INTERRELATIONSHIPS OF NUTRIENTS AND PLANT POPULATION ON THE YIELD AND COMPOSITION OF MAIZE

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MAIZE NUTRITION

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AN ABSTRACT OF THE THESIS OF

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Two adjacent irrigated field experiments were carried out in the Beqa'a Plain, North Lebanon, in 1966, to study the effects and the interrelationships of P, Zn, B, S, Cl, N, and plant population on the yield and composition of maize. Each variable was studied at five levels and a rotatable, central composite, factorial design was used.

The high grain yield at the upper end of the yield range (15.8 m tons per hectare) indicated the considerable maize production potential in the area. Application of P with Zn, B, and plant population as variables increased yields of grain and stover and there was a greater response to P at high levels of Zn, B, and plant population. Fertilization with P when the levels of applied S, Cl, and N were high, depressed yield of grain and enhanced stover. For high yields of grain, either high levels of P or S were required, but not both. There was a greater grain yield response to applied Zn at high levels of applied P and plant population. The overall effect of applied B depended on the levels of applied P and plant population. Grain yield response to plant population was greater at high soil fertility levels. Application of N increased the yield of stover to a considerably greater extent than the yield of grain. Applied N and applied P with Zn, B, and plant population as variables significantly increased the concentrations of phosphate-P in the midribs and total-P in the leaf blades. The phosphate-P in the midribs seemed to be a more sensitive measurement of P response than the total-P content. Application of Zn significantly increased the Zn concentrations in the blade, but high levels of plant population significantly depressed it. At high plant population, the positive and significant Zn-B-plant population interaction on Zn concentration cancelled the negative and significant Zn-B interaction. Concentrations of Zn in the blade of 50 to 75 ppm were required for high grain yields. Applied B significantly increased the B concentrations in the midribs, but the relation between

B concentration and yield of grain was influenced by the level of applied P. Applied N significantly increased the total S concentration in the blade. The depressing effects of applied S on grain yield seemed to be indirect. The concentrations of nitrate-N in the midribs and total-N in the blades were significantly increased by N application. The critical levels of nitrate-N and total-N seemed to be above 1000 ppm and 2.9 percent, respectively. The nitrate-N of the midribs appeared to be a very sensitive indicator of the N status of the plants.

Levels of applied P should be considered in relation to soil test values and fertilizers containing S should not be used under conditions similar to those for the Beqa'a Plain where grain production is of primary importance. Further work is needed to obtain efficient response to Zn and B. Levels of plant population should be adjusted to obtain ear weights of 200 to 250 g. Rates of N application should be decided with respect to the expected yield level and the probable N-supplying power of the soil.

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I. INTRODUCTION

Maize (*Zea mays* L.) has much potential as a farm crop in the Middle East. Exploratory fertilizer experiments under irrigation at the Agricultural Research and Education Center (AREC) of the American University of Beirut (AUB), have indicated the possibility of very high yields of grain. The soils of the Middle East are generally calcareous and are associated with the unavailability of some of the micronutrient elements. The need for these elements becomes more intensified at the high plant population pressure required for maximum yield under irrigation. Previous work in the area shows a need for high levels of P, Zn, B, and plant population, and considerable interaction among them at high yield levels of irrigated maize. Other work in the area indicated considerable response to N and P applications, but little response or negative response to S and Cl. Much S and Cl may be added incidently in fertilizer and irrigation water. Further study of these nutrients at very high yield levels is necessary in order to learn more about the effects of anion balance.

The purpose of this study was to investigate the optimum nutritional conditions for maximum yield of maize at the AREC under climate and soil conditions approximating those of much of the Middle East. Two field experiments were initiated with objectives as follows:

1. To further explore interaction effects among P, Zn, B, and plant population at high yield levels.
2. To explore the effect of applied nutrients on anion balance at high yield levels as affected by N, P, S, and Cl applications.
3. To study the relationship of the above variables on plant composition.

II. REVIEW OF LITERATURE

Ultimate return from maize growing is determined by the extent to which all the resources for maize production are used. Under irrigation, plant population and fertilizer application are two major factors determining maximum maize yields. The following paragraphs contain some of the literature pertaining to the nutrient elements and plant population comprising this study.

Effect of Plant Population

Ear weight and number of ears per area are two important yield components determining maize grain yields. Number of ears per area increases with increasing rates of plant population, but ear weight decreases. For maximum maize grain yields, the rate of plant population should be adjusted to obtain ears weighing about 200 to 250 g.

Jordan *et al*. (1950) observed that 12,000 plants per acre of corn depressed yield as compared to 4,000 plants on low fertility soils, but with reasonably adequate N supply (60 to 120 lb N/acre) total production of dry matter increased with increased plant population. Dungan *et al*. (1958) reported higher corn yields with 20,000 plants per acre that had average ear weight of 0.45 pounds.

Carlson _et al_. (1959) growing an 83 days maturity hybrid corn, reported 10,000 plants per acre as optimum population on dry land condition regardless of N fertilization, but in case of adequate moisture supply, yields were higher with higher plant population and N fertilization. Stickler (1964) and Colville (1962) stated that although leaf area per plant, ear weight, number of ears per 100 plants, and mean grain protein percentage decreased, still, increasing plant population significantly increased grain yield per acre under irrigation. Norden (1966) studying five population rates of corn found a positive curvilinear relationship between plant population and grain yield per acre. He observed that where moisture and nutrients were not limiting, the crop yield per acre increased with increasing number of plants per acre up to an optimum level. Colville and McGill (1962) observed that maximum net return from irrigated corn could only be obtained when use was made of all the resources at hand and suggested that plant population per acre was a major factor determining yield and ultimate extent of return.

Norden (1964) studying the relation between root weight and root distribution with plant population, found a negative curvilinear and a negative linear relationship between the width and depth of root clump, respectively, and plant population. He observed that although the dry weight of roots per plant decreased by 72 percent as a result of increasing the plant population from 5,000 to 25,000 plants per acre, the yield of dry roots increased with increase in plant population. Stickler and Laude (1960) reported that ecological data, as well as yield data, suggested that corn in narrow rows would not furnish sufficient cover to control weeds through competition unless an extremely high population was used.

Stinson _et al_. (1960) testing the response of some high population tolerant and intolerant corn varieties to shady environments under conditions of adequate soil moisture and fertility, found that the grain yield from the tolerant group was significantly higher than that from the intolerant group. He observed that plant barrenness contributed to the differential yield response. Yao and Shaw (1964a) reported that mutual shading, supply of available moisture and plant nutrients, plant diseases, and CO_2 movement were some factors influencing the effects of spacing and plant population on yield. Berger _et al_. (1957) observed that large plant population together with heavy fertilization may conceivably place a greater stress on the available B supply.

Yao and Shaw (1964b) reported that the effect of spacing and plant population on yield were largely due to a change in the radiant energy distribution. They observed that with closer spacing, or high plant population, more radiant energy would be intercepted by the plants and less would fall on the soil surface to cause evaporation. In spacing and plant population experiments, they found maximum evaporation losses, as estimated from net radiation data, were least with 21 inch row space and 28,000 plants per acre and most with 42 inch and 14,000 plants per acre. Yao and Shaw (1964a) found higher yield and water use efficiency with 21 inch row space and 28,000 plants per acre than 42 inch row space and 28,000 plants per acre.

Decisions on the rate of plant population to be used should be made with reference to available moisture and nutrient supply. When moisture and nutrient supply are not limiting, high maize yields were associated with high plant population. Fuehring et al. (1968) reported predicted yields of 20 metric tons/grain per hectare with 96,000 maize plants at high soil fertility levels.

Effect of Applied Nitrogen

Jordan et al. (1950) observed continuous requirement of N by corn throughout the season, regardless of the fluctuations in N-absorption curves. Hutton et al. (1956) observed a positive response of corn yield to N application at adequate levels of P, K, and moisture for maximum yield. Thomas (1959) reported significant increase in grain protein as a result of increasing the rate of applied N from 120 pounds to 240 pounds per acre. Carlson et al. (1961) noted that 60 pounds N per acre applied with P more than tripled forage yield and increased grain yield five times. Burleson et al. (1961) reported that applied N increased the yield of corn at low levels of soil P but depressed it when soil P was high.

Hanway (1962) found that the pattern of N accumulation by plants was influenced by the seasonal pattern of N availability which varied with the time and method of application of N fertilizers and the rate pattern of N mineralization from the soil organic matter. Fulton and Findley (1960) observed increasing percent N in the ear shoot and in grain with increasing rates of N fertilization. They reported a straight line relation between ear shoot leaf N and yield when N was the only nutrient influencing yield. They also observed that predictions of N sufficiency based on grain N were subject to more error than those based on leaf N. Fuehring (1966) noted a better correlation between nitrate-N concentration in the midribs and grain yield than total N in blade and grain yield. Reichman et al. (1959) and Viets et al. (1954) reported increasing grain and stover yield and percent N in corn tissue with N fertilization. They observed that corn yield was highly correlated with the percent N in corn leaves. Kissel and Ragland (1967) studying the redistribution of nutrient elements in corn reported that 65 percent of tissue N got redistributed from the vegetative parts during the period 12 days after tasseling to maturity and observed that if all the redistributed N moved to the developing ear, it would amount to 97 percent of the total ear N. They reported that by silking time, much of the nutrient supply for normal grain yield would have been taken.

Tyner (1946) and Viets et al. (1954) reported a tentative critical level of 2.9 percent N in the corn leaves at the bloom stage above which increased N fertilization caused a slight increase in grain yield and excessive vegetative growth. Tyner (1946) observed that N more than any other nutrient controls growth and determines yield. Viets et al. (1954) noted a high positive correlation between corn yield and leaf-N at silking and reported partial regression analysis which showed that leaf-N was probably the dominant determinant of yield. Garg and Welch (1967) and Viets et al. (1954) observed that leaf-N content decreased with delayed sampling and correlated better with yield. Andharia et al. (1953) stated that the relationship between leaf-N percentage and yield was linear with no evidence of a departure from linearity or a flex point that could be called the critical percentage. Benett et al. (1953) and Viets et al. (1954) observed that N fertilization increased the percent N and percent P in corn leaves. Benett et al. (1953) found reduced effectiveness of applied N when the supply of other nutrients were inadequate. They reported a critical level of 2.6 to 3.1 percent N in the corn leaf for 95 percent of maximum grain yield and noted little grain yield response to applied N when leaf-N was in the range 2.8 to 3.0 percent. Ellis et al. (1956) observed a critical level of N in corn leaves under moisture deficiency conditions of about 2.5 percent or less.

Dumenil (1961) observed that the N content of corn leaves at 95 percent of maximum yield varied with the concentration of the other nutrients because of their significant interaction on yield. He reported that the critical level of N is not a point or a narrow range but includes a wide range of values depending on the levels of other nutrients in the leaves and observed varying critical levels of N at 95 percent of maximum yield at different percentages of tissue P. Leonce et al. (1966) in a series of soil and nutrient solution experiments found that addition of $(NH_4)_2SO_4$ or NH_4Cl with labelled P fertilizer increased P^{32} concentrations in corn tops as compared to labelled P fertilizer alone but addition of KNO_3 with the labelled P fertilizer reduced the P^{32} concentration in the corn tops. They suggested that the NH_4^+ may have a specific influence on the transfer of P across the root symplast to the xylem.

Nitrogen application was found to increase the growth and grain yield of maize, when N was the only nutrient influencing yield. Nitrogen fertilization was observed to increase the N concentration in maize leaves. A high positive correlation was reported to exist between maize yield and N concentration in maize leaves. The critical N concentration in the leaves was noted to vary with the levels of available moisture and other nutrients. However, many workers reported 2.95 percent N in the leaf as a critical level.

Effect of Applied Phosphorus

Hutton et al. (1956) reported that when N and K are adequate for maximum yield levels and moisture is available, the relation of corn yield to applied phosphorus fertilizer is a straight line. Reichman et al. (1959) observed that addition of phosphorus fertilizer alone decreased grain and forage yield and N content of corn tissue and did not effectively increase P concentration in corn leaves. Olson et al. (1962) noted that corn was efficient in using soil P and it was hazardous to apply phosphorus fertilizer to corn grown in soils inherently high in P supplying power.

