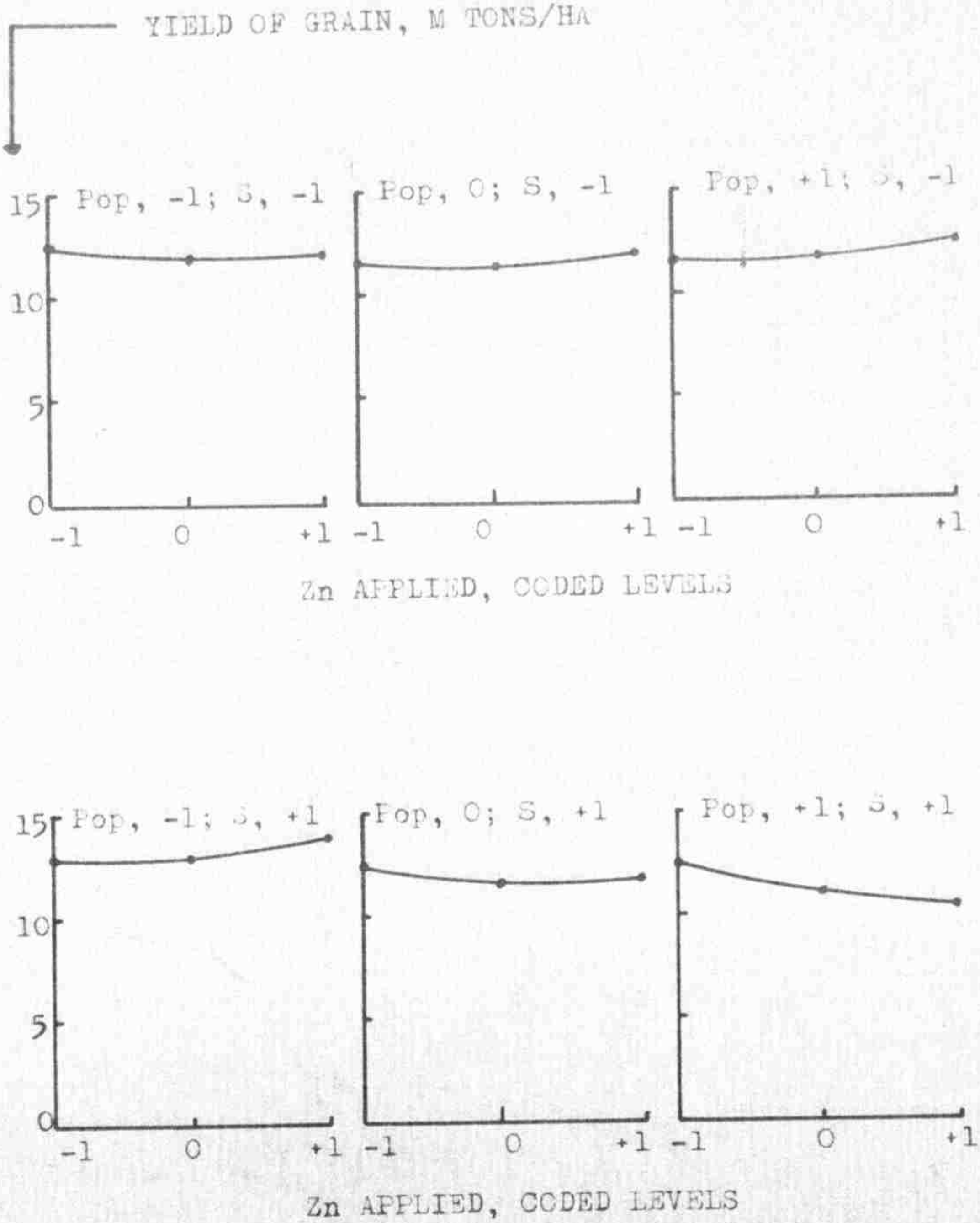

Figure 6. Yield of grain (15.5% moisture) as affected by levels of applied Zn at constant levels of plant population (Pop), S was held at -1 (above) and +1 (below) and B was held at the 0 coded level.

also negative and tended to become more negative at higher coded levels of population as indicated by the negative regression coefficient of the squared term for population (probably real but not significant, Table 6). However, the B-population interaction tended to be positive indicating that at high levels of application one tended to counteract the negative effect of the other.

The S-Zn-B interaction was significantly negative (Table 6). When Zn was applied at a low level (Figure 7), the effect of S application was to decrease the stover yield at a low B level and to increase it at a high B level resulting in a positive S-B interaction. But at a high Zn level (Figure 7), the S-B interaction was reversed and became negative. This may explain the variation in the effect of S application observed by other American University workers. Soltanpour (1963, pp. 38-40) found a significant positive first order effect of S on the stover yield of corn. But Soofi (1961, pp. 99) obtained no real effect of S application on the stover yield, and the results of the present experiment also showed the same tendency.

<u>Comparison of the effect of common variables in both experiments</u>: Since the regression coefficients of first order effects of Zn, B and plant population are

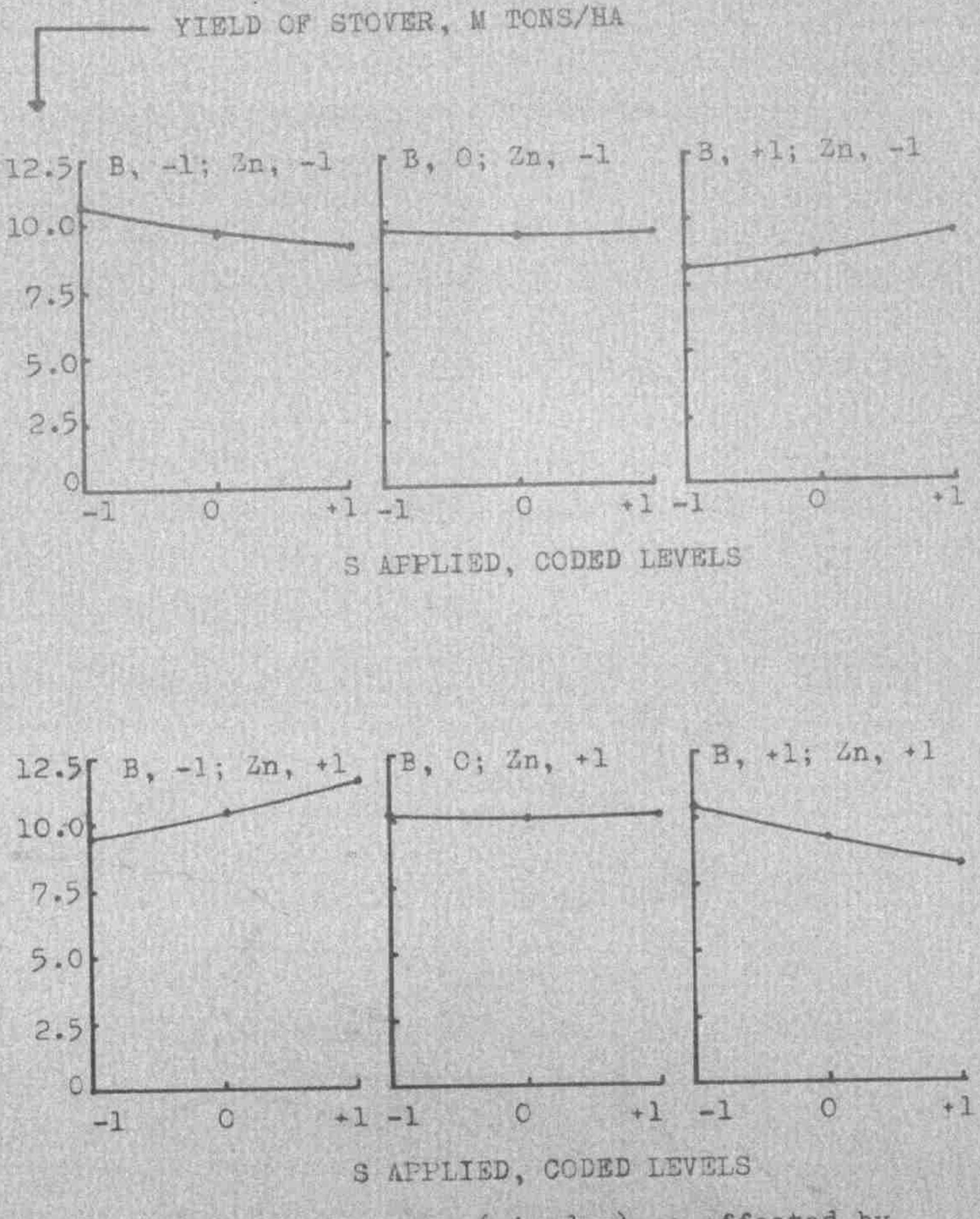

Figure 7. Yield of stover (air-dry) as affected by levels of applied S at constant levels of applied B. Zn was held at -1 (above) and +1 (below) and plant population was held at the 0 coded level.

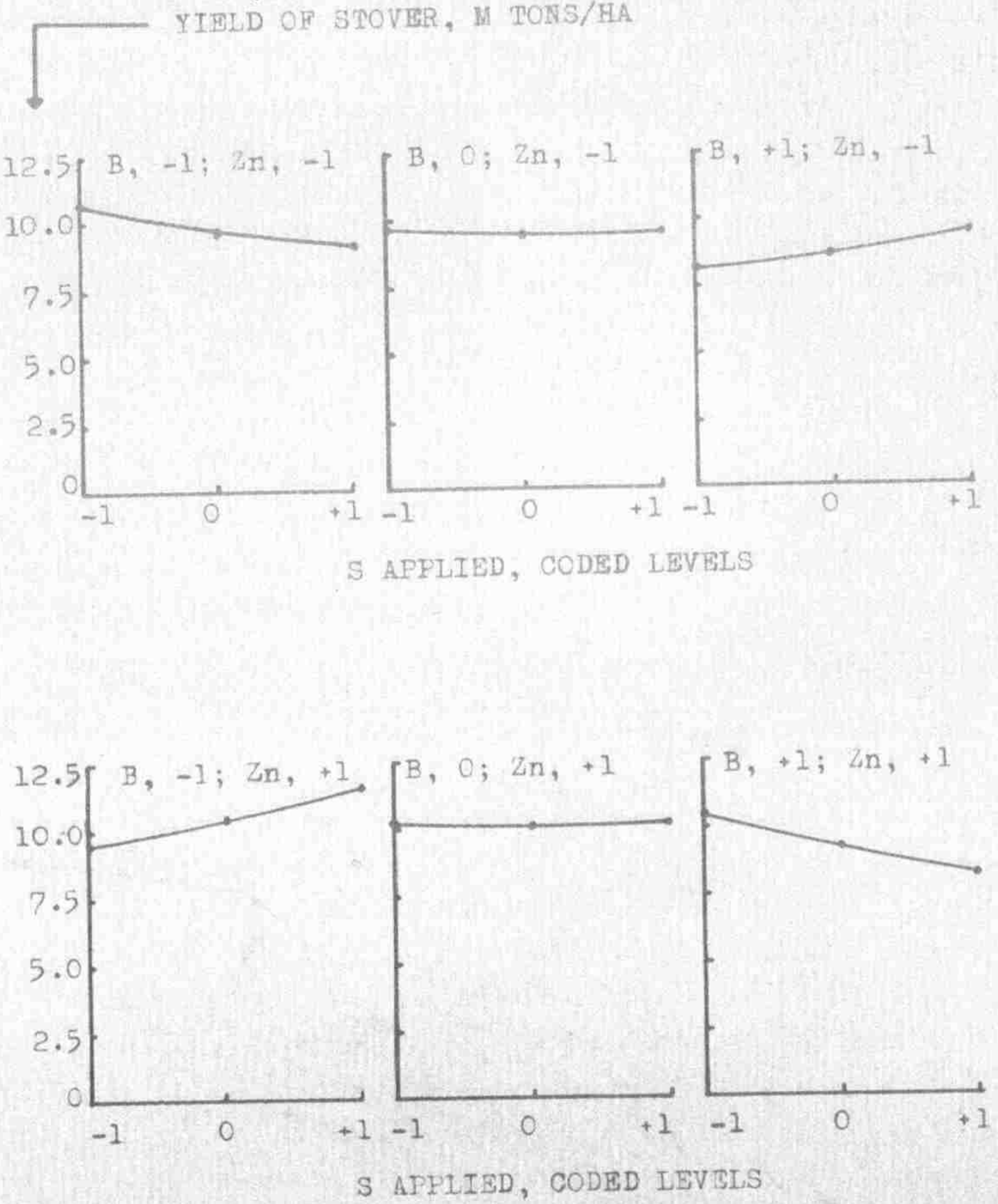

Figure 7. Yield of stover (air-dry) as affected by levels of applied S at constant levels of applied B. Zn was held at -1 (above) and +1 (below) and plant population was held at the 0 coded level.

mostly less than the standard error, their evaluation is difficult. Moreover the first order terms give only slope of the curve at the 0 coded level of all the four variables and the overall effects are influenced by the interactions. Thus a negative first order term for any one variable may be reversed by the interactions. The relatively large Zn-B-population interaction in experiment "A" (medium P, low S) agrees with Fuehring (1966) at relatively low levels of P and S but tends to disappear in experiment "B" (high P, medium S). The interactions are complex involving balances among P, S, Zn, B and plant population and probably other variables. Since differences are small and interrelated, the natural variations under field conditions gave results that tended to be inconclusive. More work is needed under more controlled conditions.

Differences in the levels of P and S gave inconsistent results between the two experiments. Plant population especially tended to require a higher level for optimum grain yield in experiment "A" than in experiment "B".

Effect of Variables on Leaf Composition

Leaf analysis is a relatively rapid way of diagnosing the nutritional needs of corn by using the plant itself as an indicator. The nutrient concentrations found within the corn leaves reflect what the plant has obtained from the soil in relation to its growth up to the time of sampling the plant. By comparing these nutrient concentrations to those already established as just deficient for growth (critical nutrient levels) the nutrient status of the plant can be ascertained. The results of the leaf analysis carried out in this study have been reported here.

Experiment "A": Interrelationships of P, Zn, B and plant population on concentrations of phosphate-P, total B and Zn in corn leaf blades and midribs have been discussed in the following paragraphs.

Phosphate-P concentration of leaf blades for the seasonal mean ranged from 1565 to 2158 ppm with an average of about 1900 (Appendix table 13). Soofi (1961, pp. 121), working under similar conditions, obtained an upper limit of 2940 ppm P concentration of the sixth leaf at tasseling time. The observed discrepancy in the results is due to the fact that he analysed for total P in the whole leaves compared to phosphate-P in the leaf blades in the present experiment. The average phosphate-P concentration of the leaf blades at first sampling data (July 2) was 1714 ppm as compared to 2081 at second sampling date indicating an accumulation of P in the leaf blades with the advancement of season. Gordan et al. (1950) also observed that P accumulates in the whole corn plant until maturity with the most rapid accumulation occurring at silking time. So the results of the present experiment are in line with their findings.

The first order effect of P (Table 7) on phosphate-P concentration of the leaf blades was significantly positive at both sampling dates and for the seasonal mean indicating that P application increased the phosphate-P concentration of the leaf blades. This is in agreement with results reported by Soofi (1961, pp. 120) under similar experimental conditions. The first order effect of B was negative (although not significant) at the first sampling date indicating that B reduced the uptake of P by corn plant at high application levels of B. The Zn-population interaction (Table 7) was highly significantly negative at the second sampling date and almost significant for the season mean indicating that an increasing level of one increased the negative effect of the other on the phosphate-P concentration of the leaf blades. The Zn-B and B-population interactions were negative and probably real at the first sampling date showing that increasing the levels of Zn and population resulted in an increased negative effect of B on the phosphate-P

Table 7. Regression coefficients (b) and their standard errors (s_b) for concentrations of phosphate-P in the leaf blades (ppm, dry basis) at two dates of sampling and for the seasonal mean as affected by various combinations of coded levels of applied P, Zn and B and plant population (Pop).

Coefficient		July 2	July 21	Seasonal Mean
Mean	b_0	+ 1754	+ 2164	+ 1959
P	b_1	+ 118*	+ 100**	+ 109**
Zn	b_2	− 5	− 26	− 15
B	b_3	− 61	+ 11	− 26
Pop	b_4	− 24	+ 31	+ 4
	s_b	± 34	± 27	± 28
P^2	b_{11}	− 34	− 47	− 40
Zn^2	b_{22}	+ 39	− 48	− 4
B^2	b_{33}	− 34	+ 23	− 6
Pop^2	b_{44}	− 23	− 35	− 29
	s_b	± 32	± 24	± 26
P-Zn	b_{12}	+ 28	− 15	+ 7
P-B	b_{13}	+ 28	+ 49	+ 38
P-Pop	b_{14}	+ 10	+ 36	+ 22
Zn-B	b_{23}	− 79	+ 30	− 25
Zn-Pop	b_{24}	− 21	− 115**	− 68
B-Pop	b_{34}	− 61	− 24	− 42
	s_b	± 42	± 33	± 34
P-Zn-B	b_{123}	− 74	− 18	− 46
P-Zn-Pop	b_{124}	+ 3	+ 39	+ 21
P-B-Pop	b_{134}	− 38	+ 13	− 12
Zn-B-Pop	b_{234}	− 48	+ 50	+ 1
	s_b	± 42	± 33	± 34

* Significant at 5 percent level.

** Significant at 1 percent level.

concentration in the leaf blades. The negative P-Zn-B interaction was probably real, although not significant, at first sampling date and for the seasonal mean indicating that the Zn-B interaction was influenced by levels of P.

Phosphate-P concentration of midribs for the seasonal mean indicated a range of about 400 to 660 ppm with an average of 532 (Appendix table 14). Application of P increased the phosphate-P concentration in the midribs highly significantly at both sampling dates and consequently for the seasonal mean phosphate-P concentration (Table 8). The significant squared term of P for the seasonal mean indicated that the positive effect of P was relatively greater at high rates of application. The negative first order effect of population was highly significant at the first sampling date and significant at the second sampling date but became highly significant for the seasonal mean indicating reduced uptake of P by corn plants at higher plant population rates. The negative first order effect of Zn for the seasonal mean was not significant but its squared term was statistically significant indicating that Zn tended to cut down the P uptake most at higher rates of application. This is in agreement with results reported by other workers (Boawn and Leggett, 1964). They found a significant

Table 8. Regression coefficients (b) and their standard errors (s_b) for concentrations of Phosphate-P in the midribs (ppm, dry basis) at two dates of sampling and for the seasonal mean as affected by various combinations of coded levels of applied P, Zn and B and plant population (Pop).

Coefficient		July 2	July 21	Seasonal Mean
Mean	b_0	+ 490.4	+ 566.7	+ 527.9
P	b_1	+ 70.8**	+ 35.8**	+ 53.1**
Zn	b_2	+ 3.2	- 14.2	- 5.5
B	b_3	+ 1.3	- 4.3	- 1.8
Pop	b_4	- 31.4**	- 20.9*	- 26.4**
	s_b	± 5.15	± 6.91	± 3.72
P^2	b_{11}	+ 27.2**	- 9.4	+ 8.8*
Zn^2	b_{22}	- 2.7	- 15.6*	- 9.1*
B^2	b_{33}	+ 7.1	+ 1.4	+ 4.4
Pop^2	b_{44}	+ 2.4	± 0.0	+ 1.4
	s_b	± 4.67	± 6.26	± 3.37
P-Zn	b_{12}	- 4.4	+ 24.4*	+ 10.6
P-B	b_{13}	- 3.4	+ 8.9	+ 2.6
P-Pop	b_{14}	+ 20.4*	+ 6.6	+ 12.9*
Zn-B	b_{23}	- 21.0*	+ 2.9	- 8.8
Zn-Pop	b_{24}	- 5.5	+ 16.1	+ 5.8
B-Pop	b_{34}	+ 1.4	- 5.9	- 2.4
	s_b	± 6.31	± 8.46	± 4.56
P-Zn-B	b_{123}	- 4.1	- 1.3	- 2.1
P-Zn-Pop	b_{124}	+ 8.7	- 12.0	- 1.4
P-B-Pop	b_{134}	+ 7.1	- 15.3	- 4.7
Zn-B-Pop	b_{234}	+ 15.4*	+ 10.2	+ 13.2*
	s_b	± 6.31	± 8.46	± 4.56

* Significant at 5 percent level.

** Significant at 1 percent level.

decrease in concentration and total P uptake as the Zn concentration in the nutrient solution was increased.

The P-Zn interaction (almost significant) and the significant P-population interaction for the seasonal mean phosphate-P concentration were positive indicating that as the amount of P was increased, the negative effects of Zn and population were decreased (Table 8). The Zn-B-population interaction was positive at both sampling dates but significant at the first sampling date and for the seasonal mean (Table 8). When plant population was at a low level (Figure 8), the effect of B was to increase the phosphate-P concentration in the midribs at a low level of Zn but to decrease it at a high level of Zn indicating a negative Zn-B interaction at a low level of plant population. However at a high level of plant population the Zn-B interaction tended to disappear. The effect of Zn application on the phosphate-P concentration of the midribs was almost similar to that of B application indicating a negative Zn-B interaction at a low level of plant population which tended to disappear at a high population level. It was concluded that the negative Zn-B interaction was effective only at low level of population and tended to disappear at a high population level.

A comparison of Tables 7 and 8 revealed that

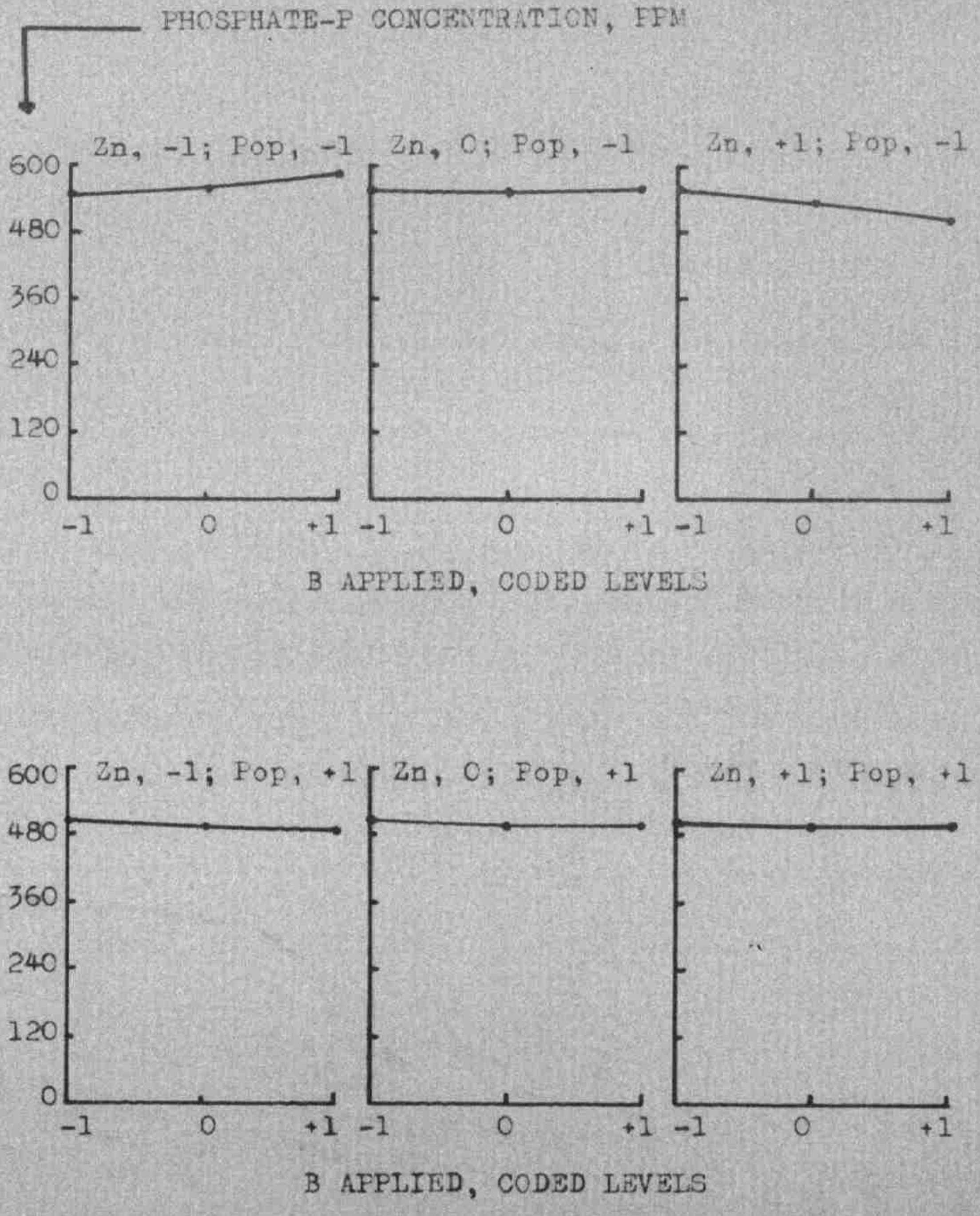

Figure 8. The seasonal mean concentration of phosphate-P of midribs (dry-basis) as affected by levels of applied B at constant levels of applied Zn. Population was held at -1 (above) and +1 (below) and P was held at the 0 coded level.