Hall et al. (1949) studying the relative use efficiency of the phosphorus carriers: Superphosphate, calcium metaphosphate, and alphatricalcium phosphate at applied rates of 50 lb P_2O_5 per acre with respect to maize found that the percent P derived from the fertilizer was about the same in the plants fed with superphosphate and calcium metaphosphate but higher than those receiving alpha-tricalcium phosphate. Knoll et al. (1964) found no difference in corn growth or P content as a result of using different phosphorus fertilizer sources, but growth, P content, and P uptake increased with increasing soil temperature and increasing P level in the soil.

Stanford and Nelson (1949) investigating corn utilization of phosphorus as affected by placement methods found that placement of phosphorus fertilizer at seed depth and in bands on one or both sides of the seed resulted in greater utilization than a single band above or below the seed. Nelson et al. (1949) also studying phosphorus fertilizer placement methods observed that at the earlier stages of corn growth the percent P derived from phosphorus fertilizer placed with the seed, or mixed in the row, were higher than that derived from broadcasted phosphorus fertilizer, but this difference disappeared later in the season. Garg and Welch (1967) experimenting with three phosphorus fertilizer placement methods - mixed, banded, and with the seed - observed that there was no difference in seedling emergence among the three placement methods, but the yield of forage, percent P in the corn tissue, and yield of P in the plant were greater when P was placed with the seed.

Garg and Welch (1967) found correlations of r = 0.84 and 0.91 between percent P in the corn tissue and dry matter yields. Viets et al. (1954) observed that corn yield was very positively correlated with P content of leaves at silking (r = 0.83 to 0.91). Viets et al. (1954) and Tyner

(1946) suggested that the critical level of P concentration in the corn leaves could be best evaluated if it was related to the critical N concentration and calculated a critical P concentration in the 6th corn leaf of 0.295 percent. Dumenil (1961) observed that the P content of corn leaves at 95 percent of maximum yield level varied with the concentration of other nutrients, because of their significant interaction on yield and suggested that the critical level of P was not a point or a narrow range, but includes a wide range of values depending on the levels of other nutrients in the leaves. Kissel and Ragland (1967) studying the redistribution of nutrients in corn observed that 76 percent of the tissue P got redistributed from the vegetative parts in the period 12 days after tasseling to maturity and if all this P really moved to the developing ear, it would amount to about 116 percent of its total P.

Maize was observed to respond considerably to P fertilization. It was noted that the use efficiency of applied P fertilizer was determined by the level of other nutrients, the type of P fertilizer carrier, and the method of application. High correlation was observed between maize yields and percent P in maize tissue. The critical level of P in maize leaves was reported to vary with the levels of other nutrients in the leaves. However, some workers reported a critical P concentration in the maize leaf of 0.295 percent.

Effects of Applied Zinc

Jurinak et al. (1955) observed in bentonite suspensions adjusted to varying pH ranges using NaOH, KOH or $Ca(OH)_2$, that Zn solubility was minimum at pH 5.5 to 6.7 in Na-bentonite and K-bentonite and increased with increasing alkalinity, while in Ca-bentonite, Zn solubility was minimum at pH 7.6 and did not increase with increasing alkalinity. They suggested that this was most probably because of the formation of low solubility calcium zincate. Boawn et al. (1957) reported that when neutral Zn solutions were added to the soil, rapid conversion of the Zn to forms not extractable by water occurred and the plants found their Zn by contact feeding from these forms. Wear (1956) observed in green house experiments that addition of 2000 pounds $CaCO_3$ per acre decreased the Zn content in sorghum plants, but increased the pH of the growth medium from 5.7 to 6.6, while addition of 2000 pounds $CaSO_4$ per acre decreased the growth medium pH (5.6 to 4.8) and slightly increased the Zn content of the sorghum plants. He concluded that reduction in plant Zn uptake was a pH effect. Massey (1957) reported that pH and dithizone extractable Zn were negatively, and significantly positively correlated with plant uptake of Zn, respectively. Ward et al. (1963) studying 15 soils reported that pH of the soil had very little relation to the amount of acid soluble Zn in the soil. Seatz et al.

(1959) observed that flax and sorghum response to Zn fertilization increased as the rate of liming was increased from 2 to 6 tons per 2 million pounds of soil. Wear (1956) noted that a ton of lime applied to a soil low in Zn reduced corn yield by 10 or more bushels per acre. He noted that the reduction in yield could be prevented by Zn application. Shukla and Morris (1967) observed that liming decreased corn growth, Zn uptake, and corn Zn content. Ellis et al. (1964) reported that decrease in soil temperature from 75° to 55°F caused decrease in corn yield, Zn concentration in the plant tissue, and total Zn uptake. Langin et al. (1962) reported that the soil factors affecting Zn concentration in corn are complex and include, among others, a beneficial action of applied Zn and a detrimental action of applied P, or lime inherently present, or added to the soil.

Nearpass (1956) growing millets and tomatoes in exchange-resin-sand culture, found a logarithmic relationship between Zn concentration in the substrate and Zn concentrations in the aerial portions of the plant. Ward et al. (1963) observed that acid soluble Zn values reasonably correlated with both plant Zn concentration and Zn yield in the crop. Brown et al. (1963) studying sweet corn in 53 soils found that 84 percent of the soils containing 0.55 ppm, or less dithizone extractable Zn responded to soil applied $ZnSO_4$ and 76 percent of the soils containing above 0.55 ppm dithizone extractable Zn did not respond to Zn application.

They suggested that 0.5 ppm of dithizone extractable Zn could be a critical level below which Zn response might be expected on sensitive crops. Brown et al. (1962) testing 14 plant species in pot experiments, reported that plants differ in their Zn absorption capacity and reported that corn developed normally with 40 ppm applied Zn while 97 ppm applied Zn caused Fe chlorosis, indicating that there is a threshold for Zn application. Ward et al. (1963) studying 15 soils, observed increased amount of acid soluble Zn with increasing amounts of soil organic matter, clay content, and decreasing K saturation.

Carlson et al. (1961) reported that application of Zn to corn increased grain yield more than stover yield. Ellis et al. (1964) noted that in calcareous Michigan soils addition of 4 pounds of Zn per acre increased corn yield from 7,504 to 8,680 pounds per acre. Shaw et al. (1954) noted that the Zn supplied by the seed furnished an important part of the plant Zn, especially when the soil Zn supply was low. They also observed that Zn was not readily redistributed within the plant. Massey et al. (1967) observed variation in inbreds in kernel Zn content which appeared to be related to the general level of Zn in the plant. This was observed to be influenced by the inbred ability to transfer Zn from the stalk and the leaves to the ear. Shaw et al. (1952) stated that maximum Zn concentration in the corn plant occurred at the node. Viets et al. (1953) reported that a level of 15 ppm Zn in the corn leaf from the node below the ear at silking was adequate for 100 to 125 bushels per acre. Fuehring and Soofi (1964) reported Zn concentration in the 6th corn leaf from the base, in the range of 20 to 145 ppm. They observed that grain yield was relatively highest at 20 ppm Zn, while yield of stover was highest at the Zn concentration of 145 ppm. They postulated a possible interference of Zn with the translocation of carbohydrates to the storage organs. They also noted that optimum Zn level in the leaves for grain production was affected to the greatest extent by the level of Mn in the leaves.

Carlson et al. (1961) observed no corn response to Zn applied with manure. They suggested that most probably the Zn in the manure was sufficient. Shaw et al. (1954) found very little difference in Zn utilization from freshly applied $ZnSO_4$, the less soluble $ZnCO_3$, Zn applied as plant material, and the Zn accumulated in the soil from $ZnSO_4$ application during the previous five years. Boawn et al. (1957) reported that plants will utilize Zn to the same degree from Zn fertilizer materials with distinct differences in their chemical and water solubility characteristics. Shukla and Morris (1967), investigating the relative efficiency of various Zn sources at different levels of lime and P application, reported that $ZnSO_4$ was slightly more effective than ZnO, or Zn Chelate and organic (polyflavinoid) Zn was the least effective source.

Zinc was observed to be mostly needed for grain production in maize. The availability and uptake of Zn were noted to depend on soil pH. Added or inherently present lime in the soil was reported to increase corn yield response to Zn fertilization. It was found that plants could utilize Zn to the same degree from Zn fertilizer materials with distinct differences in chemical and water solubility characters. Concentrations of Zn in the maize leaf from the node below the ear in the range 15 to 20 ppm were observed to be associated with high grain yields.

Effect of Applied Boron

Berger *et al*. (1945) reported that soils with high organic matter were often high in available B and stated that, usually, B deficiency occurs on alkaline soils. Studying the relation of B availability to pH, they found that available B increases in soils with a pH range of 4.7-6.7 and decreases in soils with a pH range of 7.1-8.1. Jones and Scarseth (1944) found that B starvation is generally more apt to occur on humid region soils that have been overlimed or alkaline soils than on acid soils because of the excess Ca that the plant absorbs under the former conditions.

Purvis (1940) observed that it was difficult to differentiate between the soil B content and the fraction available to plant. The same difficulty occurs in differentiating between the total B found in plants and the fraction necessary for normal growth. Reeve et al. (1944) observed that the external symptoms of B deficiency were strikingly similar to those of Ca deficiency, and suggested that the functions of B and Ca in the plant were probably intimately associated. They also grew tomatoes in culture solutions and reported that tomato plants grown in culture solutions containing 0.001 ppm B and 500 ppm K showed B deficiency only three days after the start of the experiment, while plants grown in the culture containing 0.001 ppm B and 10 ppm K were growing normally. This indicated that K at high levels accentuated B deficiency. Ca has been reported to have a similar effect.

Marsh (1940), studying Ca and B metabolism in corn grown in sand culture, observed that where other nutrients were adequate, the Ca/B ratio in corn plants grown in optimum B and optimum Ca was the same as the ratio in plants grown in deficient B and deficient Ca sand cultures. He doubted the Ca/B as an indication of B needs. Jones and Scarseth (1944) reported that alfalfa has a wide range of Ca/B ratio (80-587) in which no B deficiency or toxicity occurs, which suggests that high quantities of B could be added to heavily limed soils without danger of B toxicity development. Working with oats, they found that the plant showed B toxicity at a Ca/B ratio of 200 and grew normally at a Ca/B ratio of 600.

McIlrath *et al.* (1956) observed B toxicity symptoms and reduced growth in green house grown millets receiving nutrient solutions containing 5 to 50 ppm B. They noted that high levels of Ca in the nutrient solutions reduced the soluble and total B in plant tissue at high B levels. An inverse relationship was found to exist between the Ca/B ratio and soluble B in plant tissue as affected by the B level in the substrate. Berger *et al.* (1957) reported a green house experiment with corn grown for different periods in nutrient solutions containing varying amounts of B and observed that plants grown in 0.0, 0.01, and 0.05 ppm B had very poorly developed ears or no ears at all, depending on the length of time they were left in the B solution. However, corn plants grown in 0.25 ppm B solution to maturity had fully developed ears, but barren ears were produced when this B supply was cut off. They stated that B was essential for ear and kernel production and lack of B causes blank stalks and barren ears. They suggested a critical level of B in the upper leaves to be 11 to 13 ppm B. They also observed B immobility in the plant and suggested the necessity of continuous B supply to the crop. McIlrath *et al.* (1960) observed that B effects differ fundamentally between plants that are monocotyledons, or dicotyledons and reported that monocotyledons such as Setaria have low B requirements. They observed that at high applied B levels (10 ppm), B probably displaced other ions presumably anions in plant ash. Fuehring (1966) reported that the B concentration of leaf midribs at the point of maximum yield varied from less than 60 ppm at low plant population to 120 ppm at high plant population.