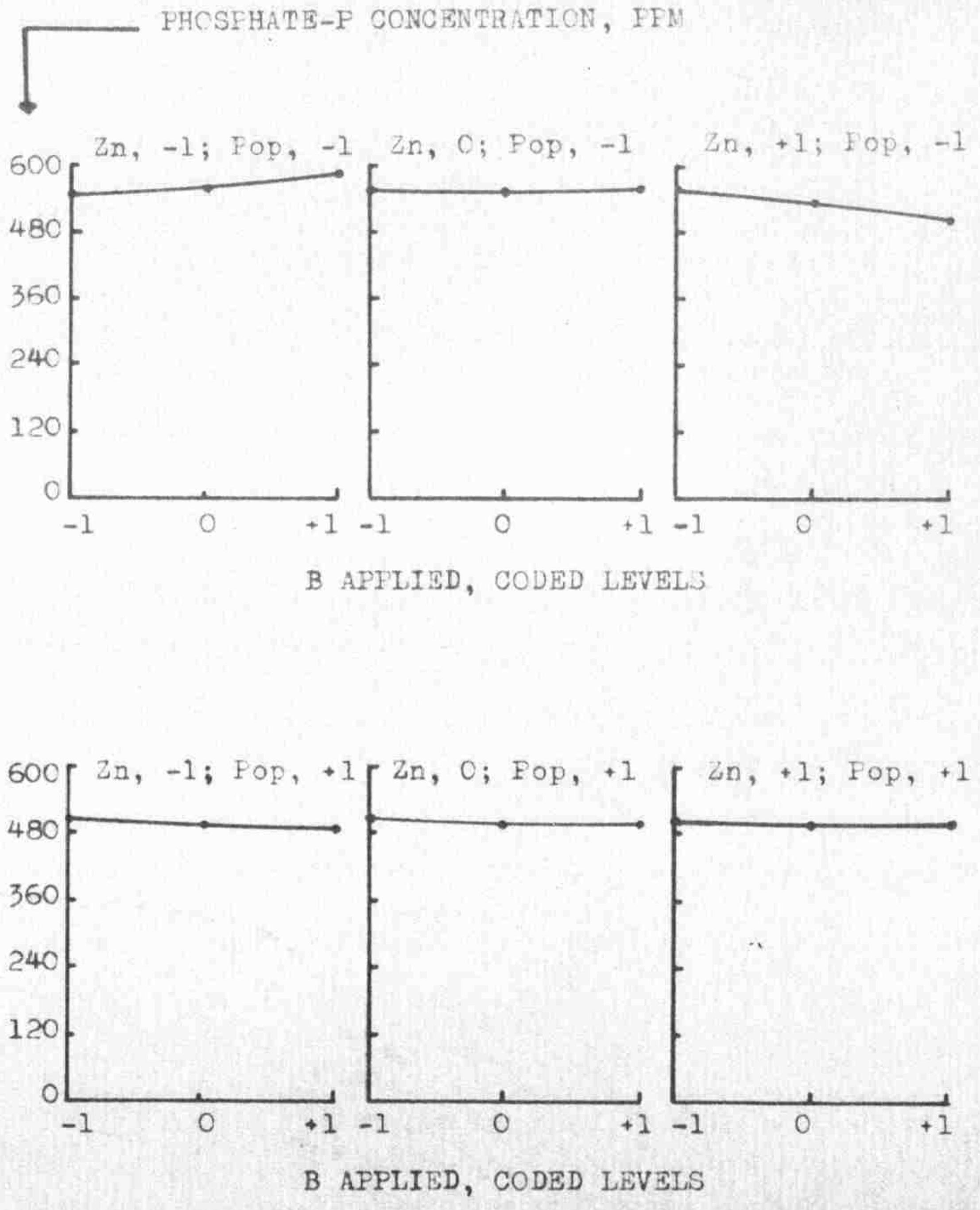

Figure 8. The seasonal mean concentration of phosphate-P of midribs (dry-basis) as affected by levels of applied B at constant levels of applied Zn. Population was held at -1 (above) and +1 (below) and P was held at the 0 coded level.

the analysis of the midribs resulted in more significant differences than that of the blades. Also the relative magnitude of change was much greater in midribs (about 10 percent of b_0) as compared to that in the leaf blades (about 5 percent of b_0). This indicated that the midribs were more sensitive to phosphate-P supply than the leaf blades. Ulrich _et_ _al_. (1959) also reported that the phosphate-P of sugar beet petiole (corresponds to midrib) was a good indicator of the P status of the plant. Thus it was concluded that phosphate-P concentration of the midribs was a better indication for the P status of corn plants. The observed phosphate-P concentration of the midribs for the seasonal mean was in the vicinity of the 500 ppm (dry basis) in the midribs suggested by Tyler and Lorenz (undated) as a "deficiency level". However, they determined phosphate-P in the midribs of the first leaf above the primary ear of sweet corn compared to the midribs of leaves below the primary ear of the field corn, Indiana 620A, in the present experiment. Since the yields of corn were not greatly affected by P application, no definite amount could be associated as an adequate level of phosphate-P in the midribs.

Total B concentration of the leaf blades collected at first sampling date (Appendix table 15) varied from 84 to 338 ppm with an average of 161. These values were considerably higher than those obtained by Soofi (1961, pp. 61) under similar experimental conditions. However, he analysed the whole leaves (sixth leaf at tasseling stage) as compared to the leaf blades (sixth leaf at pretasseling stage) in the present experiment. Since B has been found to accumulate more along the leaf margins, leaf blades would be expected to have higher total B concentrations than whole leaves. Also the levels of B applied in this experiment were higher than those used by Soofi (1961, pp. 20). The correlation coefficient between the actual concentrations and calculated values was 0.939 indicating a very close fit of the partial cubic regression equation to the actual data.

The application of B highly significantly increased the total B content of the leaf blades (Table 9). This was in agreement with results reported by Soofi (1961, pp. 54). The first order effect of P was significantly positive indicating an increase in B concentration of the leaf blades with P application. The negative P-Zn interaction was probably real indicating that the positive effect of P application on the total B concentration of the leaf blades was decreased at high levels of Zn application. The P-B, Zn-B and B-population interaction terms were positive

Table 9. Regression coefficients (b) and their standard errors (s_b) for concentrations of B and Zn (dry basis) in corn leaves at first sampling date (July 2) as affected by various combinations of coded levels of applied P, Zn and B and plant population (Pop).

Coefficient		Concentration in corn leaves		
		Total B in blades, ppm	Total B in midribs, ppm	Zn in blades ppm
Mean	b_0	+ 141.43	+ 68.86	+ 24.57
P	b_1	+ 17.46*	+ 3.00*	- 1.12
Zn	b_2	- 1.79	- 1.17	+ 4.12**
B	b_3	+ 63.79**	+ 11.58**	- 2.54*
Pop	b_4	- 0.79	- 2.58	+ 0.04
	s_b	± 6.133	± 1.226	± 0.762
P^2	b_{11}	+ 3.71	+ 4.60**	- 0.38
Zn^2	b_{22}	+ 6.09	+ 4.22**	+ 1.62
B^2	b_{33}	+ 8.09	+ 6.72**	+ 1.49
Pop^2	b_{44}	+ 6.21	+ 2.14	+ 0.74
	s_b	± 5.562	± 1.112	± 0.691
P-Zn	b_{12}	- 9.06	+ 1.75	+ 0.44
P-B	b_{13}	+ 13.31	+ 2.12	- 0.69
P-Pop	b_{14}	- 4.44	- 1.00	- 0.56
Zn-B	b_{23}	+ 11.46	+ 1.75	+ 0.69
Zn-Pop	b_{24}	+ 13.06	- 0.62	+ 0.56
B-Pop	b_{34}	+ 9.69	- 1.75	- 0.81
	s_b	± 7.516	± 1.503	± 0.934
P-Zn-Pop	b_{123}	- 1.19	- 0.25	- 0.31
P-Zn-B	b_{124}	+ 9.81	- 2.62	- 0.69
P-B-Pop	b_{134}	+ 1.69	- 0.25	+ 0.44
Zn-B-Pop	b_{234}	+ 21.94*	+ 1.88	+ 0.56
	s_b	± 7.516	± 1.503	± 0.934

* Significant at 5 percent level.

** Significant at 1 percent level.

and probably real indicating that the positive effect of B application on the total B content of the leaf blades was enhanced at high levels of applied P and Zn and plant population. The positive Zn-population interaction (probably real) indicated that the positive effect of one was increased by increasing the level of the other.

The Zn-B-population interaction for the total B concentration of the leaf blades was significantly positive (Table 9). When B was at a low level, application of Zn generally decreased the total B concentration of the leaf blades with maximum depressing effect at a high plant population level (Figure 9). However, at a high level of B, response to Zn application was negative at a low level of population but positive at a high level of population. This indicated that the Zn-population interaction was important at a high B level but tended to be negative at a low B level. It was concluded that the Zn-population interaction was most positively effective at a high B level.

<u>The total B concentration of midribs</u> at the first sampling date varied from 55 to 120 ppm with an average of 82 for all 31 plots (Appendix table 15). These values are in agreement with those reported by Fuehring (1966) under similar experimental conditions. The highly significant positive regression coefficient

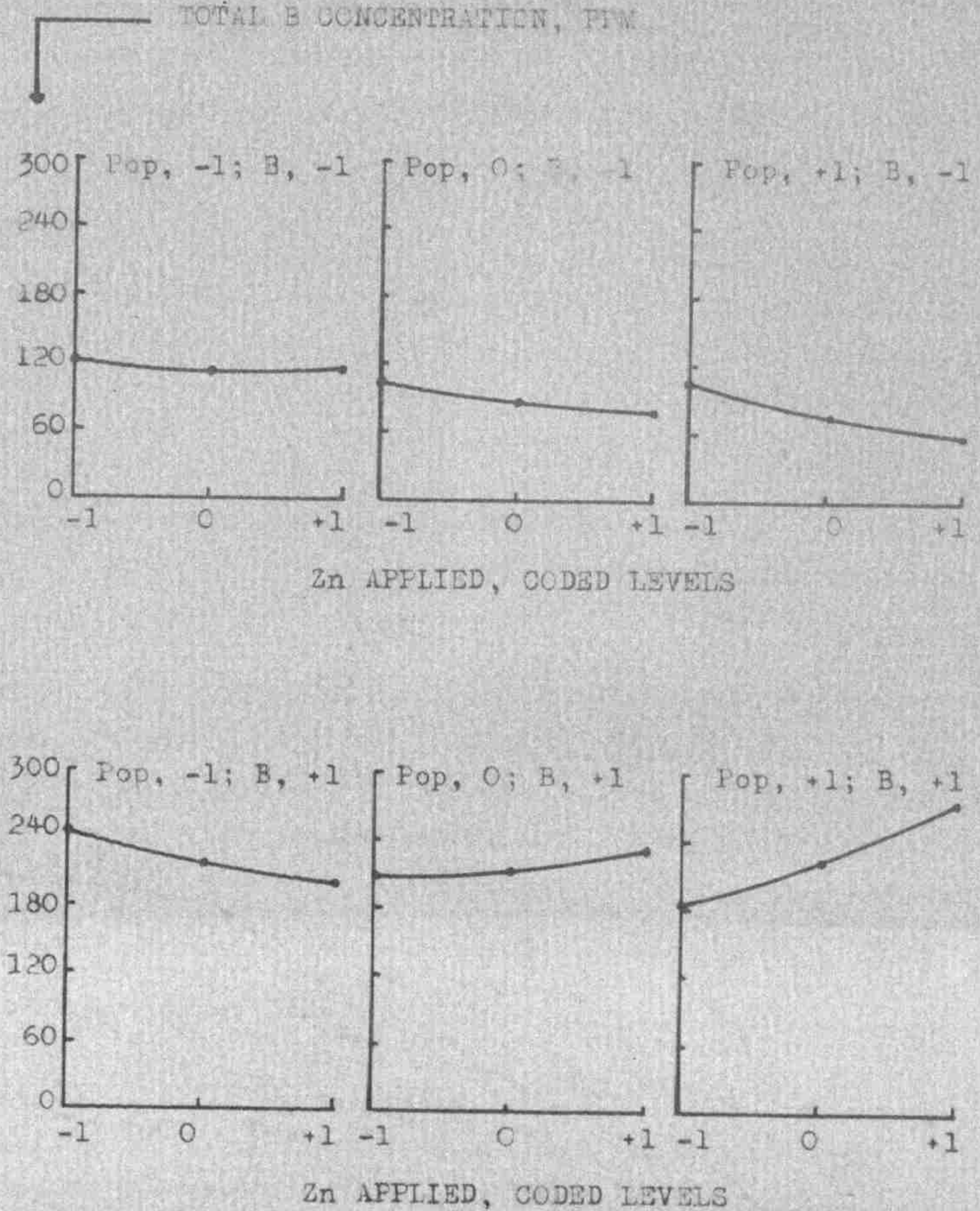

Figure 9. Concentration of total B of the leaf blades (dry basis) as affected by levels of applied Zn at constant levels of population (Pop). B was held at -1 (above) and +1 (below) and P was held at the 0 coded level.

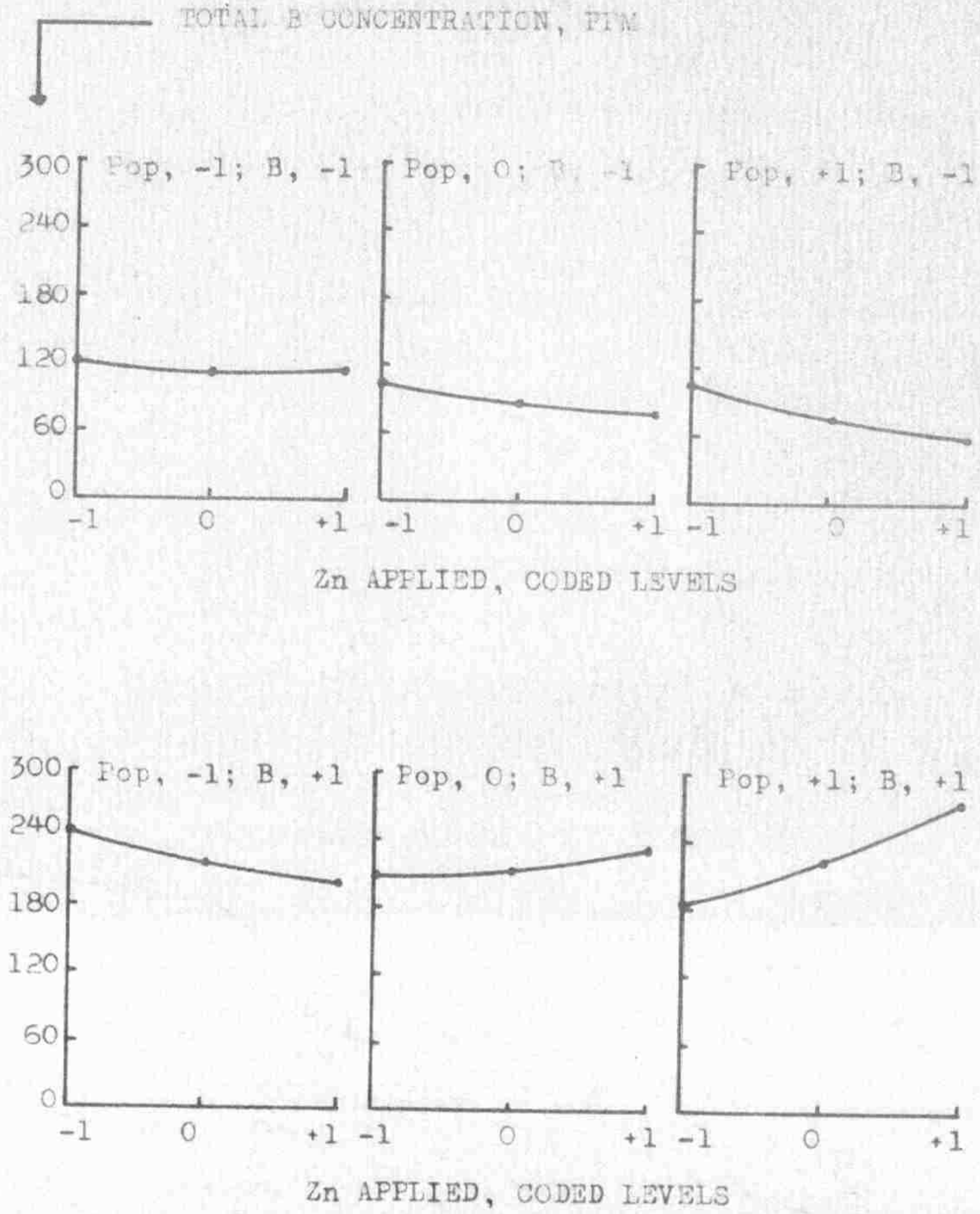

Figure 9. Concentration of total B of the leaf blades (dry basis) as affected by levels of applied Zn at constant levels of population (Pop). B was held at -1 (above) and +1 (below) and P was held at the 0 coded level.

for B (Table 9) indicated that B application increased the total B concentration of the midribs at first date of sampling. This is in line with the findings of another American University researcher (Fuehring, 1966). The squared term for B was also highly significantly positive showing an increasing positive effect of B on the total B concentration of the midribs at the relatively higher rates of application. The positive effect of P application (significant) was relatively greater at high P levels as indicated by the highly significantly positive squared term. The P-B interaction was positive and probably real indicating that the positive effect of one variable was enhanced at the higher levels of the other. The Zn-B-population interaction was probably real and positive as in case of the leaf blades indicating that the interaction between two of the variables involved tended to be influenced by the third variable.

A comparison between the regression coefficients of total B in leaf blades and midribs (Table 9) indicated that the leaf blades of the sixth leaf at pretasseling stage were more sensitive in giving significant differences than the midribs. The relative magnitude of change in the total B concentration of the leaf blades was much greater (45 percent of b_0) than that in the total B concentration of the midribs (16 percent of b_0). Moreover, the relatively higher R value and the much broader range of values for the total B concentration in the leaf blade (Appendix table 15) indicated a probable more sensitive test of the B status of plant than the total B content of the midribs. Since there was no definite response of corn yields to B application as compared to a highly significant effect of B application on the total B contents of the leaf blades and midribs, no definite critical level of total B in these plant parts could be suggested. However, the observed total B concentration of the midribs were within the optimum range of 60 to 100 or 120 ppm (depending on plant population levels) suggested by Fuehring (1966).

Concentration of Zn in the leaf blades at the first sampling date (July 2) ranged from 16 to 38 ppm with an average of 27 (Appendix table 15). The correlation coefficient (R) between the observed concentrations and the calculated concentrations was 0.907 indicating a very close fit of the partial cubic regression equation to the actual data. The application of Zn highly significantly increased the Zn concentration of the leaf blades (Table 9). The first order effect of B was significantly negative indicating that B application decreased the Zn uptake by corn plants. The first order effect of P application on the Zn concentration of the leaf blades was negative and probably real, although not significant , indicating that P application depressed the Zn uptake by corn plants. This may confirm the mutual antagonism between P and Zn in their uptake by corn plants reported by many researchers (Bingham and Garber, 1960; Ellis _et al_., 1964; Watanabe _et al_., 1965).

The application of Zn had little effect on the grain yield in contrast to the highly significant positive effect on Zn concentration in the leaf blades. However, relatively high grain yields (Table 3) were obtained over the entire range of 16-38 ppm Zn concentration in the leaf blades at the first sampling date (Appendix table 15). These values are in agreement with those reported by Viets _et al_. (1953) and Soofi (1961, pp. 47) as being adequate for high corn yields.

Experiment "B": Interrelationships of S, Zn, B and plant population on concentrations of the sulfate-S, total B, and Zn in corn leaves (leaf blades and midribs) have been reported in the following paragraphs.

Sulfate-S concentration of leaf blades for the seasonal mean ranged from about 1060 to 2050 ppm with an average of 1450 (appendix table 16). The multiple regression coefficient (R) between the observed seasonal mean concentration and those calculated from the regression equation indicated a very close fit of the regression equation to the actual data. The average sulfate-S concentration of the leaf blades was 1650 ppm at first sampling date as compared to 1280 ppm at the second sampling date indicating a decrease in S supply with the advancement of season.

The application of S highly significantly increased the sulfate-S concentration at the first sampling date and for the seasonal mean and significantly at the second sampling date (Table 10). This is in agreement with results reported by Soofi (1961, pp.147) who found that the S concentration of the sixth leaf at tasseling was highly significantly increased by S application. The first order effect of Zn application was positive (probably real) at the second sampling date and for the seasonal mean. The squared term for Zn was significantly positive at both sampling dates and became highly significant for the seasonal mean concentration of the leaf blades indicating that the positive effect of Zn was relatively greater at higher rates of Zn application. The squared term for population was positive at both sampling dates but significant at first sampling date and for the seasonal mean showing that at higher population rates sulfate-S tended to accumulate in the leaf blades. Prine and Schroder (1964) reported that above ground factors, especially reduction in light, limit corn growth at high plant densities. Since the sulfate-S

Table 10. Regression coefficients (b) and their standard errors (s_b) for concentrations of sulfate-S in the blades (ppm, dry basis) at two dates of sampling and for the seasonal mean as affected by various combinations of coded levels of applied S, Zn and B and plant population (Pop).

Coefficient		July 2	July 21	Seasonal Mean
Mean	b_0	+ 1466	+ 1157	+ 1317
S	b_1	+ 186**	+ 130*	+ 136**
Zn	b_2	+ 11	+ 51	+ 48
B	b_3	− 41	+ 41	+ 24
Pop	b_4	+ 20	− 37	+ 16
	s_b	± 28	± 40	± 20
S^2	b_{11}	+ 59	+ 1	+ 24
Zn^2	b_{22}	+ 72*	+ 88*	+ 74**
B^2	b_{33}	+ 37	+ 14	+ 19
Pop^2	b_{44}	+ 71*	+ 55	+ 56*
	s_b	± 26	± 36	± 19
S-Zn	b_{12}	− 19	− 109	− 28
S-B	b_{13}	+ 66	+ 18	+ 68*
S-Pop	b_{14}	− 22	+ 1	+ 15
Zn-B	b_{23}	+ 23	+ 36	− 3
Zn-Pop	b_{24}	− 10	+ 33	− 21
B-Pop	b_{34}	− 219**	− 64	− 172**
	s_b	± 35	± 48	± 25
S-Zn-B	b_{123}	− 7	− 46	− 57
S-Zn-Pop	b_{124}	− 44	+ 45	− 30
S-B-Pop	b_{134}	− 45	+ 9	− 50
Zn-B-Pop	b_{234}	+ 31	+ 0	+ 41
	s_b	± 35	± 48	± 25

* Significant at 5 percent level.

** Significant at 1 percent level.

taken up by plants is metabolized into proteins for which organic substrate is needed, reduction in light may possibly block the sulfate-S metabolism and result in sulfate accumulation.

The S-B interaction was significantly positive for the seasonal mean concentration indicating that B application increased the positive effect of S on the sulfate-S concentration of the leaf blades (Table 10). The B-population interaction was highly significantly negative at the first sampling date and for the seasonal mean denoting that B was depressing the positive effect of population on the sulfate-S concentration of the leaf blades. The S-B-population interaction was negative (almost significant) for the seasonal mean concentration. When S was at a low level, the effect of plant population on the sulfate-S concentration of the leaf blades for the seasonal mean was positive at a low level of B but negative at a high B level, indicating a negative B-population interaction (Figure 10). This negative B-population interaction became more pronounced at a high S level. The effect of B application was similar to that of plant population (described above). It was concluded that the B-population interaction for the seasonal mean sulfate-S concentration of the leaf blades was negative at both low and high S levels.

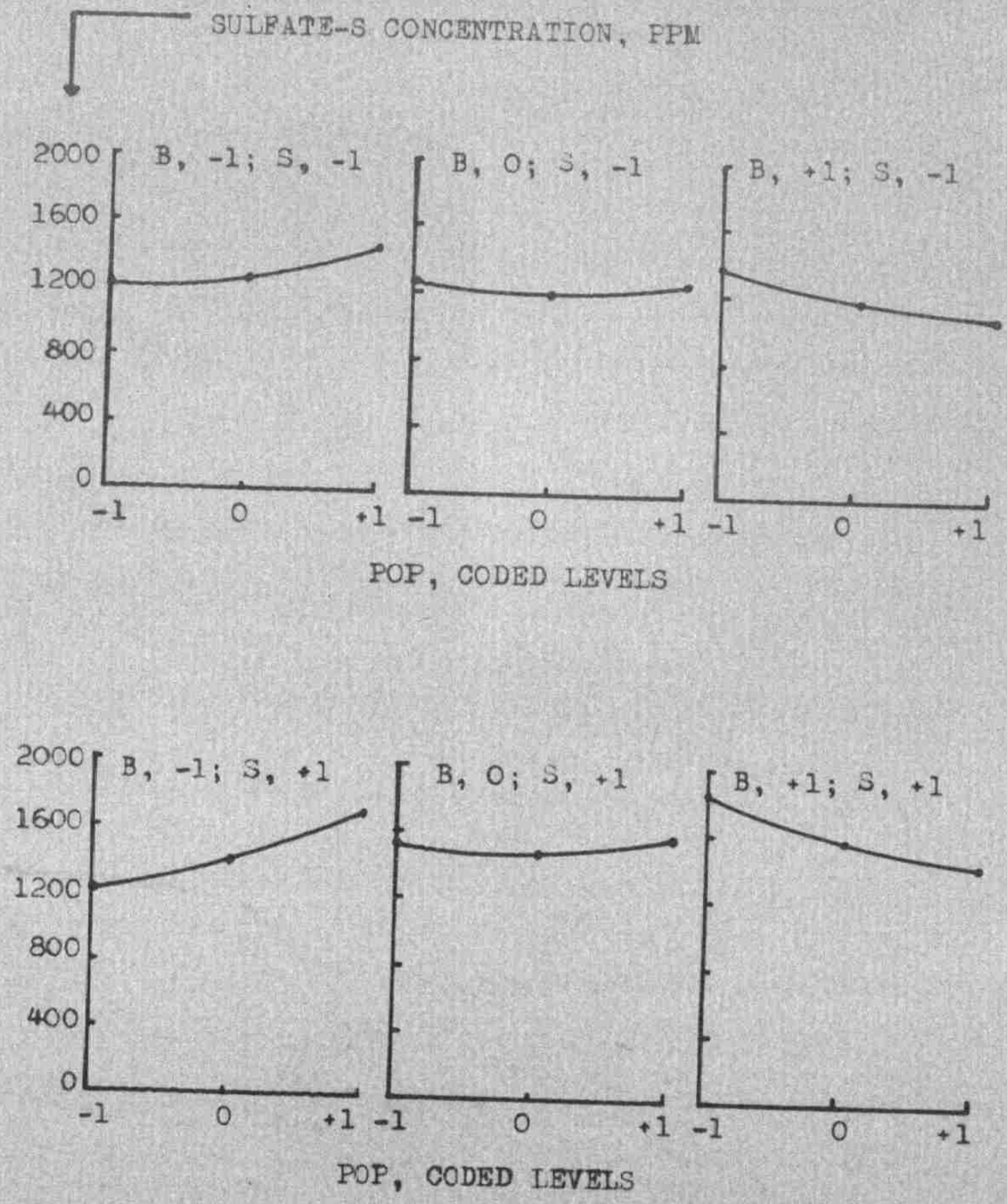

Figure 10. The seasonal mean sulfate-S concentration of the leaf blades (dry basis) as affected by levels of population at constant levels of B. S was held at -1 (above) and +1 (below) and Zn was held at the 0 coded level.