Boron requirements and effects on the monocotyledonous plants, were reported to differ from the dicotyledonous plants. Boron was observed to be required for ear and kernel production in maize and lack of B was noted to cause blank stalks and barren ears. Maize was found to have low B requirements and B deficiency was observed, most commonly, to occur with the high plant populations used for large maize yields.

Effect of Applied Sulfate

Nightingale et al. (1932), working with tomatoes, observed that in the absence of adequate S, there was accumulation of nitrates, soluble nitrogenous compounds, and some carbohydrates in the plant. They suggested that this may be due to a lowered nitrate reduction and to the inability of the plant to synthesize protein, because of the lack of sufficient amino acids. Volk et al. (1945) reported an increase of 18.1 to 33.8 percent plant material when S was applied with non-sulfur containing phosphorus fertilizers. Seatz et al. (1958), studying anion effects on the yield and chemical composition of corn and tomatoes, reported high yields in the two crops when sulfate was a major anion.

Corbett and Gausman (1960) reported a highly significant negative correlation between Cl in the nutrient solution and the uptake of sulfate in the top of potato plants. They observed that the uptake of sulfate by roots was significantly enhanced by phosphorus additions. Beaton (1966) noted that the need for S depended on the level of the other nutrients. He observed that S fertilization increased corn yield in several soils and reported that S deficiency caused profound changes in N metabolism.

Effect of Applied Chloride

Seatz *et al*. (1958), studying anion effects on the growth and chemical composition of corn and tomatoes, noted that yield of corn was significantly lower when chloride was the major anion as compared to sulfate and carbonate as major anions. They observed high Cl content in the plants growing in the Cl series and noted that increased Cl in plant tissue did not affect the S or P content in the plants. Corbett and Gausman (1960), studying Cl effects on plant nutrition, stated that the Cl anion and its associated cation had combined effects that were difficult to separate. They observed that Cl functions in plant nutrition include interference with carbohydrate metabolism, modification of plant chlorophyl content, hydrogen ion concentration and cation and anion absorption.

Broyer *et al.* (1954), working with tomatoes, reported that the plant Cl requirement was large as compared to other micronutrients. They found 250 ppm Cl in the leaves of tomato plants suffering from Cl deficiency and suggested that Br can partially substitute in plant functions normally dependent on Cl. Teater (1960) reported increased uptake of Cl by corn plants with increasing rates of Cl applications. He stated that increased Cl uptake had no apparent effect on the growth characteristics of corn at any stage of growth, nor did it affect the quantity of N and P absorbed by the plant.

Gillingham and Page (1965), studying the influence of anions on the uptake of Ca and Mg by sunflower, observed that Cl increased Ca uptake, but Mg uptake was increased by all anions studied except Cl. Carter and Lathwell (1967) reported that chloride salts such as KCl may tend to displace Ca from the outer cytoplasmic membrane when roots were exposed over a long period to solutions with high K/Ca ratio. They noted that Cl concentrations normally found in the soil solution neither enhanced nor reduced P uptake by corn plants.

Interaction

Maximum maize yield is an index of a balanced nutrient supply and a good maize crop has heavy requirements for all the nutrients in their proper proportions. The interactions among the nutrient elements determine, to a considerable extent, the direction and magnitude of the crop response to the applied variable(s). For a large positive maize yield response, all the required nutrients must be available in proper proportions in order to enhance their combined favorable effects. The following are some of the important interactions among the variables comprising this study.

Jordan et al. (1950) reported that response to mineral nutrients was high with high N rates and dense plant population. Bingham et al. (1958) noted micronutrient imbalances on citrus when soils differing widely in total B and Zn were fertilized heavily with $Ca(H_2PO_4)_2$. They suggested that Ca could be a factor in the reduced B uptake by causing formation of the relatively unsoluble calcium borate or by the phosphate anions competing with borate anions for absorption by plants. Fuehring (1966) reported important positive interaction between plant population and B indicating that limited B may be part of the reason for the decrease in yield with high plant population. Langin et al. (1962) observed that Zn deficiency in corn was aggravated by modest row application or heavier broadcast and mixed application of readily available P. Ward et al. (1963) observed that irrigation, soil compaction, and high soil P portend Zn deficiency problems. They noted that pH was not a major factor governing P-Zn relations, but the larger the soil K saturation, the less reduction by applied P on plant utilization of Zn. Ellis et al. (1964) reported that addition of 437 pounds P per acre caused a decrease in Zn concentration in corn tissue. They noted in most of their experiments a negative correlation between Zn concentration and P concentration in corn. Shukla and Morris (1967) observed that high P fertilization decreased corn Zn content, but tended to increase growth when supplied with Zn. Fuehring (1966) observed important positive interaction between plant population and Zn indicating that limited Zn may be part of the reason for the decrease in yield with high plant population. He noted that high rates of applied Zn (90-180 kg Zn/ha) were depressing to grain yield with low plant populations (40,000-53,333 plants/ha) but increased yield at high plant populations (80,000-93,333 plants/ha).

Grunes et al. (1958), working with barley, observed that addition of N fertilizer generally increased the percentage of total P absorbed by the plants from banded P fertilizer. They noted that addition of $(NH_4)_2SO_4$ with P was more effective in increasing the percentage P derived from the fertilizer than separate bands of N and P. Garg and Welch (1967) found correlation of $r = 0.87$ and 0.85 between percent N and percent P in corn tissue at 21 and 28 days, respectively, after planting and observed that percent N and percent P had correlation of $r = 0.91$ and 0.90, respectively, with dry matter yield.

III. MATERIALS AND METHODS

Two adjacent field experiments were established on a calcareous clay soil at AREC. The factors P, Zn, B, and plant population (Pop) comprised experiment I and P, S, Cl, and N comprised experiment II. Each factor was studied at five levels which were varied on a logarithmic scale for the nutrient factors and on a linear scale for plant population (Table 1). The levels were coded as -2, -1, 0, +1, and +2 as required by the design.

The experimental design used was a central composite, rotatable, factorial, given as design 8.A.1, pp 370, Cochran and Cox (1957). This design is particularly suitable for exploratory experiments of four variables because of the small number of treatments as compared to a complete factorial design. It allows the study of the main effects of the factors and their various interactions, using the coded values. It is also possible to evaluate the response surfaces for yield, or leaf composition as influenced by the different factors and their interactions. A general form of the partial third order regression equation used is as follows:

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

Where

y = Quantitative factor measured

b = Regression coefficient for treatment effect

x_1= Coded level for P

x_2= Coded level for Zn, Exp. I; S, Exp. II

x_3= Coded level for B, Exp. I; Cl, Exp. II

x_4= Coded level for Pop, Exp. I; N, Exp. II

The study was exploratory and one replicate made up of 25 treatments was used for each experiment. For the estimation of the experimental error (error 1), the treatment where all the factors were set at the third level (coded value 0) was replicated seven times and the variation used for calculation of the probable experimental error. The collected data was statistically analysed and the significance of the first order, second order, third order, and the lack of fit terms was determined by the "F" test while the "t" test was used to determine the significance of the individual regression coefficients. When the F value for the lack of fit term was less than one, the sum of squares of the lack of fit term was pooled with the sum of squares of error 1 to form error 2 which was then used to determine the significance of the regression coefficients.

Table 1. Applied rates of the variables P, Zn, B, S, Cl, N, and plant population and the corresponding coded values.

Level	Coded value	Nutrients applied						Plant population
		P	N	S	Cl	Zn	B	
		kg/ha						plants/ha
1	-2	37	37	37	37	11	11	32,000
2	-1	75	75	75	75	22	22	48,000
3	0	150	150	150	150	45	45	64,000
4	+1	300	300	300	300	90	90	80,000
5	+2	600	600	600	600	180	180	96,000

Field Methods

The treatment plots were randomly distributed over the respective experiments. Each experiment consisted of 31 treatment plots of four rows, 5 m long with 0.625 m between rows (5 x 2.5 m). The field studies formed a solid block with no pathways between plots.

Concentrated superphosphate, zinc chloride, borax, calcium sulphate, calcium chloride, and ammonium nitrate were used as sources of the nutrient factors P, Zn, B, S, Cl, and N, respectively. In experiment I, $CaSO_4$ and $CaCl_2$ were added to all plots in the amounts necessary to equalise for the S and Cl added with the P and Zn fertilizer carriers, respectively. Since the soil was calcareous and inherently high in Ca, it was assumed that the Ca added with $CaSO_4$ and $CaCl_2$ was immaterial. All plots of experiment I received a uniform N application of 300 kg/ha as NH_4NO_3.

The ingredients of each treatment were thoroughly mixed and applied in furrows which were covered by splitting the ridges to form new ridges above the fertilizer bands. The ridges were packed with a roller. On April 15, 1966, the maize variety Indiana 620 A was sown thickly on the ridges directly above the fertilizer band with a hand planter, at a depth of about 4 cm. The plots were adjusted to the final stand when the seedlings were at the three or four leaf stage (May 10, 1966). Weekly sprinkler irrigation was practiced until the plants were well established. Subsequent irrigations were by furrow.

Leaf samples were collected at about 80 percent tasseling (July 12, 1966). The sampled leaves were the second leaf below the ear, collected from ten plants randomly picked from the middle 4 m of the two central rows of each plot. The sampled leaf was immediately separated into the midrib portion from approximately the lower half of the leaf and the blade portion which comprised the remainder of the leaf. The midribs and the blades of each plot were separately composited for analysis.

The maize crop was harvested on September 13, 1966. The yield data were collected from the middle 4 m of the two central rows and reported as yield of grain at 15.5 percent moisture and yield of air-dry stover.

Analytical Procedures

The midrib and blade samples were dried in a forced ventilation oven at 70°C for three days and then ground in a micro-Wiley mill fitted with a 40-mesh sieve. The ground plant material was dried at 70°C, mixed thoroughly, and representative samples were taken for each analysis which were reported on the oven-dry basis.

The blade and midrib samples of experiment II were analysed for total N and nitrate-N, respectively. Total N in the blade was determined by the Kjeldahl method (Jackson, 1958, pp 187-193) while the nitrate-N in the midrib was extracted and determined according to the method described by Johnson and Ulrich (1959, pp 44-45). Nitric-perchloric acid digests of blade samples from both experiments were prepared to determine the total concentrations of P, S, and Zn. Total P was determined colorimetrically using the ammonium molybdate-stannous chloride method (Johnson and Ulrich, 1959, pp 49-52). Total S was determined turbidimetrically according to the method described by Jackson (1958, pp 265-266). Total Zn was determined using an atomic absorption spectrophotometer. The water soluble Cl in the leaf blades of experiment II were extracted and titrimetrically determined (Johnson and Ulrich, 1959, pp 38-39). Midrib samples from experiment I were ashed in a muffle furnace at 550°C and used to determine total B colorimetrically by the curcumin-oxalic acid method (Johnson and Ulrich, 1959, pp 62-64). Midribs from the two experiments were extracted with 2 percent acetic acid and the phosphate-P determined colorimetrically by the ammonium molybdate-stannous chloride method (Johnson and Ulrich, 1959, pp 49-52).

IV. RESULTS AND DISCUSSION

Two adjacent field experiments were designed to study the interrelationships of P, Zn, B, S, Cl, N, and plant population on the yield and composition of irrigated maize.

Experimental Design and Statistical Analysis

The experimental design was a central composite, rotatable, factorial (Cochran and Cox, 1957, design 8.A.1). This design allows the study of the effects of the various factors and their interactions. The effects were expressed as regression coefficients in a partial third order equation including second order, and three-way interaction terms. The regression equations were used to show the response surfaces for yield and nutrient concentrations in the plant in relation to the studied factors.

The significance of the regression coefficients were determined using the "t" test. A "significant" or "highly significant" regression coefficient means that the probability of its being true are 0.95 and 0.99, respectively. A regression coefficient that was not significant at the 5 percent level, but greater than its respective standard error was termed "probably real".