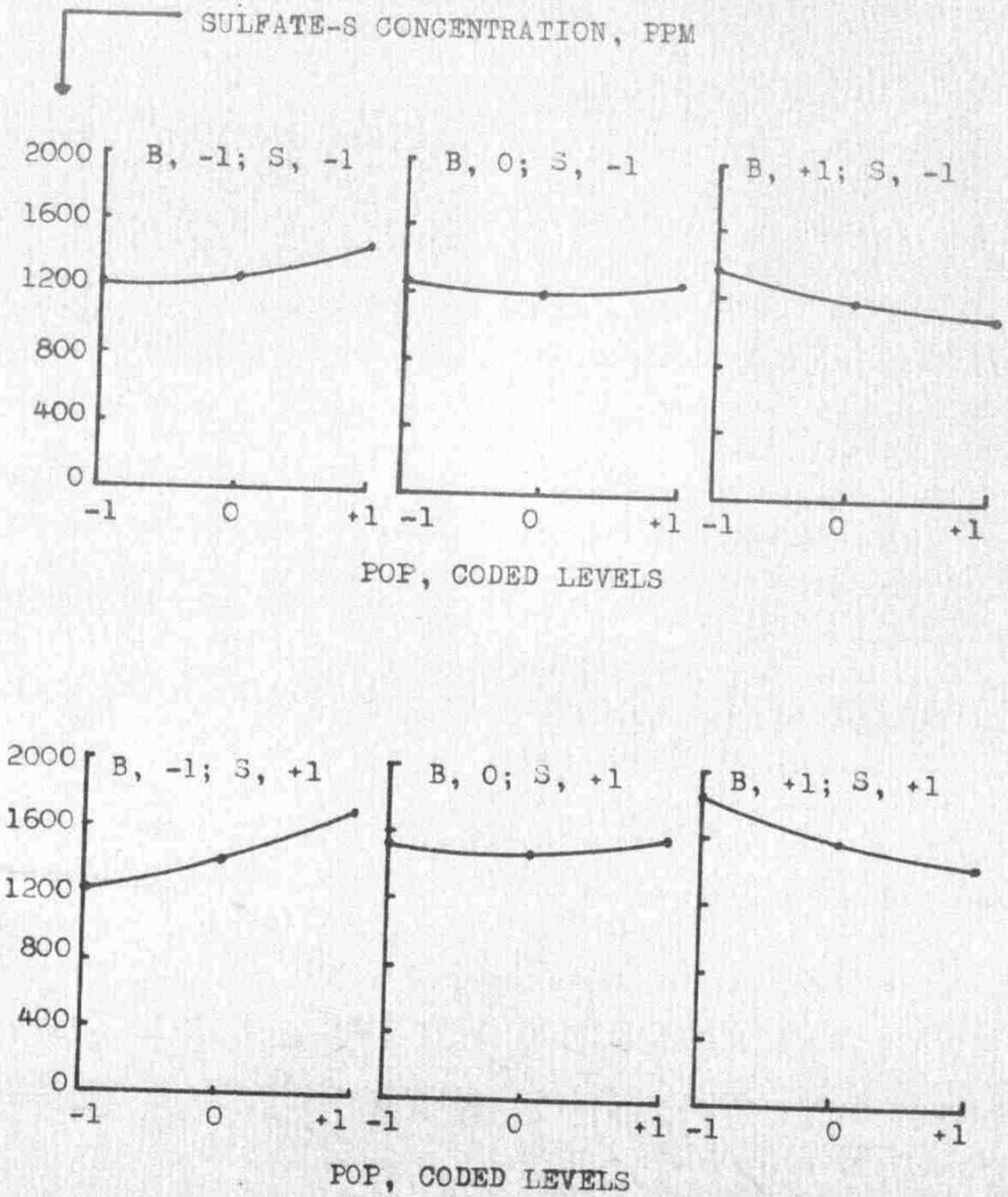

Figure 10. The seasonal mean sulfate-S concentration of the leaf blades (dry basis) as affected by levels of population at constant levels of B. S was held at -1 (above) and +1 (below) and Zn was held at the 0 coded level.

However, the effect was relatively more marked at a high level of S.

<u>Sulfate-S concentration of the midribs</u> for the seasonal mean varied from 642 to 1240 ppm with an average of 917 (Appendix table 17). The average sulfate-S concentration of the midribs at the first sampling date (July 2) was 936 ppm compared to 910 at the second sampling date (July 21).

The effect of S application on the sulfate-S concentration of the midribs was significantly positive at both sampling dates and became highly significant for the seasonal mean (Table 11). The first order effect of plant population was consistantly negative at both sampling dates and became almost significant for the seasonal mean concentration indicating that the rate of S uptake tended to be decreased as the plant density was increased. This further supported the hypothesis that increased sulfate-S concentration in the leaf blades was not due to increased supply of S from the soil but because of enhanced accumulation of sulfate-S possibly induced by reduction in light and decreased metabolism of S at higher plant densities. The Zn-population interaction was significantly negative at the second sampling date and negative (although not significant) for the seasonal mean indicating that increasing level of one increased the negative effect

Table 11. Regression coefficients (b) and their standard errors (s_b) for concentrations of sulfate-S in the midribs (ppm, dry basis) at two dates of sampling and for the seasonal mean as affected by various combinations of coded levels of applied S, Zn and B and plant population (Pop).

Coefficient		July 2	July 21	Seasonal Mean
Mean	b_0	+ 923	+ 977	+ 950
S	b_1	+ 77*	+ 83*	+ 79**
Zn	b_2	− 42	− 28	− 28
B	b_3	+ 36	+ 12	+ 26
Pop	b_4	− 58	− 29	− 46
	s_b	± 25	± 24	± 19
S^2	b_{11}	+ 17	− 54*	− 17
Zn^2	b_{22}	+ 26	− 2	+ 12
B^2	b_{33}	− 2	− 36	− 26
Pop^2	b_{44}	− 25	+ 6	− 10
	s_b	± 23	± 22	± 17
S-Zn	b_{12}	+ 1	− 39	− 16
S-B	b_{13}	+ 51	+ 16	+ 24
S-Pop	b_{14}	− 2	+ 48	+ 13
Zn-B	b_{23}	− 31	− 31	− 28
Zn-Pop	b_{24}	− 30	− 76*	− 50
B-Pop	b_{34}	+ 21	+ 3	+ 3
	s_b	± 31	± 30	± 23
S-Zn-B	b_{123}	− 28	− 46	− 27
S-Zn-Pop	b_{124}	− 31	− 22	− 17
S-B-Pop	b_{134}	− 16	+ 18	− 2
Zn-B-Pop	b_{234}	− 4	− 17	− 1
	s_b	± 31	± 30	± 23

* Significant at 5 percent level.

** Significant at 1 percent level.

of the other on the sulfate-S concentration in the midribs.

A comparison of Tables 10 and 11 revealed that analysis of leaf blades resulted in slightly more significant differences than the analysis of midribs. The relative magnitude of change in the sulfate-S concentration of the leaf blade per coded unit of applied S was about 10 percent of the b_0 value as compared to about 8 percent for the midribs. Ulrich et al. (1959, pp. 18) reported that sugar beet leaf blades appear to be a better indicator of the S status of the plant than the petioles. However, the tendency for sulfate-S to accumulate in the leaf blades at high plant population levels suggests that the midrib analysis may result in a better indication of the current S supplying power of the soil. Further investigation is needed on this phase of the S nutrition of corn.

The relatively small effect of other variables on the sulfate-S content of the leaf blades and midribs as compared to the significant positive effect of S application indicated that the sulfate-S concentration of these plant tissues was a good indication for the S supply to the plant. Since the yields of corn were not influenced very much by S application, no definite amount could be suggested as an adequate level of sulfate-S concentration in these corn leaf parts.

Total B concentration of leaf blades at the first sampling date (July 2) observed in this experiment indicated a range of 47 to 243 ppm with an average of 129 (Appendix table 18). These values were considerably higher than those obtained by Soofi (1961, pp. 61) as discussed previously for experiment""A". The application of B highly significantly increased the total B concentration in the leaf blades at the first sampling date (Table 12). This is in accordance with results reported by Soofi (1961, pp. 54) under similar experimental conditions. The B-population interaction was significantly negative indicating that increasing population level decreased the positive effect of B application on the total B concentration of the leaf blades.

The S-B-population interaction was negative and statistically significant for the total B concentration of the leaf blades at first sampling date (Table 12). When S was at a low level, the effect of plant population was negligible at both low and high levels of B (Figure 11). However, at a high level of S, response to plant population was slightly positive at a low B level but markedly negative at a high B level indicating a negative B-population interaction. Response to B application was positive at all levels

Table 12. Regression coefficients (b) and their standard errors (s_b) for concentrations of B and Zn (dry basis) in corn leaves at first sampling date (July 2) as affected by various combinations of coded levels of applied S, Zn and B and plant population (Pop).

Coefficient		Concentration in corn leaves		
		Total B in blades, ppm	Total B in midribs, ppm	Zn in blades, ppm
Mean	b_0	+ 110.57	+ 48.94	+ 20.86
S	b_1	− 2.67	+ 1.83	+ 0.29
Zn	b_2	+ 4.92	− 0.49	+ 4.96**
B	b_3	+ 37.42**	+ 12.97**	− 2.62**
Pop	b_4	− 5.33	+ 1.04	− 1.46
	s_b	± 5.650	± 1.511	± 0.671
S^2	b_{11}	+ 3.77	+ 4.76*	+ 1.65*
Zn^2	b_{22}	+ 0.15	+ 1.12	+ 2.27**
B^2	b_{33}	+ 11.52	+ 6.38**	+ 2.40**
Pop^2	b_{44}	+ 7.77	+ 3.53*	+ 0.65
	s_b	± 5.123	± 1.370	± 0.608
S-Zn	b_{12}	− 4.12	+ 0.44	+ 0.94
S-B	b_{13}	− 6.50	− 1.51	+ 0.69
S-Pop	b_{14}	− 8.38	− 0.12	− 0.31
Zn-B	b_{23}	− 1.75	− 0.93	− 0.44
Zn-Pop	b_{24}	− 4.38	− 2.00	− 0.19
B-Pop	b_{34}	− 20.75*	+ 2.93	+ 1.06
	s_b	± 6.924	± 1.851	± 0.822
S-Zn-B	b_{123}	− 4.62	+ 1.16	− 0.31
S-Zn-Pop	b_{124}	+ 10.75	+ 1.67	+ 0.19
S-B-Pop	b_{134}	− 16.88*	− 1.43	+ 0.19
Zn-B-Pop	b_{234}	− 5.12	− 2.14	+ 1.56
	s_b	± 6.924	± 1.851	± 0.822

* Significant at 5 percent level.

** Significant at 1 percent level.

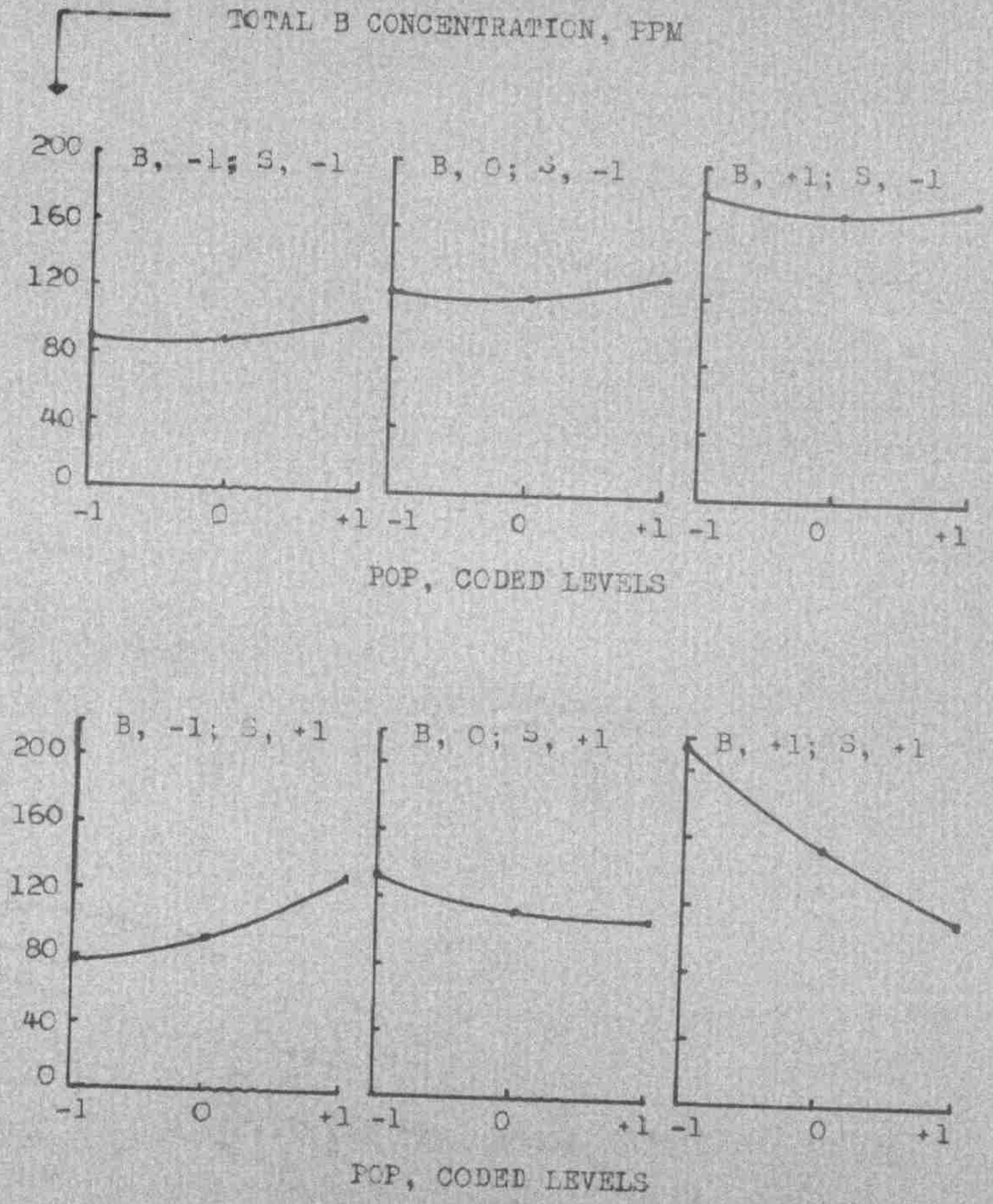

Figure 11. Concentration of total B of the leaf blades (dry basis) as affected by levels of population (Pop) at constant levels of applied B. S was held at -1 (above) and +1 (below) and Zn was held at the 0 coded level.

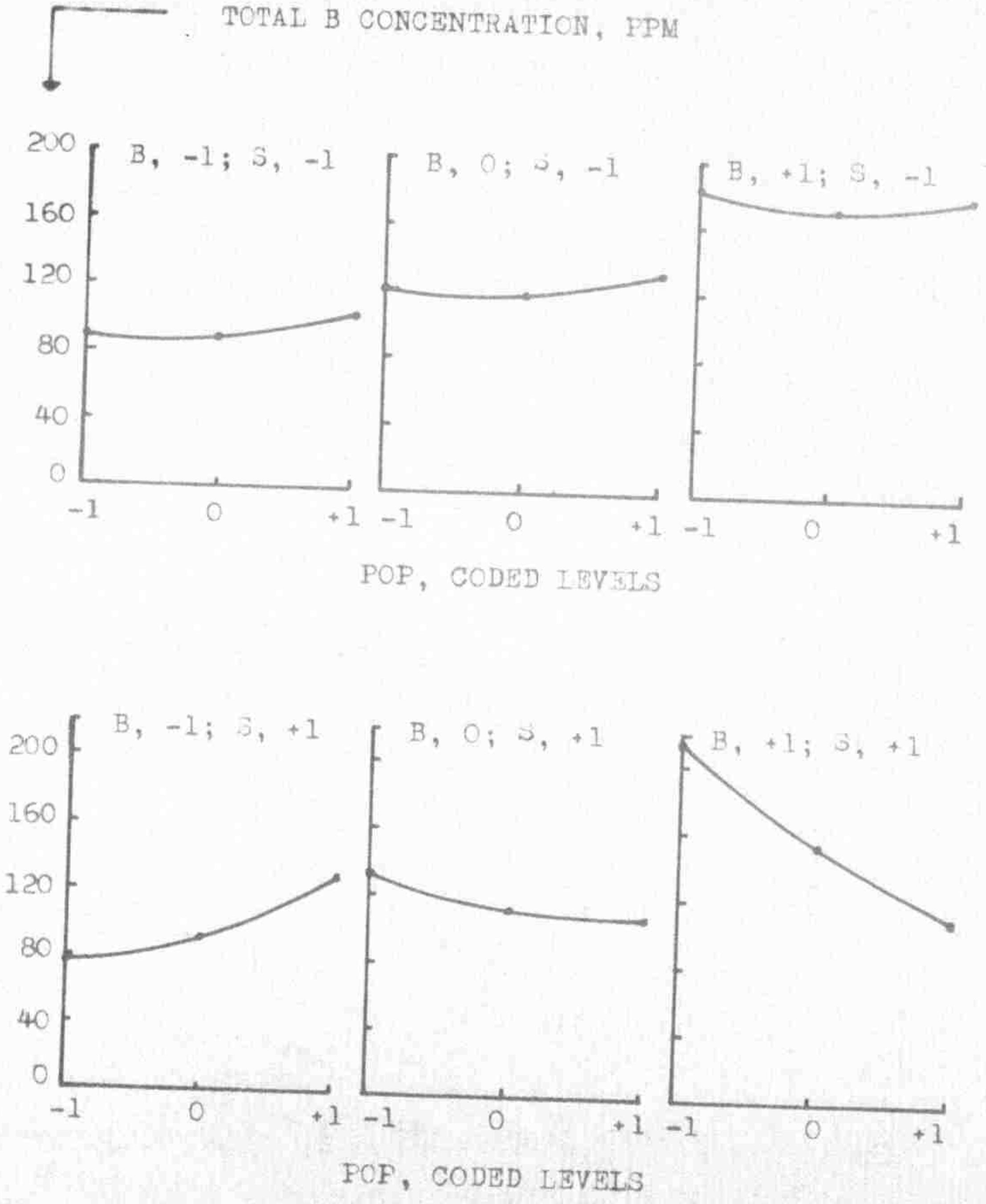

Figure 11. Concentration of total B of the leaf blades (dry basis) as affected by levels of population (Pop) at constant levels of applied B. S was held at -1 (above) and +1 (below) and Zn was held at the 0 coded level.

of plant population when S was at a low level (Figure 12). But at a high level of S, B application increased the total B concentration of the leaf blades at a low plant population level but the effect was negligible at a high plant population level indicating enhanced B requirements of corn plants at high plant population rates as reported by Fuehring (1966). It was concluded from figures 11 and 12 that the negative B-population interaction was important only at a high level of S application.

Total B concentration of midribs at the first sampling date (July 2) varied from 38 to 98 ppm with an average of 61 (Appendix table 18). These values are in line with results reported by Fuehring (1966). The application of B highly significantly increased the total B content of the corn midribs (Table 12),the squared term for B was also highly significantly positive indicating that the positive effect of B application was relatively greater at the higher coded levels of application. These results coincide with the finding of another American University research worker (Fuehring, 1966) under similar conditions. The first order effect of S application was positive, although too small to be significant, but its squared term was significantly positive showing that S application at the higher coded levels had relatively greater positive effect on B

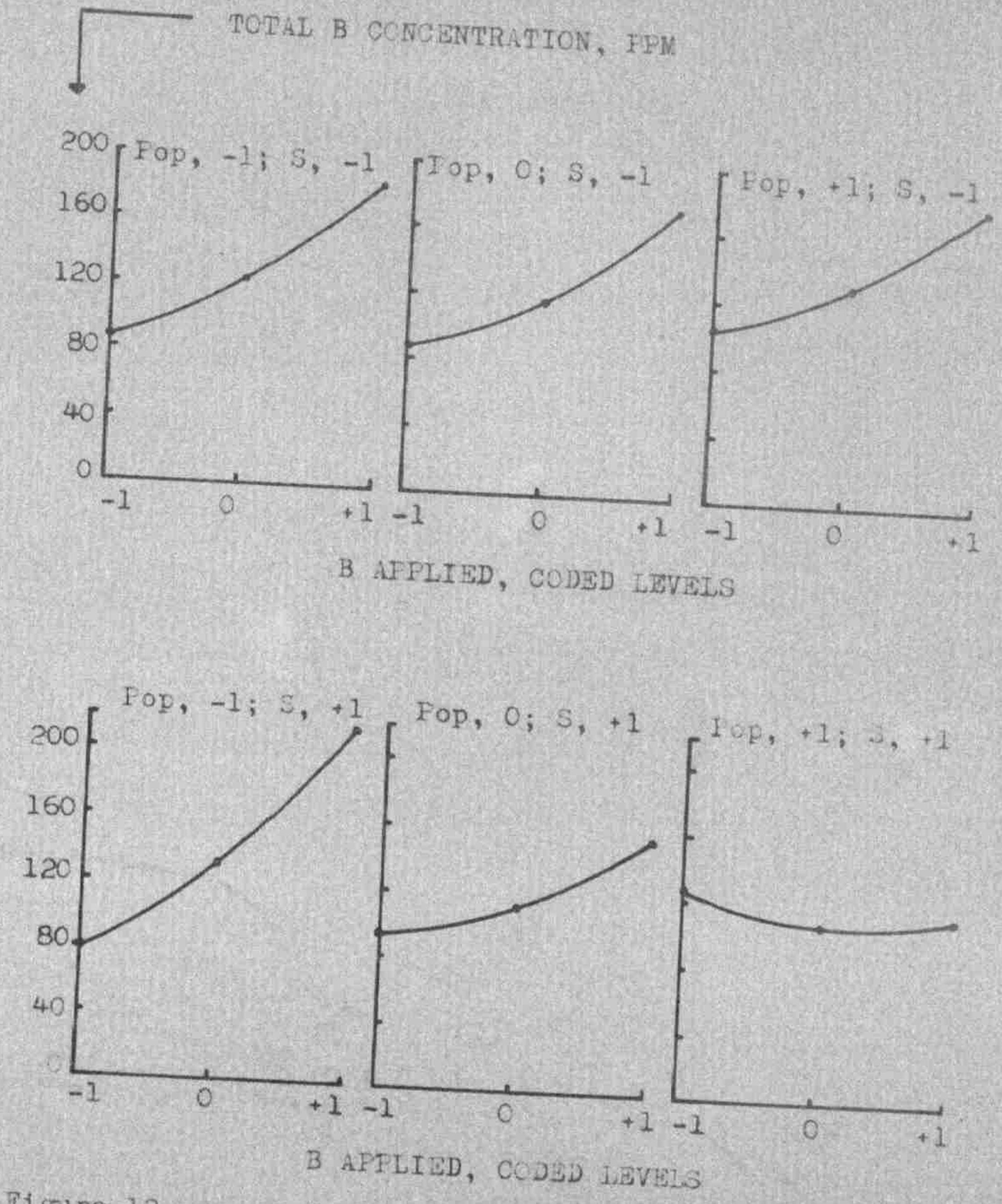

Figure 12. Concentration of total B of the leaf blades (dry basis) as affected by levels of applied B at constant levels of population. S was held at -1 (above) and +1 (below) and Zn was held at the 0 coded level.