A first order regression coefficient represents the tangent of the response curve to the respective variable at the "O" coded level when all the other component variables of the equation were set at their "O" coded levels. A positive regression coefficient implied that there was an increasing effect at that point to the variable, while a negative coefficient implied a depressing effect. The ultimate magnitude and direction of the response to a particular variable are determined by the combined effects of all the regression coefficients in which the variable is a component. A positive regression coefficient for a squared term implied that the response to increasing amounts of the variable became more positive, or less negative (upward curvature) and a negative coefficient implied that the response became less positive or more negative (downward curvature). A positive two-way interaction regression coefficient indicated that the net effect of the interaction would be positive when both of the interacting variables were applied at high coded levels, or both at low coded levels, while a negative two-way interaction coefficient implied that one of the two variables should be applied at a high level and the other at a low level for a positive net effect. The net effect in both cases would depend on the other effects of the variables. The three-way interaction effect depended on the sign of the regression coefficient as well as the sign of the coded levels of the three variables involved.

Properties of Soil and Irrigation Water

Soil analysis (Ahmad, 1966, Table 2) showed that the soil was a calcareous clay, with low organic matter content. The available P (Olsen method) was "medium".

Water analysis (Soltanpour, 1963, Table 2) indicated that the irrigation water was of good quality. The amounts of Cl and S added by the irrigation water were relatively small compared to the applied rates.

Effects of P, Zn, B and Plant Population on Yields of Grain and Stover and on Plant Composition

The grain and stover yields are reported at 15.5 percent moisture and air dry weights, respectively. The grain yields ranged from 6.9 to 15.8 metric tons per hectare, with an average of 11.6, while the yields of stover ranged from 5.7 to 12.5 metric tons per hectare with an average of 8.9 (Table 3). The high grain and stover yields at the upper end of the range indicated the considerable maize production potential in the area with good cultural practices. The statistical analysis of the yield data of the grain and stover indicated that the partial cubic regression equation used to investigate the individual effects as well as the interrelationships of P, Zn, B, and plant population on maize yields accounted for much of the yield variation as was indicated by the multiple coefficients of correlation between the observed and predicted grain

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

Soil analysis (Ahmad, 1966)		Water analysis (Soltanpour, 1963)	
pH	7.9	Na	0.282 me/l
$CaCO_3$, %	12.8	Ca	0.705 me/l
Organic matter, %	2.1	Mg	0.833 me/l
(wet oxidation)		K	0.056 me/l
P, ppm	16.5	S	0.125 me/l
(bicarbonate soluble)		Cl	0.318
Soil texture		Electrical conductivity	0.155 mmhos/cm
Sand, %	16.4		
Silt, %	27.6		
Clay, %	56.0		

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

Treatment No.	Treatment combinations				Observed grain yield	Predicted grain yield	Observed stover yield	Predicted stover yield	Grain-stover
	P	Zn	B	Pop					
	Coded levels				M tons/ha				Ratio
1	-1	-1	-1	-1	8.98	9.19	7.97	6.98	1.13
2	+1	-1	-1	-1	7.99	9.60	10.75	11.14	0.74
3	-1	+1	-1	-1	9.24	11.34	8.32	8.13	1.11
4	+1	+1	-1	-1	11.10	10.32	8.20	8.16	1.35
5	-1	-1	+1	-1	9.90	12.19	7.90	9.18	1.25
6	+1	-1	+1	-1	10.87	10.28	8.07	9.51	1.35
7	-1	+1	+1	-1	10.29	10.19	6.90	7.76	1.49
8	+1	+1	+1	-1	7.84	9.14	4.89	7.12	1.60
9	-1	-1	-1	+1	11.82	13.55	7.92	7.44	1.49
10	+1	-1	-1	+1	13.81	12.66	12.01	11.68	1.15
11	-1	+1	-1	+1	14.61	13.95 →	9.08	8.17	1.61
12	+1	+1	-1	+1	13.83	14.57	9.39	9.86	1.47
13	-1	-1	+1	+1	10.66	10.19	6.85	7.41	1.56
14	+1	-1	+1	+1	11.47	12.40	7.73	9.67	1.48
15	-1	+1	+1	+1	6.88	8.30	5.97	7.33	1.15
16	+1	+1	+1	+1	15.78	14.32	8.67	10.19	1.82
17	+2	0	0	0	9.64	10.22	13.98	11.31	0.69
18	-2	0	0	0	11.50	9.12	7.18	7.57	1.60
19	0	+2	0	0	14.29	13.89	7.97	6.46	1.79
20	0	-2	0	0	14.78	13.38	8.80	8.03	1.68

Table 3 (Continued).

Treatment No.	Treatment combinations				Observed grain yield	Predicted grain yield	Observed stover yield	Predicted stover yield	Grain-stover
	P	Zn	B	Pop					
	Coded levels				M tons/ha				Ratio
21	0	0	+2	0	11.41	10.64	16.14	11.69	0.71
22	0	0	-2	0	13.70	12.68	10.36	12.54	1.32
23	0	0	0	+2	12.46	12.80	7.53	6.60	1.66
24	0	0	0	-2	10.52	8.38	7.01	5.66	1.50
25	0	0	0	0	12.30	12.26	8.68	9.49	1.42
26	0	0	0	0	13.09	12.26	11.04	9.49	1.19
27	0	0	0	0	12.56	12.26	11.31	9.49	1.11
28	0	0	0	0	10.26	12.26	8.13	9.49	1.26
29	0	0	0	0	12.53	12.26	10.80	9.49	1.16
30	0	0	0	0	11.29	12.26	8.66	9.49	1.30
31	0	0	0	0	13.81	12.26	7.81	9.49	1.77
	R^1				0.82		0.74		

1 Multiple regression coefficient.

yields, R = 0.82, and the observed and predicted stover yields, R = 0.74 (Table 3).

Fuehring *et al*. (1968) compiled data from several studies on maize nutrition including this study and reported that the optimum combination of P, Zn, B, and plant population for maximum grain yield was at high levels for all, when combined with a high level of N and low levels of S, Cl, and Mn. Since the combined results are more comprehensive they will be used as guide lines for discussion. However, the combined results were affected by the presence of N, S, Cl, and Mn as variables and the results of this experiment are sometimes at variance. The equations used to assess the grain yield were the regression equation of this experiment (Equation A, Table 4) and the equation of Fuehring *et al*. (1968) (Equation B) which was as follows:

$$\begin{aligned} Y = {} & 0.82^{**}N + 0.07\,P - 0.13\,S - 0.11^{e}\,Cl + 0.4\,Zn \\ & - 0.32^{*}\,B - 0.15\,Mn + 0.25^{e}\,Pop - 0.33^{**}\,N^2 + \\ & 0.01\,P^2 + 0.08\,S^2 + 0.00\,Cl^2 + 0.15^{e}\,Zn^2 - \\ & 0.06\,B^2 + 0.51^{e}\,Mn^2 + 0.02\,Pop^2 \\ & + 0.05\,NP + 0.08\,NS - 0.07\,NCl + 0.00\,NZn + \\ & 0.09\,NB - 0.26\,NMn - 0.26\,N\,Pop - 0.24^{e}\,PS \\ & - 0.05\,PZn + 0.21^{e}\,PB - 0.17^{e}\,PCl + 0.22^{e}\,P\,Pop \\ & - 0.11\,SZn - 0.26^{e}\,SCl - 0.14\,S\,Pop + 0.09\,ZnB \\ & - 0.22\,ZnMn - 0.16^{e}\,ZnCl + 0.29^{e}\,Zn\,Pop + \\ & 0.53^{e}\,BMn + 0.01\,B\,Pop - 0.14\,Mn\,Pop - 0.18\,SB \end{aligned}$$

+ 0.08 PZnB - 0.08 PZn Pop + 0.44[e] PB Pop + 0.38[e] ZnB Pop - 0.26 PSCl - 0.74[e] PSN - 0.16 PClN + 0.15 SClN - 0.35 SZnB - 0.54 SZn Pop + 0.29 SB Pop.

Y = Quantitative factor measured. Letter or letters following the coefficient represent the coded levels of the respective variables applied. Pop refers to plant population.

The grain yield regression equation of this experiment was solved for the optimum combination for maximum grain yield when the variables were held between the arbitrary limits of -1.5 and +1.5 coded levels. The best combination was -0.1, +1.5, -1.5, and +1.5 for P, Zn, B, and plant population respectively, in contrast to the combination +1 for all the four variables when held arbitrarily between -1 and +1 as reported by Fuehring _et al_. (1968). The coded levels of applied S, Cl and N amounted to -1.3, +0.4 and +1, respectively in the study reported here, and were constant for all treatments. These could not be accounted for in the regression analysis for this experiment and may account for some of the differences in results between the two equations.

The grain response to application of P was closely related to the applied B levels using either the regression equation of this experiment or the equation of Fuehring _et al_. (1968). At the -1 coded level of applied B, there was little effect of P (Figure 1a and 1c) while at the +1 coded level of B, P had a relatively large positive effect (Figure 1b and 1d). Thus one of the chief effects of applied P was to balance the effect of applied B on yield of grain.

The first order effect of P fertilization on grain yield was positive and probably real (regression coefficient greater than standard error, Table 4). The significantly negative squared term indicated that the response to P application became less positive (or more negative) at increasing levels of applied P (Figure 1a and 1b). The two-way and the three-way interactions involving P for the yield of grain were positive and probably real effects (Table 4), indicating more response to, and greater requirement for, P as the levels of Zn, B, and plant population were increased. The P-Pop was the largest interaction term and was statistically significant. Thus, the positive P-B and P-B-Pop interactions resulted in enhanced response to P (Figure 1a and 1b).

The yields of stover were increased to a considerably greater extent than the grain yields by P fertilization, as was indicated by the significantly positive first order effect of P on stover yield, and the negative and probably real first order effect of P on the grain-stover ratio (Table 4, Figure 1a and 2a). The P-Pop and P-Zn-B interaction effects on yield of stover were positive and probably real while the P-Zn interaction was negative and

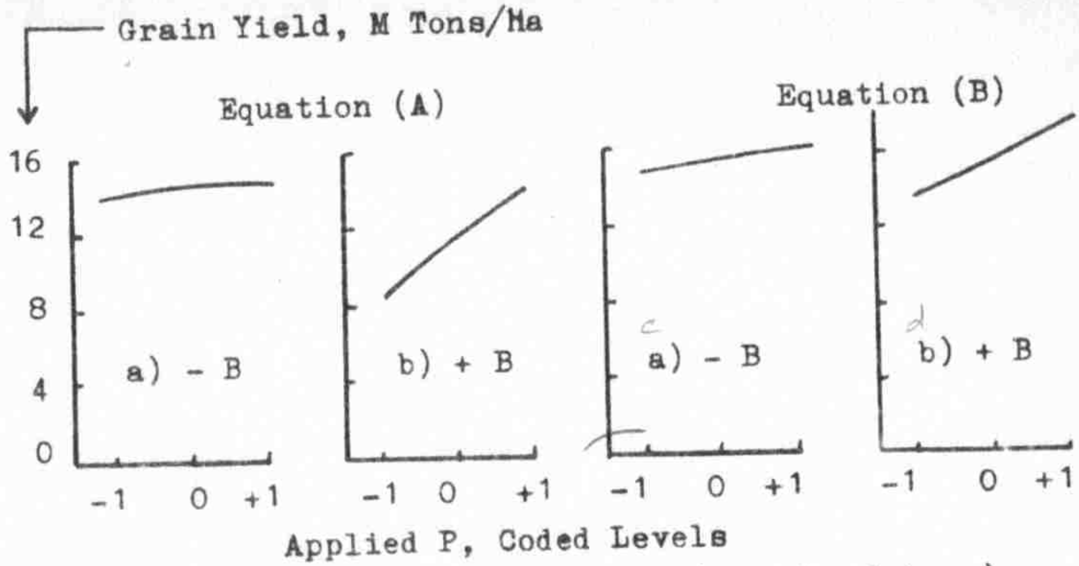


Figure 1. Predicted grain yield (15.5% moisture) using the equation of this experiment (A) or Fuehring et al. (B) as affected by levels of applied P. Levels of Zn and Pop were held constant at the +1 coded level.