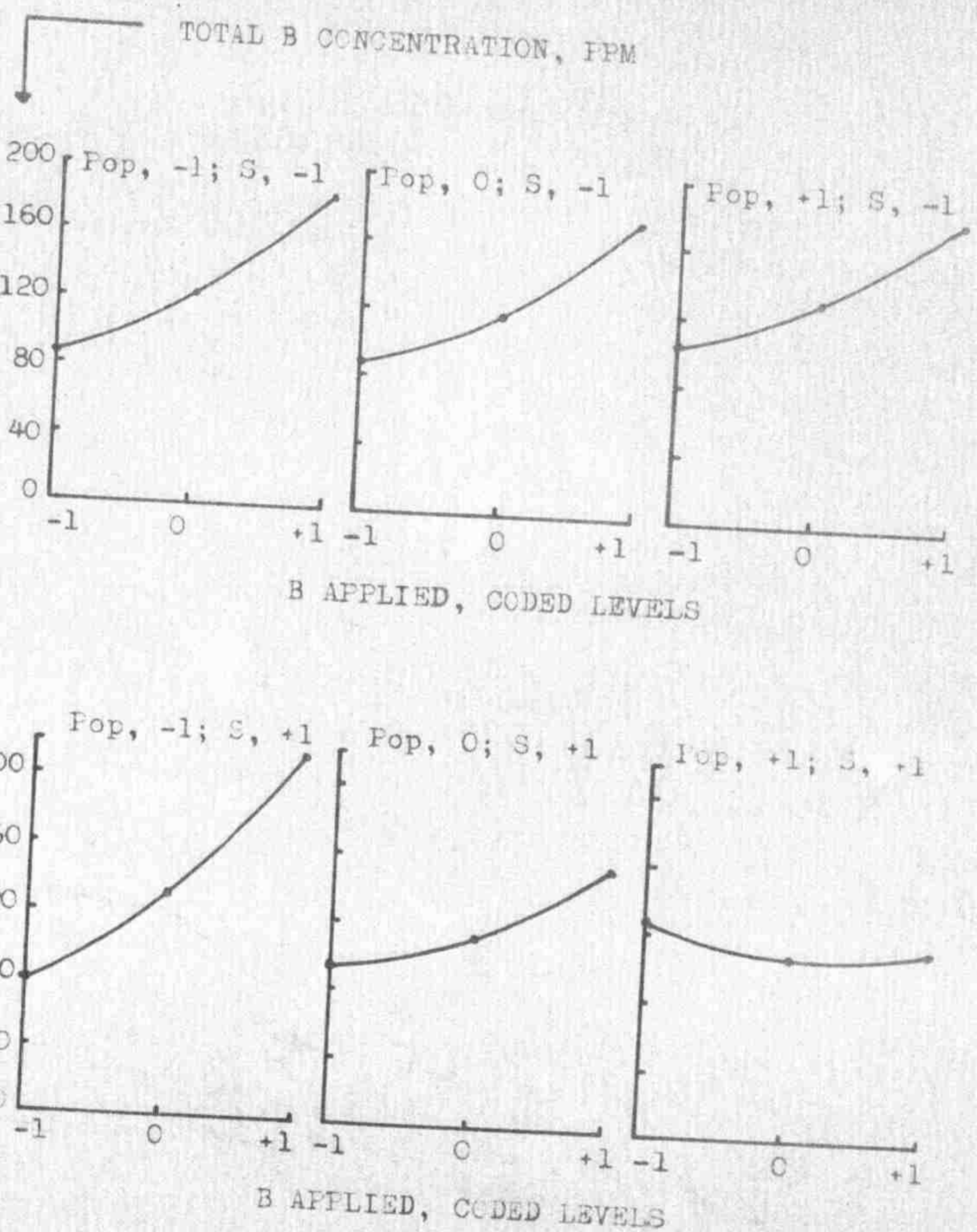

Figure 12. Concentration of total B of the leaf blades (dry basis) as affected by levels of applied B at constant levels of population. S was held at -1 (above) and +1 (below) and Zn was held at the 0 coded level.

concentration of the midribs. The first order effect of plant population was negligible but its significant squared term indicated that the B concentration in the corn midribs was increased at higher coded levels of plant population as also found by Fuehring (1966).

A comparison of the regression coefficients for the concentrations of total B in leaf blades and midribs (Table 12) revealed that the analysis of the leaf blades resulted in more significant differences than the analysis of midribs. The relative magnitude of change in concentration of total B of the leaf blades was about 34 percent of b_0 as compared to 25 percent for the midribs. Similar observations were obtained in experiment "A" reported above. On the basis of the results from these two experiments, it was concluded that the total B concentration of the leaf blades was a better indicator of the B status of corn plants at pretasseling stage. With regard to "critical level", no definite suggestion can be made as yet and considerable more work at deficiency levels is needed.

Zn concentration of the leaf blades of the sixth corn leaf at pretasseling stage had a range of 15 to 41 ppm with an average of 26 (Appendix table 18). The values are in agreement with those reported by Soltanpour (1963, pp. 40-44) and also found in experiment "A" (above), under similar experimental conditions. The first order effect of Zn application on the Zn concentration of the leaf blades was highly significantly positive (Table 12). Its squared term was also highly significantly positive indicating that the positive effect of Zn application was relatively greater at high coded levels of Zn application. Similar findings were reported by other American University workers (Soofi, 1961, pp. 48; Soltanpour, 1963, pp. 40-44) under similar experimental conditions. The application of B decreased the Zn concentration of the leaf blades as indicated by the highly significant negative first order regression coefficient. However, the squared term for B was highly significantly positive indicating that the effect of B was less negative at high coded levels of B application. The probably real first order effect of plant population was negative (although not significant) indicating that the Zn requirements of the corn plants were enhanced at high plant population rates as reported by Fuehring (1966). The regression coefficient for the S-Zn and B-population interactions were positive and probably real, although not significant, indicating that the positive effect on Zn concentration of the variables involved in each interaction tended to be enhanced by increasing the level of the other variable. The Zn-B-population interaction was positive and probably real, although not significant, indicating that the interaction between any two variables involved tended to depend on the third variable.

Since the yield response to Zn application was negligible as compared to the highly significantly positive effect of Zn application on Zn concentration of the leaf blades, no definite level of Zn concentration in this plant part could be suggested. However, a range of 15 to 30 ppm Zn in the leaf blades resulted in high grain yields in this experiment and this is in line with the findings of Viets et al. (1953) in Central Washington and Soofi (1961, pp. 47) at the American University of Beirut.

Comparison of the effects of common variables in both experiments:

The total B concentration of the leaf blade and the leaf midrib at the first sampling date was relatively higher in experiment "A" (average, 161 ppm) than in experiment "B" (average, 129 ppm) indicating a possible depressing effect of S on total B concentration in the leaf blades. (Appendix tables 15 and 18). Application of B consistantly increased the total B concentration of the leaf blade and midrib in both experiments, (Tables 9 and 12). Since the interactions involving P, S, Zn, B and plant population are complex, the variable results for the interaction terms were possibly due to different influences of P and S on the various interactions in the two experiments.

The concentration of Zn in the leaf blades at the first sampling date was affected positively by Zn application but negatively by B application (Table 9 and 12). The effect of plant population was negative in experiment "B" but tended to disappear in experiment "A". The levels of Zn found in the leaf blades were about the same in both experiments.

V. SUMMARY AND CONCLUSIONS

Two irrigated field experiments ("A" and "B") were conducted on a calcareous soil at the Agricultural Research and Education Centere of the American University of Beirut, in the Beka'a Plain of Lebanon in 1965. The objective was to evaluate the individual effects and interactions of P, S, Zn, B and plant population on corn yield and leaf composition. Experiment "A" consisted of four variables, P, Zn, B, and plant population, while experiment "B" included S, Zn, B, and plant population as the four variables. A central composite, rotatable, incomplete factorial design incolving four variables with each at 5 levels ranging from very high to very low rates of application (Table 1) was used in both the experiments. This design allowed determination of partial cubic regression equations on the basis of the coded levels which were used to characterize the response surfaces for yield and concentration of nutrients as affected by some of the important interactions. In each experiment there were 25 treatments one of which (at the third level of application for all variables) was replicated seven times in order to estimate the experimental error.

Two sets of leaf samples were taken, one at pretasseling stage and another at post-silking stage. The seasonal means of nutrient concentration were assumed to correspond to the leaf composition at tasseling time. The corn was harvested after a 5½ months growing period and reported as yields of grain at 15.5 percent moisture and yields of stover on the air-dry basis.

The grain yields ranged up to 14.43 and 15.08 metric tons per hectare in experiment "A" and "B", respectively, indicating that the climatic conditions for corn were very good and that with the right combination of applied nutrients and other cultural practices, high yield may be obtained. The direct effects on the grain yields by the variables studied were small.

The direct effect of P on grain yield was negligible, however, when plant population was at a low level, P application tended to increase the grain yield at a high level of Zn and to decrease it at a low level of Zn indicating that, at a low level of Zn, heavy application of P induced Zn deficiency. The effect of the Zn-B-population interaction on grain yield tended to be positive indicating that grain yields can be enhanced by increasing plant population per unit area provided high levels of Zn and B are applied. Response of grain yield to B application tended to be negative (experiment "B") but at a high Zn level, B application tended to increase grain yield indicating that the negative effect of B was counteracted by high Zn levels.

Stover yields were significantly increased by increasing plant population in experiment "A" but the effect of the Zn-population interaction tended to be negative indicating that the positive effect of plant population was counteracted by a high Zn level in the soil. The effect of the S-Zn-B interaction on stover yield was significantly negative indicating a positive S-B interaction at a low Zn level but negative at a high Zn level.

The application of P increased phosphate-P concentration of the leaf blades and midribs. Response of seasonal mean phosphate-P concentration of midribs to plant population and Zn application (especially at high levels) tended to be negative. The P-Zn (almost significant) and P-population interactions on the seasonal mean phosphate-P concentrations of midribs were positive indicating that effects of Zn and population were less negative at a high level of P applications. The Zn-B-population interaction was positive indicating a negative Zn-B interaction at a low level of population. The phosphate-P concentration of the midribs was found to be a better indication for the P status of corn plant than the P concentration of the leaf blades.

The seasonal mean sulfate-S concentration of the leaf blades and midribs was increased by S application. The S-B-population interaction on the seasonal mean concentration of sulfate-S of leaf blades tended to be negative indicating a negative B-population interaction particularly at a high level of S application. No conclusive results were obtained with regard to the suitability of these plant parts to indicate the S status of corn plants.

The total B concentrations of the leaf blades and midribs at first sampling date were increased by application of B and P. The effect of the Zn-B-population interaction on the total B of leaf blades was positive indicating that the Zn-population interaction was most positively effective at a high B level. The total B in leaf blades of sixth leaf at pretasseling stage was found to be a more sensitive test of the B status of corn plants than the B content of the midribs.

The Zn concentration of the leaf blades at first sampling date was increased by Zn application but decreased by B application. Plant population and P application tended to depress the Zn concentration in the leaf blades.

In general corn yields were not influenced much by the variables studied as compared to significant effects on the nutrient concentrations. As such no definite "critical levels" for the elements analysed can be suggested. Since the differences were small and natural variation under field conditions resulted in inconclusive results, more work is needed under more controlled conditions.

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APPENDICES

Table 13. Observed phosphate-P concentrations in the leaf blades (dry basis) at two dates of sampling and the seasonal mean as affected by various combinations of coded levels of applied P, Zn and B and plant population (Pop).

Treatment level				July 2 ppm	July 21 ppm	Seasonal Mean, ppm
P	Zn	B	Pop			
2	2	2	2	1744	1810	1777
4	2	2	2	1644	1875	1759
2	4	2	2	1615	2056	1835
4	4	2	2	2042	2125	2088
2	2	4	2	1486	1757	1621
4	2	4	2	2073	2190	2131
2	4	4	2	1659	2145	1902
4	4	4	2	1922	2139	2030
2	2	2	4	1586	2249	1917
4	2	2	4	1793	2396	2094
2	4	2	4	1684	1826	1755
4	4	2	4	2183	1996	2089
2	2	4	4	1556	1996	1776
4	2	4	4	1891	2316	2014
2	4	4	4	1312	1818	1565
4	4	4	4	1606	2311	1958
5	3	3	3	1625	2140	1882
1	3	3	3	1470	1790	1630
3	5	3	3	1749	1850	1799
3	1	3	3	1939	2071	2002
3	3	5	3	1375	2223	1799
3	3	1	3	1718	2264	1991
3	3	3	5	1595	1996	1795
3	3	3	1	1592	2027	1809
3	3	3	3	1498	1958	1729
3	3	3	3	1802	2139	1970
3	3	3	3	1762	2280	2020
3	3	3	3	1580	1990	1785
3	3	3	3	1918	2397	2158
3	3	3	3	1954	2176	2065
3	3	3	3	1776	2207	1987
	R			0.850	0.900	0.844

Table 14. Observed phosphate-P concentrations in the midribs (dry basis) at two dates of sampling and the seasonal mean as affected by various combinations of coded levels of applied P, Zn and B and plant population (Pop).

Treatment level				July 2 ppm	July 21 ppm	Seasonal Mean, ppm
P	Zn	B	Pop			
2	2	2	2	425	649	537
4	2	2	2	585	582	584
2	4	2	2	559	507	533
4	4	2	2	635	598	616
2	2	4	2	572	608	590
4	2	4	2	658	650	654
2	4	4	2	523	448	486
4	4	4	2	595	624	610
2	2	2	4	385	512	448
4	2	2	4	515	588	551
2	4	2	4	353	448	400
4	4	2	4	565	571	568
2	2	4	4	400	474	437
4	2	4	4	609	522	560
2	4	4	4	410	460	435
4	4	4	4	572	560	566
5	3	3	3	751	582	666
1	3	3	3	453	448	450
3	5	3	3	485	498	490
3	1	3	3	480	483	482
3	3	5	3	449	559	504
3	3	1	3	594	558	576
3	3	3	5	501	561	531
3	3	3	1	504	547	525
33	3	3	3	478	544	511
3	3	3	3	453	586	519
3	3	3	3	491	535	513
3	3	3	3	525	523	524
3	3	3	3	496	596	546
3	3	3	3	517	614	560
3	3	3	3	473	570	522
	R			0.918	0.892	0.929

Table 15. Observed concentrations of B and Zn in corn leaves (dry basis) at first sampling date (July 2) as affected by various combinations of coded levels of applied P, Zn and B and plant population (Pop).

Treatment level				Concentration in corn leaves		
P	Zn	B	Pop	Total B in blades, ppm	Total B in midribs, ppm	Zn in blades, ppm
2	2	2	2	88	91	28
4	2	2	2	106	83	27
2	4	2	2	99	79	38
4	4	2	2	111	91	37
2	2	4	2	178	111	26
4	2	4	2	312	115	23
2	4	4	2	215	101	32
4	4	4	2	204	120	31
2	2	2	4	84	86	29
4	2	2	4	103	87	28
2	4	2	4	85	76	36
4	4	2	4	87	74	34
2	2	4	4	183	94	21
4	2	4	4	202	102	19
2	4	4	4	256	98	33
4	4	4	4	338	103	30
5	3	3	3	207	80	16
1	3	3	3	115	63	26
3	5	3	3	135	70	38
3	1	3	3	206	70	20
3	3	5	3	270	105	22
3	3	1	3	87	55	35
3	3	3	5	170	64	27
3	3	3	1	172	59	24
3	3	3	3	160	59	24
3	3	3	3	125	70	22
3	3	3	3	157	70	21
3	3	3	3	129	66	29
3	3	3	3	137	78	28
3	3	3	3	149	66	28
3	3	3	3	133	73	20
R				0.939	0.800	0.907

Table 16. Observed sulfate-S concentrations in the leaf blades (dry basis) at two dates of sampling and the seasonal mean as affected by various combinations of coded levels of applied S, Zn and B and plant population (Pop).

Treatment level				July 2 ppm	July 21 ppm	Seasonal Mean, ppm
S	Zn	B	Pop			
2	2	2	2	1510	1119	1314
4	2	2	2	1701	1594	1648
2	4	2	2	1491	1278	1348
4	4	2	8	1829	1414	1621
2	2	4	2	1516	1115	1316
4	2	4	2	2201	1903	2052
2	4	4	2	1514	1694	1604
4	4	4	2	2247	1586	1916
2	2	2	4	1951	1068	1510
4	2	2	4	2429	1422	1926
2	4	2	4	1959	1271	1615
4	4	2	4	2196	1460	1828
2	2	4	4	1154	969	1062
4	2	4	4	1729	1418	1574
2	4	4	4	1392	1300	1346
4	4	4	4	1703	1505	1604
5	3	3	3	1776	1169	1472
1	3	3	3	1317	911	1114
3	5	3	3	1629	1445	1537
3	1	3	3	1568	1332	1450
3	3	5	3	1616	1144	1380
3	3	1	3	1302	1034	1168
3	3	3	5	1591	1378	1484
3	3	3	1	1598	1128	1363
3	3	3	3	1619	964	1292
3	3	3	3	1631	1029	1330
3	3	3	3	1312	994	1153
3	3	3	3	1435	1242	1338
3	3	3	3	1389	1373	1381
3	3	3	3	1569	1384	1476
3	3	3	3	1336	1174	1255
R				0.878	0.818	0.906

Table 17. Observed sulfate-S concentrations in the midribs (dry basis) at two dates of sampling and the seasonal mean as affected by various combinations of coded levels of applied S, Zn and B and plant population (Pop).

Treatment level				July 2 ppm	July 21 ppm	Seasonal Mean, ppm
S	Zn	B	Pop			
2	2	2	2	1001	911	956
4	2	2	2	1017	918	968
2	4	2	2	977	962	970
4	4	2	2	1180	1031	1106
2	2	4	2	861	911	886
4	2	4	2	1203	1036	1120
2	4	4	2	787	1032	910
4	4	4	2	1098	965	1032
2	2	2	4	923	756	840
4	2	2	4	1065	914	990
2	4	2	4	865	604	734
4	4	2	4	951	755	853
2	2	4	4	892	707	800
4	2	4	4	1240	1241	1240
2	4	4	4	760	601	680
4	4	4	4	922	653	788
5	3	3	3	976	1065	1020
1	3	3	3	808	550	679
3	5	3	3	886	1033	960
3	1	3	3	987	969	978
3	3	5	3	1108	863	986
3	3	1	3	524	861	642
3	3	3	5	529	1240	884
3	3	3	1	920	823	871
3	3	3	3	755	1031	893
3	3	3	3	864	1021	942
3	3	3	3	996	823	910
3	3	3	3	1096	1029	1062
3	3	3	3	987	1146	1066
3	3	3	3	786	822	804
3	3	3	3	980	964	972
	R			0.730	0.780	0.845

Table 18. Observed concentrations of total B and Zn in corn leaves (dry basis) at first sampling date (July 2) as affected by various combinations of coded levels of applied S, Zn and B and plant population (Pop).

Treatment level				Concentration in corn leaves		
P	Zn	B	Pop	Total B in blades, ppm	Total B in midribs, ppm	Zn in blades, ppm
2	2	2	2	98	57	28
4	2	2	2	102	64	25
2	4	2	2	125	60	39
4	4	2	2	101	58	41
2	2	4	2	167	77	25
4	2	4	2	243	79	26
2	4	4	2	238	81	30
4	4	4	2	224	82	32
2	2	2	4	104	52	28
4	2	2	4	112	57	23
2	4	2	4	104	49	32
4	4	2	4	144	58	32
2	2	4	4	190	98	23
4	2	4	4	110	86	22
2	4	4	4	168	78	32
4	4	4	4	109	80	35
5	3	3	3	97	67	26
1	3	3	3	105	50	22
3	5	3	3	94	46	38
3	1	3	3	79	41	15
3	3	5	3	217	91	17
3	3	1	3	47	38	37
3	3	3	5	149	59	16
3	3	3	1	85	47	24
3	3	3	3	85	40	22
3	3	3	3	143	47	26
3	3	3	3	140	40	22
3	3	3	3	130	55	17
3	3	3	3	72	59	18
3	3	3	3	99	49	18
3	3	3	3	105	53	23
R				0.872	0.892	0.898

Table 19. Analysis of variance for yields of grain (15.5% moisture) and stover (air-dry) as affected by various combinations of coded levels of applied P, Zn, and B and plant population.

Source	Total	First order	Second order	Third order	Lack of fit	Error 1	Error 2[1]	C.V. %	Equation sufficiency[2], %
d.f.	30	4	10	4	6	6	12		
Grain yield, m tons/ha								12.01	57.17
S.S.	53.9984	3.8080	5.4710	13.9919	17.4278	13.2997			
M.S.		0.9520	0.5471	3.4980	2.9046	2.2166			
Stover yield, m tons/ha								16.96	75.94
S.S.	75.1565	25.7884	15.7161	0.7145			32.9375		
M.S.		6.4471	1.5716	0.1786			2.7448		

[1] Pooling sums of squares for error 1 and lack of fit terms.

[2] Percentage of total treatment sum of squares accounted for by the partial cubic regression equation.

Table 20. Analysis of variance for yields of grain (15.5% moisture) and stover (air-dry) as affected by various combinations of coded levels of applied S, Zn, and B and plant population.

Source	Total	First order	Second order	Third order	Error 2[1]	C.V. %	Equation sufficiency[2], %
d.f.	30	4	10	4	12		
Grain yield, m tons/ha						19.99	57.92
S.S.	106.7393	15.2176	19.5643	8.3116	63.6458		
M.S.		3.8044	1.9564	2.0779	5.3038		
Stover yield, m tons/ha						13.74	86.88
S.S.	64.0242	13.5315	14.2742	15.3893	20.8293		
M.S.		3.3829	1.4274	3.8473	1.7358		

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[1] Pooling sums of squares for error 1 and lack of fit terms.

[2] Percentage of total treatment sum of squares accounted for by the partial cubic regression equation.

Table 21. Analysis of variance for concentration of phosphate-P (ppm, dry basis) in the leaf blades at two dates of sampling and the seasonal mean as affected by various combinations of coded levels of applied P, Zn, and B and plant population.

Source	Total	First order	Second order	Third order	Lack of fit	Error 1	Error 2[1]	C.V. %	Equation sufficiency, %[2]
d.f.	30	4	10	4	6	6	12		
First sampling date								9.45	82.96
S.S.	1261135	436149	325756	147316	186670	165244			
M.S.		109037	32576	36829	31112	27541			
Second sampling date								6.04	92.95
S.S.	1023522	280092	465605	72726			205098		
M.S.		70023*	46560	18182			17092		
Seasonal mean								7.03	86.18
S.S.	784408	304779	207447	43941			228240		
M.S.		76195*	20745	10985			19020		

1. Pooling sums of squares for error 1 and lack of fit terms.
2. Percentage of total treatment sum of squares accounted for by the partial cubic regression equation.

* Significant at 5 percent level.

Table 22. Analysis of variance for concentration of phosphate-P (ppm, dry-basis) in the midribs at two dates of sampling and the seasonal mean as affected by various combinations of coded levels of applied P, Zn, and B and plant population.

Source	Total	First order	Second order	Third order	Lack of fit	Error 1	C.V. %	Equation sufficiency[1], %
d.f.	30	4	10	4	6	6		
First sampling date (July 2).							5.14	85.69
S.S.	222729	144229	37317	6058	31304	3820		
M.S.		36057**	3732*	1514	5217*	637		
Second sampling date (July 21)							5.97	85.26
S.S.	100212	46439	25425	7715	13755	6879		
M.S.		11610**	2542	1929	2292	1146		
Seasonal Mean							3.45	87.71
S.S.	116574	85222	12042	3235	14079	1995		
M.S.		21306**	1204	809	2346*	332		

* Significant at 5 percent level.

** Significant at 1 percent level.

[1] Percentage of total treatment sum of squares accounted for by the partial cubic regression equation.

Table 23. Analysis of variance for concentrations of total B and Zn (ppm, dry basis) in corn leaves at first sampling date (July 2) as affected by various combinations of coded levels of applied P, Zn, and B and plant population.

Source	Total	First order	Second order	Third order	Lack of fit	Error 1	C.V. %	Equation sufficiency[1], %
d.f.	30	4	10	4	6	6		
Total B in blades							21.25	93.91
S.S.	145709	105073	14095	9309	11808	5424		
M.S.		26268**	1410	2327	1968	904		
Total B in midribs							8.73	65.42
S.S.	9488	3629	2268	168	3206	217		
M.S.		907**	227*	42	534**	36		
Total Zn in blades.							15.20	89.98
S.S.	967.93	593.84	184.61	17.25	88.52	83.71		
M.S.		148.46**	18.46	4.31	14.75	13.95		

[1] Percentage of total treatment sum of squares accounted for by partial cubic regression equation.

* Significant at 5 percent level.

** Significant at 1 percent level.

Table 24. Analysis of variance for concentration of sulfate-S (ppm, dry basis) in the leaf blades at two dates of sampling and the seasonal mean as affected by various combinations of coded levels of applied S, Zn and B and plant population.

Source	Total	First order	Second order	Third order	Lack of fit	Error	C.V. %	Equation sufficiency[1] %
d.f.	30	4	10	4	6	6		
First sampling date (July 2)							9.43	80.28
S.S.	2803801	884100	1195307	79526	530168	114700		
M.S.		221025**	119531*	19881	88361*	19117		
Second sampling date (July 21)							16.76	76.49
S.S.	1788363	540266	586972	68223	367354	225548		
M.S.		135066	58697	17056	61226	37591		
Seasonal mean							7.61	84.88
S.S.	1770147	521708	796176	133526	258345	60391		
M.S.		130427**	79618**	33382	43057*	10065		

[1] Percentage of total treatment sum of squares accounted for by partial cubic regression equation.

* Significant at 5 percent level.

** Significant at 1 percent level.

Table 25. Analysis of variance for concentration of sulfate-S (ppm, dry basis) in midribs at two dates of sampling and the seasonal mean as affected by various combinations of coded levels of applied S, Zn and B and plant population.

Source	Total	First order	Second order	Third order	Lack of fit	Error	C.V. %	Equation sufficiency[1] %
d.f.	30	4	10	4	6	6		
First sampling date (July 2)							13.48	59.82
S.S.	852860	294510	127783	32238	305253	93076		
M.S.		73627*	12778	8060	50876	15513		
Second sampling date (July 21)							12.11	67.00
S.S.	904851	209017	289722	51232	270854	84026		
M.S.		52254	28972	12808	45142	14004		
Seasonal mean							9.86	79.78
S.S.	499844	235732	104271	16725	90403	52713		
M.S.		58933*	10427	4181	15067	8785		

[1] Percentage of total treatment sum of squares accounted for by partial cubic regression equation.

* Significant at 5 percent level.

Table 26. Analysis of variance for concentrations of total B and Zn (ppm, dry basis) in the corn leaves at first sampling date (July 2) as affected by various combinations of coded levels of applied S, Zn and B and plant population.

Source	Total	First order	Second order	Third order	Lack of fit	Error 1	C.V. %	Equation sufficiency[1] %
d.f.	30	4	10	4	6	6		
Total B in blades							25.04	81.04
S.S.	74630	35034	14551	7168	13275	4602		
M.S.		8758**	1455	1792	2212	767		
Total B in midribs							15.13	82.98
S.S.	8039.21	4146.90	2078.71	172.41	1312.13	329.06		
M.S.		1036.72**	207.87	43.10	218.69	54.84		
Total Zn in blades							15.75	84.17
S.S.	1513.94	808.51	396.44	41.75	229.38	64.86		
M.S.		202.13**	36.94	10.44	38.23	10.81		

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[1] Percentage total treatment sum of squares accounted for by partial cubic regression equation.

** Significant at 1 percent level.