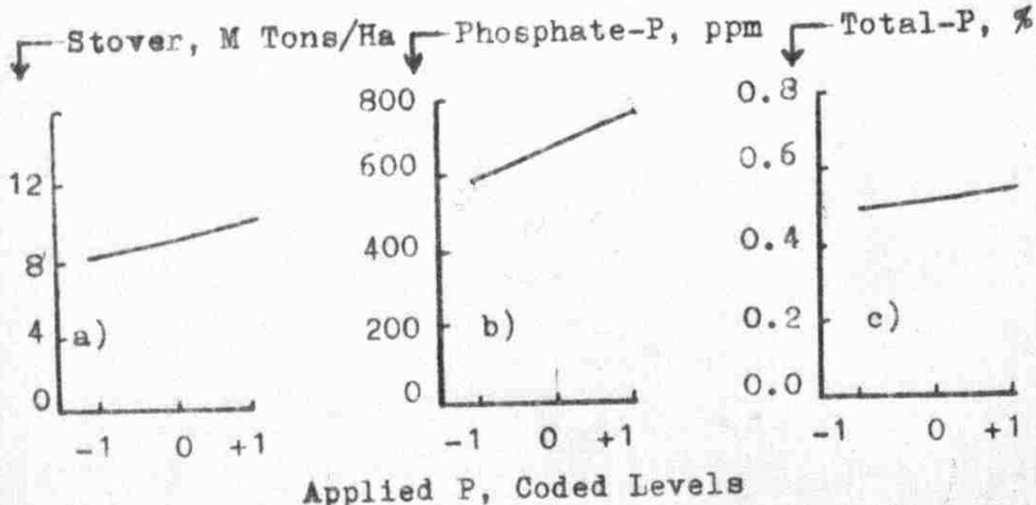


Figure 2. Predicted yield of air-dry stover (a), phosphate-P (b), and total-P (c) as affected by levels of applied P. Coded levels of Pop and Zn were held constant at +1 and B at -1.

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

Regression coefficient		Grain yield	Stover yield	Grain-stover Ratio
		M tons/ha		
Mean	b_0	12.263	9.490	
P	b_1	+0.275^e	+0.933*	-0.069^e
Zn	b_2	+0.129	-0.393^e	+0.069^e
B	b_3	-0.511^e	-0.213	+0.018
Pop	b_4	+1.105**	+0.236	+0.085^e
	s_b	0.2384	0.3054	±0.0458
P^2	b_{11}	-0.648*	-0.012	-0.044^e
Zn^2	b_{22}	+0.343^e	-0.561^e	+0.104*
B^2	b_{33}	-0.151	+0.655^e	-0.077^e
Pop^2	b_{44}	-0.418^e	-0.840	+0.064^e
	s_b	0.2162	0.2769	±0.0415
P-Zn	b_{12}	+0.297^e	-0.440^e	+0.099^e
P-B	b_{13}	+0.384^e	-0.333	+0.089^e
P-Pop	b_{14}	+0.721*	+0.448^e	+0.003
Zn-B	b_{23}	-0.518^e	-0.029	-0.038
Zn-Pop	b_{24}	+0.163	-0.311	-0.044
B-Pop	b_{34}	-0.679^e	-0.106	-0.067^e
B-Zn-B	b_{123}	+0.287	+0.395^e	-0.004
P-Zn-Pop	b_{124}	+0.368^e	+0.195	+0.019
P-B-Pop	b_{134}	+0.678^e	+0.230	+0.044
Zn-B-Pop	b_{234}	+0.233	+0.219	-0.026
	s_b	0.2922	0.3743	±0.0562

e Regression coefficient greater than standard error (probably real).
* Regression coefficient significant (5 percent level).
** Regression coefficient highly significant (1 percent level).

probably real. This, together with the positive and probably real P-Zn and P-B interactions on the grain-stover ratio, implied that applied P enhanced stover yields to a greater extent at high levels of Pop and low levels of Zn and B.

P fertilization significantly increased the concentration of the phosphate-P in the midribs and the total-P in the leaf blades at tasseling time as was indicated by the significantly positive first order terms for applied P on the phosphate-P and total-P (Table 5). The concentrations of phosphate-P and total-P increased with applied P and ranged from 560 to 896 ppm and 0.46 to 0.60 percent, respectively (Table 6). The relationship between grain yield and level of phosphate-P depended on the level of applied B with grain yield parallelling and increasing with applied P (Figure 1b and 2b). At a low B level, grain yield had little relationship to the phosphate-P level (Figure 1a and 2b). Therefore no definite critical level could be determined. The phosphate-P of the midribs appeared to be a more sensitive measurement of P response than total-P of the leaf blades (Figure 2b and 2c).

The net effect of Zn on grain yield tended to be positive (Figure 3a and 3c) and was more positive as levels of P and B were increased (Figure 3b and 3d). Most of the interactions involving Zn tended to be positive implying a more positive response to Zn at higher levels of P and plant population (Table 4). The Zn-B interaction was negative

Table 5. Regression coefficients (b) and their standard errors (s_b) for leaf composition as affected by the various combinations of the coded levels of applied P, Zn, B, and Pop at the tasseling stage.

Regression coefficient		Phosphate-P of midribs	Total-P of blades	Total-Zn of blades	Total-B of midribs
		ppm	%	ppm	Log. of ppm
Mean	b_0	734.59	0.547	55.36	1.924
P	b_1	+51.13**	+0.022*	+1.10	+0.018
Zn	b_2	-2.46	+0.004	+4.63**	+0.007
B	b_3	+2.71	-0.012^e	-0.28	+0.149*
Pop	b_4	-6.29	+0.002	-6.33**	-0.033^e
	s_b	±9.921	±0.0065	±1.193	±0.0213
P^2	b_{11}	+12.63^e	+0.001	-1.03	+0.010
Zn^2	b_{22}	-26.87*	-0.010^e	+3.53*	+0.007
B^2	b_{33}	-28.37*	-0.003	-2.22^e	-0.013
Pop^2	b_{44}	-1.50	-0.014^e	+0.96	-0.013
	s_b	±8.997	±0.0059	±1.082	±0.0194
P-Zn	b_{12}	+16.69^e	+0.004	+2.09^e	-0.001
P-B	b_{13}	-20.81^e	-0.003	+0.36	-0.023
P-Pop	b_{14}	-16.19^e	-0.001	+1.66^e	-0.006
Zn-B	b_{23}	+2.31	-0.005	-4.96*	+0.024
Zn-Pop	b_{24}	+10.69	-0.009^e	+1.81^e	-0.013
B-Pop	b_{34}	-5.81	+0.007	-3.06^e	-0.079*
P-Zn-B	b_{123}	-27.69^e	-0.010^e	+0.43	-0.013
P-Zn-Pop	b_{124}	-3.56	-0.004	+1.20	-0.021
P-B-Pop	b_{134}	+1.94	+0.003	+2.05^e	+0.018
Zn-B-Pop	b_{234}	+3.06	-0.003	+3.60*	+0.011
	s_b	±12.159	±0.0079	±1.462	±0.0262

e Regression coefficient greater than standard error (probably real).
* Regression coefficient significant (5 percent level).
** Regression coefficient highly significant (1 percent level).

Table 6. Observed P, Zn, and B concentrations "dry basis" in the leaf at tasseling as affected by various combinations of levels of P, Zn, B, and plant population.

Treatment No.	Treatment combinations				Phosphate-P of midribs	Total P of blades	Total Zn of blades	Total B of midribs
	P	Zn	B	Pop				
	Coded levels				ppm	%	ppm	ppm
1	-1	-1	-1	-1	625	0.50	58	45
2	+1	-1	-1	-1	785	0.52	57	52
3	-1	+1	-1	-1	567	0.50	67	40
4	+1	+1	-1	-1	752	0.60	75	58
5	-1	-1	+1	-1	717	0.46	80	150
6	+1	-1	+1	-1	730	0.51	78	127
7	-1	+1	+1	-1	600	0.50	60	160
8	+1	+1	+1	-1	750	0.53	56	151
9	-1	-1	-1	+1	740	0.50	48	70
10	+1	-1	-1	+1	675	0.53	48	72
11	-1	+1	-1	+1	560	0.50	52	56
12	+1	+1	-1	+1	825	0.56	56	58
13	-1	-1	+1	+1	622	0.50	42	82
14	+1	-1	+1	+1	759	0.56	43	97
15	-1	+1	+1	+1	741	0.50	32	110
16	+1	+1	+1	+1	653	0.53	55	90
17	+2	0	0	0	896	0.59	51	115
18	-2	0	0	0	661	0.52	52	81
19	0	+2	0	0	657	0.50	98	103
20	0	-2	0	0	584	0.52	41	84
21	0	0	+2	0	620	0.50	49	134

Table 6 (Continued).

Treatment No.	Treatment combinations				Phosphate-P of midribs	Total P of blades	Total Zn of blades	Total B of midribs
	P	Zn	B	Pop				
	Coded levels				ppm	%	ppm	ppm
22	0	0	-2	0	609	0.58	45	45
23	0	0	0	+2	672	0.49	60	58
24	0	0	0	-2	772	0.50	59	105
25	0	0	0	0	663	0.53	56	80
26	0	0	0	0	772	0.55	55	71
27	0	0	0	0	710	0.51	47	102
28	0	0	0	0	700	0.54	64	118
29	0	0	0	0	800	0.52	50	102
30	0	0	0	0	724	0.59	61	66
31	0	0	0	0	773	0.59	55	65

and probably real implying less response to Zn at high B levels. However, the two three-way interactions involving Zn and B tended to be positive and would cancel the negative Zn-B effect at high levels of P and plant population. The effect of Zn application on yield of stover was negative as compared to the net positive effect on grain yield. This was implied by the negative and probably real first order and squared term effects of Zn (Table 4) and the negative two-way interactions. However, the three-way interactions tended to be positive thus cancelling the two-way effects when all variables were at high levels. The positive and probably real first order effect of Zn on the grain-stover ratio implied that Zn application tended to shift the grain-stover ratio towards the production of grain under the conditions for very high yields that prevailed during this study. The amounts of Zn required to be applied, however, were far in excess of the amounts taken up by the plants and also tended to be uneconomic. Further work is required on securing more efficient response to Zn. Spray application offers the greatest possibilities, but timing and frequency of application requires study. Also, the form of Zn and method, and time of soil application offer possibilities of improvement in efficiency of Zn utilization.

Zn fertilization significantly increased the Zn concentration in the leaf blades at tasseling time as was implied by the positive and highly significant first order term and the positive and significant squared term for applied Zn (Table 5). The highly significant and negative first order effect of plant population on Zn concentration of leaf blades implies that Zn application is increasingly important as population levels and yield levels are pushed up. The general effect of P application on Zn concentration was not particularly depressing as expected from literature reports (Koukoulakis, 1967; Stukenholtz et al., 1966).

The significantly negative Zn-B interaction implies an increasing effect of B application on Zn concentration at low levels of applied Zn and a decreasing effect at high levels. However, the significantly positive three-way Zn-B-Pop interaction implied that the Zn-B relationship described above was enhanced at a low population level and cancelled out at a high population level. At the optimum combination of P, B, and Pop for grain yield, Zn concentration in the blade and grain yield were increased by increasing levels of applied Zn (Figure 3a and 4b). The curves tended to be parallel with both grain yield and Zn concentration increasing to greatest extent between the 0 and +1 coded levels. The yield of stover decreased between the 0 and +1 coded levels (Figure 4a). It appeared that Zn concentrations in the leaf blades at tasseling of 50 to 75 ppm were necessary to secure the high grain yield obtained in this experiment. These are high levels as

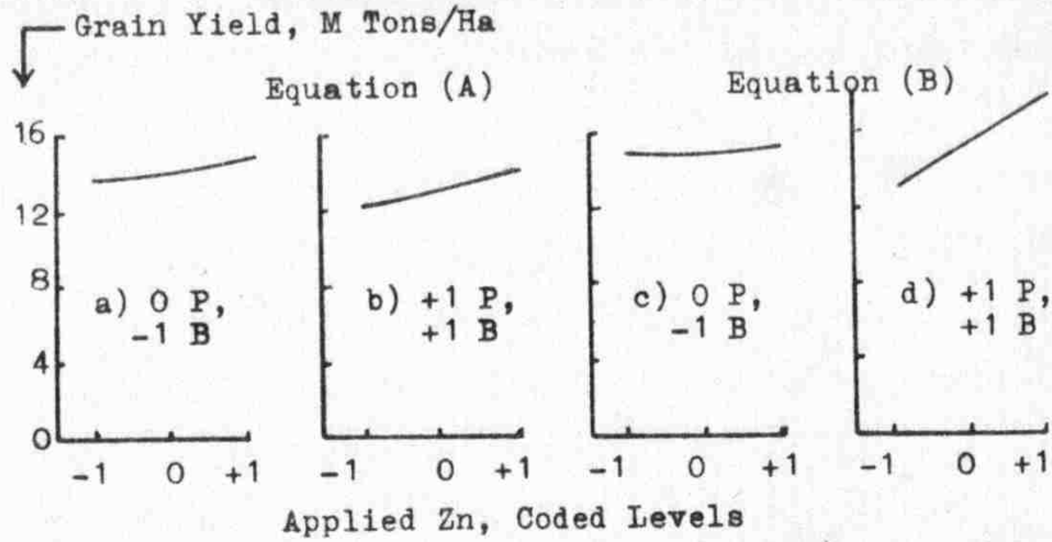


Figure 3. Predicted grain yield (15.5% moisture) using the equation of this experiment (A) or Fuehring *et al*. (B) as affected by levels of applied Zn. Level of Pop was held constant at the +1 coded level.

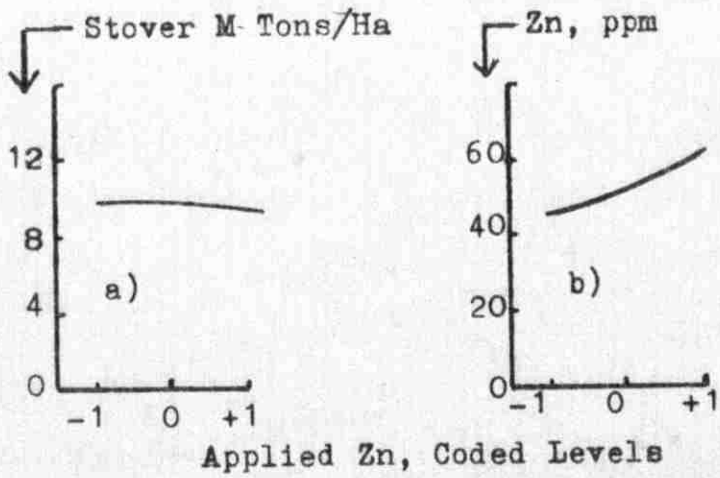


Figure 4. Predicted yield of air dry stover (a) and Zn concentration in the blade (b) as affected by levels of applied Zn. Levels of P, B, and Pop were held constant at the 0, -1, and +1 coded levels, respectively.

compared to the levels reported in the literature. Ahmad (1966), in a similar study, reported a considerably smaller Zn concentration of leaf blades ranging from 16 to 38 ppm at the pretasseling stage. Soltanpour (1963), analysing the whole leaf rather than separating it into blade and midrib, reported a Zn concentration range of 18-48 ppm at tasseling. Fuehring and Soofi (1964) observed Zn concentrations of 20 to 145 ppm in the whole leaf at tasseling, with more grain yield at the lower end of the range and high stover at the upper end. The presence of Mn as a variable in the study had considerable influence, however.

The first order effect of applied B on yield of grain was negative and probably real (Table 4), but the over all effect of B on grain was determined by the levels of applied P, Zn, and plant population. At the 0 coded level of applied P, increasing levels of applied B depressed yield of grain (Figure 5a), but, when P was raised to the +1 coded level, the depressing effect of B disappeared (Figure 5b). At high levels of P, Pop, and Zn, the positive P-B and the positive three-way interactions involving B cancelled the negative Zn-B and B-Pop interaction effects on yield of grain (Table 4). The amount of B taken up by the crop was far less than the amounts applied, which tended to be uneconomic. Further work is required on securing more efficient response to B. Since B is mostly needed at the grain producing stage, spraying or dusting of

B in small amounts, several times, especially at the ear-shooting stage, offers greatest possibilities. However, timing, frequency and form of application need study. Also, the method and time of soil application of B offer possibilities of improvement in efficiency of B utilization.

Applied B significantly increased the concentration of total B in the midribs at tasseling, as was implied by the significant and positive first order coefficient of applied B (Table 5). The negative and probably real first order effect of Pop on B concentration in the midribs indicated the need for B application at the high plant population levels required for high grain yields. Concentration of B in the midribs at tasseling ranged from 40 to 160 ppm (Table 6). Ahmad (1966) and Fuehring (1966) reported B concentrations of 55 to 120 ppm and 51 to 124 ppm, respectively, under similar conditions. The relationship between grain yield and B concentration in the midribs at tasseling seemed to depend on the level of soil P (Figure 5a, 5b, 6a, and 6b) with applied P overcoming B toxicity. At a medium level of applied P, levels of B above about 50 ppm were associated with decreasing yield of grain (Figure 5a and 6a) while at a higher level of applied P, levels of B up to about 90 ppm had little effect on yield of grain (Figure 5b and 6b).

The large grain yield response to increasing levels of plant population in the equation of this experiment

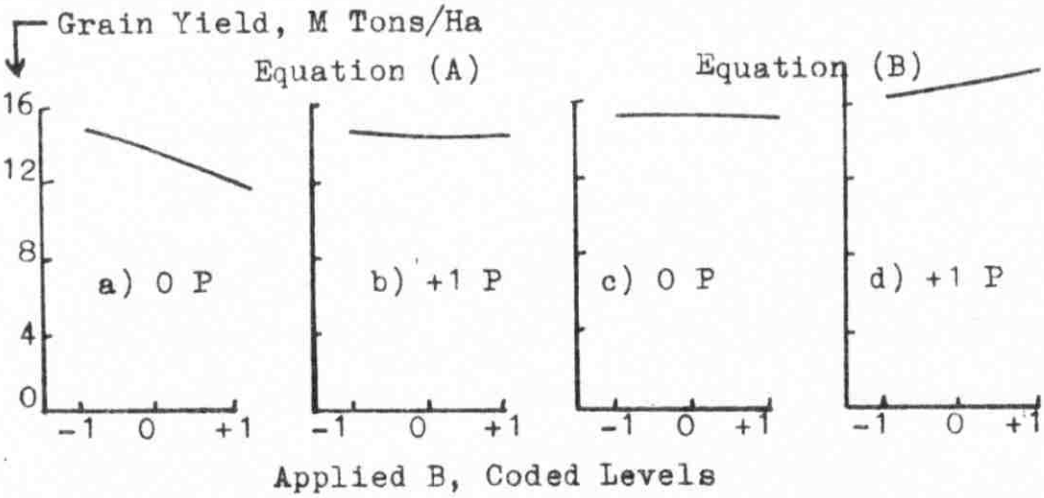


Figure 5. Predicted grain yield (15.5% moisture) using the equation of this experiment (A) or Fuehring <u>et al</u>. (B) as affected by levels of applied B. Levels of Zn and Pop were held constant at the +1 coded level.

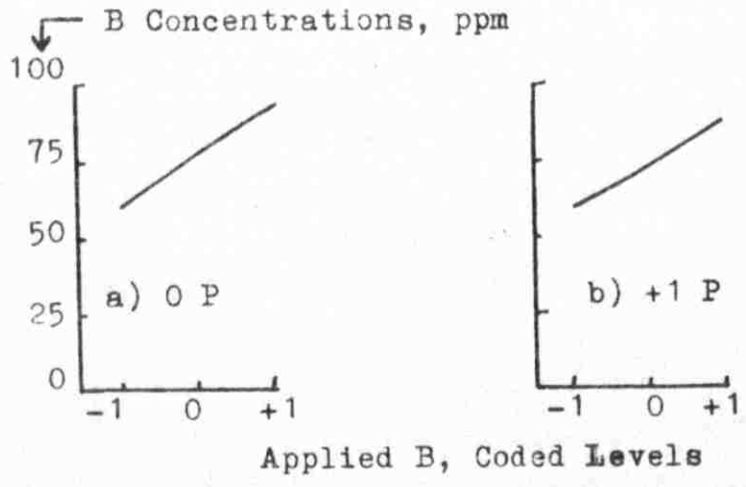


Figure 6. Concentrations of B in midribs as affected by levels of applied B. Levels of Zn and Pop were held constant at the +1 coded level.

(highly significant first order term, Table 4) and the equation of Fuehring et al. (1968) (Figure 7), indicated the need for a high plant population for a maximum grain yield. All the two-way and three-way interactions involving Pop, except the B-Pop, were positive, implying that at high soil fertility levels, high plant population levels were required for large grain yields. Maize grain yield is determined by the two major grain yield components, number of ears per area and ear weight. The total number of ears per area increases with increasing levels of plant population but the ear weight decreases (Stickler, 1964, and Colville, 1962). The levels of plant population should be adjusted to result in an ear weight of about 200-250 g. The maximum yield of equation A and equation B (Figure 7a and 7d) were 15 and 18 metric tons per hectare, respectively, which corresponded to ear weight of about 178 and 225 g, respectively. Fuehring et al. (1968) reported an average predicted ear weight of 209 g with 96,000 plants per hectare (20 m tons/ha).

Effect of Applied P, S, Cl, and N on Grain and Stover Yields

The grain and stover yields are reported at 15.5 percent moisture and air dry weights, respectively. Yields of grain ranged from 6.9 to 11.9 metric tons per hectare with an average of 9.45 and yields of stover ranged

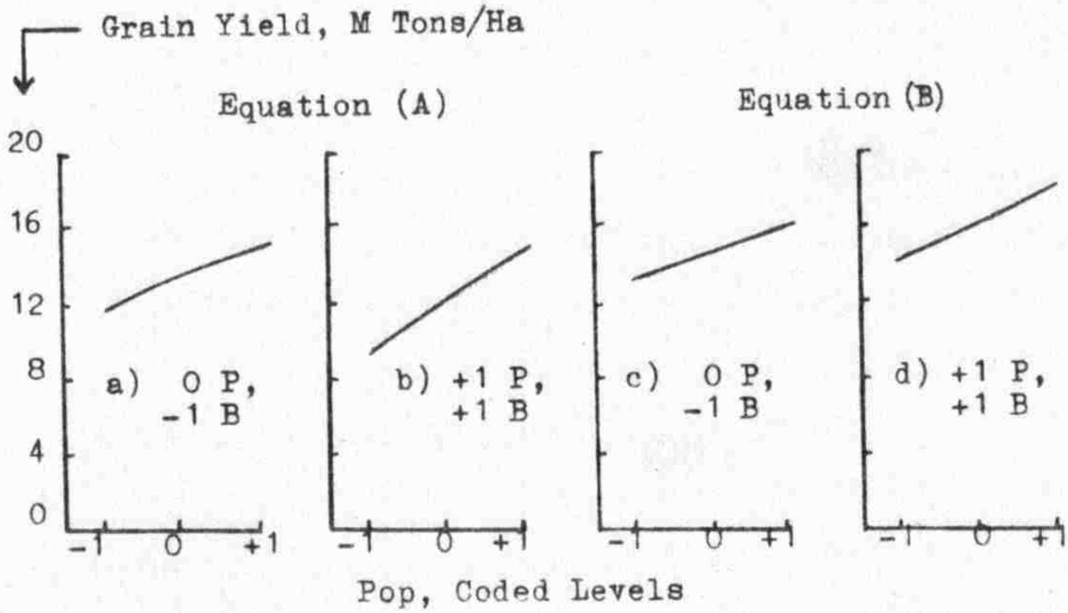


Figure 7. Predicted grain yield (15.5% moisture) using the equation of this experiment (A) or Fuehring et al. (B), as affected by levels of Pop. Levels of Zn was held constant at the +1 coded level.

from 3.4 to 13.2 metric tons per hectare with an average of 7.19 (Table 7). Analysis of the yield data for grain and stover resulted in multiple correlation coefficients of R = 0.79 and R = 0.76 between the observed and predicted yields of grain and stover, respectively. This implied that the partial cubic regression equations used had accounted for much of the variation due to treatments.

The experiment was designed to study the effects of anion balance on grain and stover yields of maize. Noggle (1966) observed in some plant species that the rate of growth may be proportional to the amount of organic anions contained. Since the presence of excess available inorganic anions may tend to decrease the amount of organic anions in the plant and hence depress growth, an experiment was initiated to investigate the effects of the inorganic fertilizer anions P, S, Cl, and N.

Fuehring <u>et al</u>. (1968) compiling data from several studies on maize nutrition, including this experiment, reported highest maize grain yields with a nutrient combination consisting of high levels of applied P and N and low levels of S and Cl, and since the combined results are more comprehensive, they will be used as guide lines for discussion. Since the combined results are affected by the presence of Zn, B, Pop, and Mn as variables, however, the results of this experiment are sometimes at variance.

Solving the grain yield regression equation of this

Table 7. Observed and predicted yields of grain, 15.5% moisture, stover, air-dry weight, and grain-stover ratio, as affected by various combinations of P, S, Cl, and N.

Treatment No.	Treatment combinations				Observed grain yield	Predicted grain yield	Observed stover yield	Predicted stover yield	Grain-stover
	P	S	Cl	N					
	Coded levels				M tons/ha				Ratio
1	-1	-1	-1	-1	11.92	11.41	7.47	6.56	1.60
2	+1	-1	-1	-1	8.75	9.39	6.52	7.07	1.34
3	-1	+1	-1	-1	8.22	9.02	6.69	7.60	1.23
4	+1	+1	-1	-1	9.34	9.12	7.05	5.33	1.32
5	-1	-1	+1	-1	10.50	10.77	6.82	7.60	1.54
6	+1	-1	+1	-1	10.86	10.11	8.04	6.18	1.35
7	-1	+1	+1	-1	8.92	8.34	7.57	6.07	1.18
8	+1	+1	+1	-1	7.18	7.74	4.71	4.67	1.52
9	-1	-1	-1	+1	7.66	7.95	5.67	7.00	1.35
10	+1	-1	-1	+1	11.56	10.83	9.11	7.80	1.27
11	-1	+1	-1	+1	9.77	9.20	8.22	7.27	1.19
12	+1	+1	-1	+1	7.67	8.25	7.92	8.43	0.97
13	-1	-1	+1	+1	9.67	8.57	8.15	7.07	1.19
14	+1	-1	+1	+1	11.45	11.50	6.76	7.14	1.69
15	-1	+1	+1	+1	10.77	11.00	7.30	8.04	1.48
16	+1	+1	-1	+1	8.84	8.03	13.16	11.26	0.67
17	+2	0	0	0	11.26	11.36	6.64	8.58	1.70
18	-2	0	0	0	11.32	11.68	8.83	8.41	1.28
19	0	+2	0	0	7.09	6.87	5.37	6.59	1.32
20	0	-2	0	0	8.65	9.33	5.72	6.02	1.51
21	0	0	+2	0	8.50	9.34	6.46	7.94	1.32

Table 7 (Continued).

Treatment No.	Treatment combinations P	S	Cl	N	Observed grain yield	Predicted grain yield	Observed stover yield	Predicted stover yield	Grain-stover
	Coded levels				M tons/ha				Ratio
22	0	0	-2	0	9.50	9.12	7.67	7.70	1.24
23	0	0	0	+2	8.06	8.87	7.38	7.76	1.09
24	0	0	0	-2	9.38	9.03	3.40	4.53	2.76
25	0	0	0	0	11.79	9.45	6.99	7.20	1.69
26	0	0	0	0	9.98	9.45	6.57	7.20	1.52
27	0	0	0	0	9.67	9.45	6.88	7.20	1.41
28	0	0	0	0	10.65	9.45	8.03	7.20	1.33
29	0	0	0	0	9.34	9.45	7.86	7.20	1.19
30	0	0	0	0	6.89	9.45	6.71	7.20	1.03
31	0	0	0	0	7.85	9.45	7.37	7.20	1.07
			R[1]		0.79		0.76		

1 Multiple regression coefficient.

experiment for maximum grain yield when the variables were held between the arbitrary limits of -1.5 and +1.5 coded levels indicated the optimum combination to be -1.5, +1.5, +1.5, and +1.5 for P, S, Cl, and N, respectively, resulting in a maximum grain yield of 14.8 metric tons per hectare. This was at variance with results of Fuehring <u>et</u> <u>al</u>. (1968) who reported that high levels of P and low levels of S and Cl were required for maximum grain yield. The difference was probably due to the presence of Zn and B as variables in some of the Fuehring <u>et</u> <u>al</u>. studies. In experiment I of this study it was shown that the positive response to P depended on the level of B applied and since B was not applied, less response to P would be expected in experiment II. The P-S and P-S-N interactions for grain were negative and probably real (Table 8) implying grain response to P at high levels of N and low levels of S, or response to S at low levels of P and high levels of N. The levels of applied N and S along with the levels of applied B, as shown in experiment I determined to a large extent the grain response to P. There was a considerable positive response of yield of grain to P at high levels of N and low levels of S (Figure 8b), but the positive effect disappeared at other combinations of N and S (Figure 8a, 8c and 8d). Therefore, it appeared that either P or S was required for high grain yield under the conditions of this experiment, but not both.

Table 8. Regression coefficients (b) and their standard errors (s_b) for yields of grain and stover and the grain-stover ratio as affected by various combinations of applied P, S, Cl, and N.

Regression coefficient		Grain yield	Stover yield	Grain-stover
		M tons/ha		Ratio
Mean	b_0	9.453	7.202	1.320
P	b_1	-0.079	+0.042	+0.008
S	b_2	-0.616^e	+0.141^e	-0.090^e
Cl	b_3	+0.054	+0.060	+0.021
N	b_4	-0.039	+0.808**	-0.192*
	s_b	±0.3370	±0.1159	±0.0491
P^2	b_{11}	+0.517^e	+0.323*	+0.005
S^2	b_{22}	-0.338^e	-0.224^e	-0.012
Cl^2	b_{33}	-0.055	+0.156^e	-0.047^e
N^2	b_{44}	-0.125	-0.263*	+0.114*
	s_b	±0.3055	±0.1051	±0.0446
P-S	b_{12}	-0.470^e	-0.046	-0.036
P-Cl	b_{13}	-0.080	+0.018	+0.019
P-N	b_{14}	+0.318	+0.615**	-0.037
S-Cl	b_{23}	-0.118	+0.116	-0.004
S-N	b_{24}	+0.318	+0.609**	-0.038
Cl-N	b_{34}	+0.303	+0.315^e	+0.009
P-S-Cl	b_{123}	-0.256	+0.350*	-0.062^e
P-S-N	b_{124}	-0.744^e	+0.393*	-0.146^e
P-Cl-N	b_{134}	-0.164	+0.149^e	-0.021
S-Cl-N	b_{234}	+0.151	+0.408*	-0.029
	s_b	±0.4129	±0.1420	±0.0603

e Regression coefficient greater than standard error (probably real).
* Regression coefficient significant (5 percent level).
** Regression coefficient highly significant (1 percent level).

The positive and highly significant P-N interaction and the significantly positive P-S-Cl and P-S-N interactions for stover (Table 8) along with the general positive regression coefficients for the first order and interaction terms implied that high levels of applied P at high levels of N, S and Cl enhanced the vegetative growth of maize (Figure 9b). Since at this combination, applied P depressed grain yield (Figure 9a), it seems that the increased vegetative growth was at the expense of grain production. In general, stover production and, to a more limited extent, total dry matter production depended on applying high levels of all four anions, while grain production was depressed when both P and S were applied. The generally lower yields of grain in experiment II, as compared to experiment I, may be related to the absence of applied Zn and B in experiment II.

The negative and probably real first order and squared term coefficients for the effect of S application on yield of grain and the negative and probably real first order effect of S on the grain-stover ratio (Table 8) implied that applied S depressed grain production in maize. Grain yield response to applied S was determined to a large extent by the levels of applied P and N as was indicated by the negative and probably real P-S and P-S-N interactions (Table 8). There was a considerable response to S at low levels of P and high levels of N (Figure 10b) while applied S tended to depress yield of grain at the

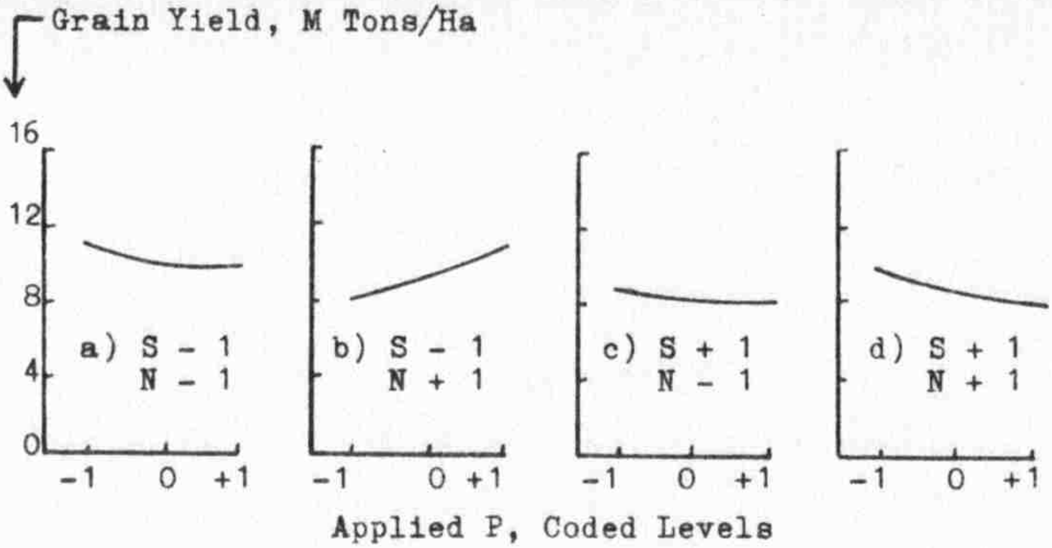


Figure 8. Predicted grain yield (15.5% moisture) as affected by levels of applied P. Level of Cl was held constant at the 0 coded level.

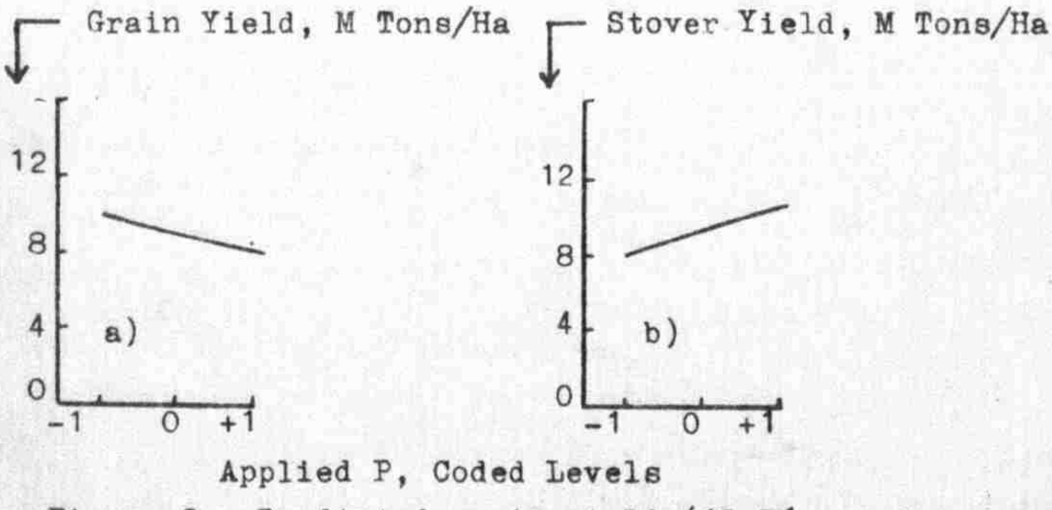


Figure 9. Predicted grain yield (15.5% moisture) (a) and air dry stover (b) as affected by levels of applied P. Levels of S, Cl, and N were held constant at the +1 coded levels.

other combinations of P and N (Figure 10a, 10c and 10d). In general, yield of stover was enhanced by application of S (Table 8).

Generally, the effect of applied Cl was small on yield of grain but was positive for yield of stover when N, P and S were at high levels (Table 8).

The negative and probably real P-S-N interaction on grain (Table 8) implied that grain response to N depended on the levels of applied P and S. Applied N depressed the yield of grain at low levels of P and S (Figure 11a) and increased grain yield at low P and high S or low S and high P (Figure 11b and 11c). Nitrogen fertilization increased stover production to a considerably greater extent than grain production as was implied by the positive and highly significant first order coefficient for the effect of N on stover and the negative and significant first order effect of N on the grain-stover ratio (Table 8). The positive and highly significant P-N and S-N interactions and the positive and significant P-S-N and S-Cl-N interactions on stover indicated that high levels of applied N at high levels of soil P, S, and Cl results in large stover production.

The depressing effect of S on yield of grain at high levels of P and N may have considerable importance, because the amounts of S added in the fertilizer carriers and irrigation water are not ordinarily considered, when fertilizing maize. The differential response to nutrients between yields of grain and yield of stover can be attributed chiefly to the N-P-S interaction which was negative for yield of grain and significantly positive for yield of stover. Each of the four variables resulted in considerably different net response between yields of grain and stover when the other three were at high levels (Figure 12 and Figure 13). Stover yields were particularly increased with P (Figure 12a and 13a) and S (Figure 12b and 13b) but at the expense of yield of grain.

Effect of Applied P, S, Cl, and N on Plant Composition

The positive and probably real first order and squared term coefficients of applied P (Table 9) implied that P fertilization increased the phosphate-P concentration in the midribs at the time of tasseling. The phosphate-P concentration tended to be depressed by applied S and Cl and was significantly increased by applied N as was implied by the negative and probably real first order effect of S and Cl and the highly significant positive first order effect of N (Table 9). The positive and probably real S-Cl interaction implied that high levels of S and Cl interacted to decrease their negative first order effects on the phosphate-P concentrations. The positive effect of N and the negative effect of Cl were enhanced by the negative Cl-N interaction when N was applied at a high level and

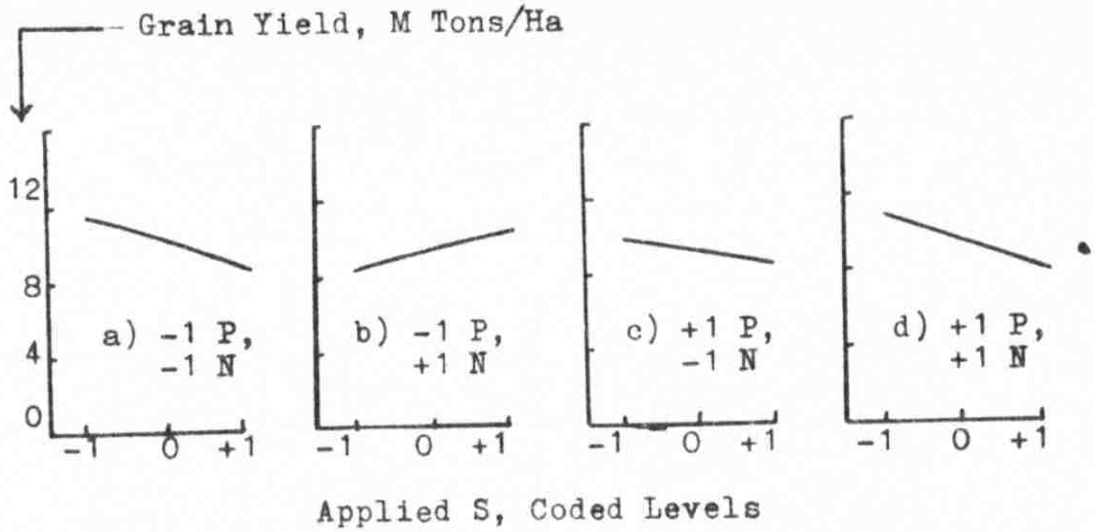


Figure 10. Predicted grain yield (15.5% moisture) as affected by levels of applied S. Levels of Cl was held constant at the 0 coded level.

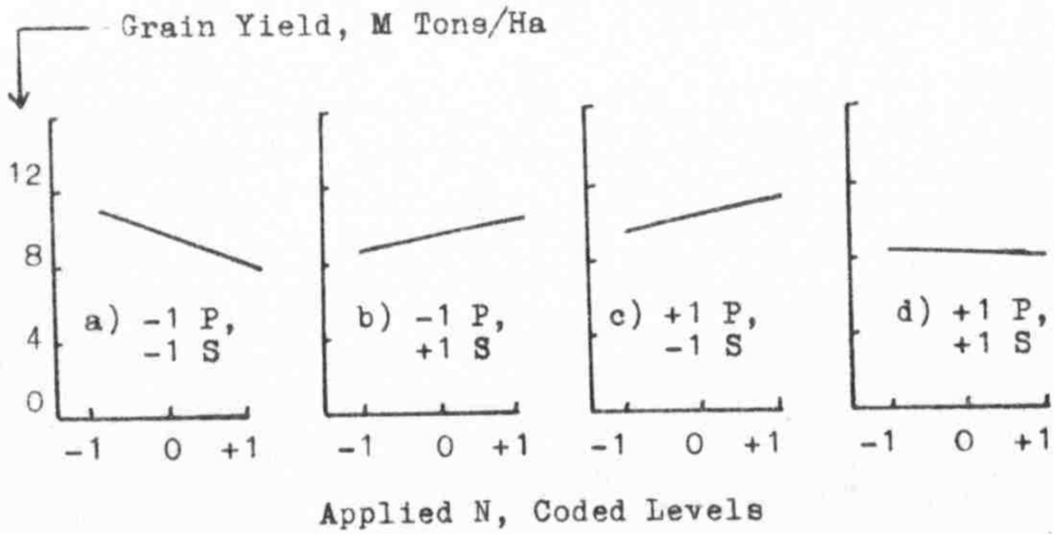


Figure 11. Predicted grain yield (15.5% moisture) as affected by levels of applied N. Level of Cl was held constant at the 0 coded level.

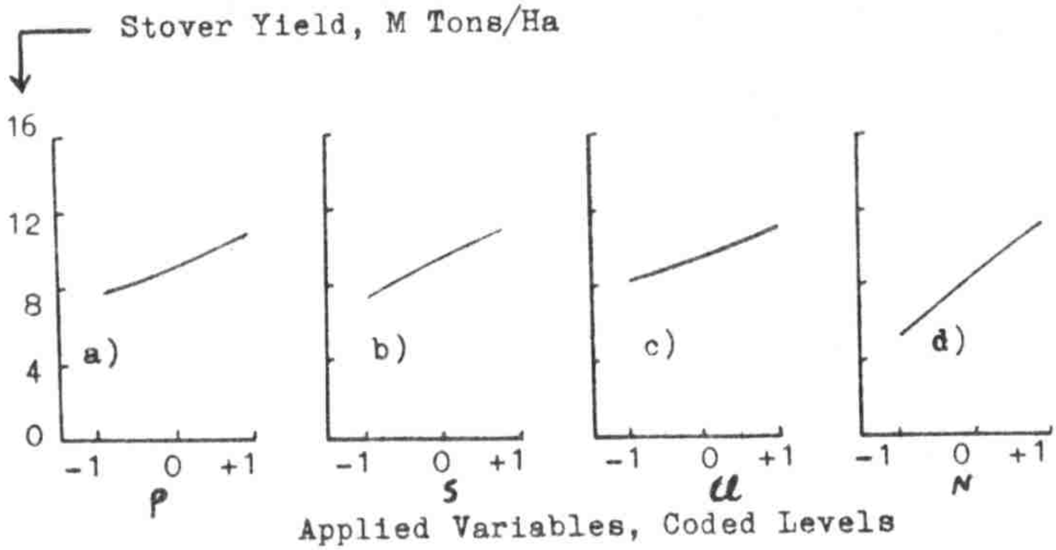


Figure 12. Predicted air dry stover yield as affected by applied levels of each of the variables P, S, Cl, and N at high levels of the other three.

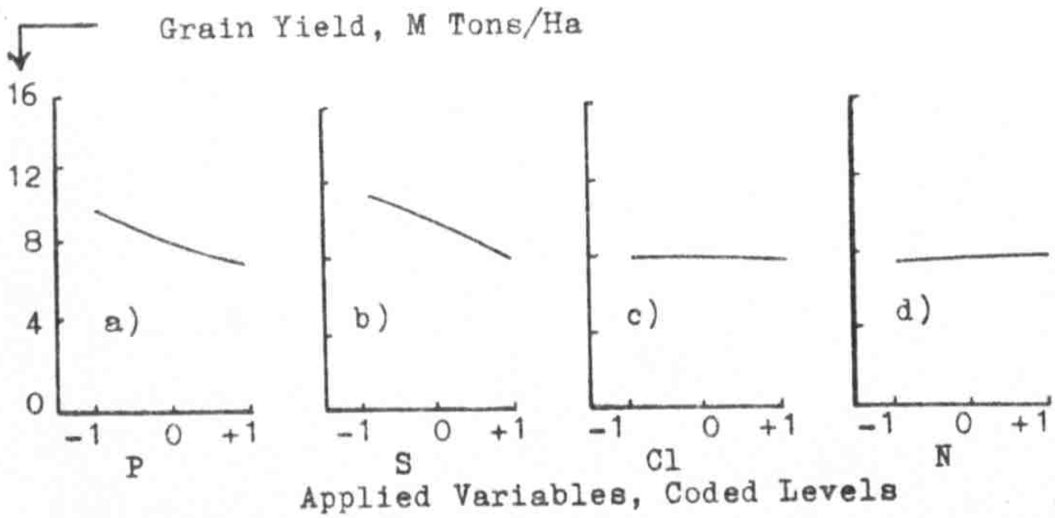


Figure 13. Predicted grain yield (15.5% moisture) as affected by applied levels of each of the variables P, S, Cl, and N at high levels of the other three.

Table 9. Regression coefficients (b) and their standard errors (s_b) for plant composition as affected by the various combinations of the coded levels of applied P, S, Cl, and N at tasseling.

Regression coefficient	Phosphate-P of midribs	Total-P of blades	Total-S of blades	Water soluble Cl of blades	Total-N of blades	Nitrate-N of midribs
	ppm	%	%	%	%	Log. of ppm
Mean b_0	551.73	0.489	0.200	0.424	2.61	2.989
P	+23.92[e]	+0.004	+0.001	-0.011	-0.01	+0.001
S	-39.92[e]	-0.009[e]	-0.001	-0.005	-0.04	+0.006
Cl	-21.42[e]	-0.009[e]	0.000	+0.060[e]	-0.04	+0.005
N	+83.00**	+0.039**	+0.015**	+0.020	+0.28**	+0.236**
s_b	±17.044	±0.0075	±0.0033	±0.0305	±0.052	±0.0283
P^2	+18.48[e]	0.000	+0.002	+0.028[e]	+0.02	+0.002
S^2	+20.85[e]	-0.001	-0.007[e]	-0.002	0.00	+0.056[e]
Cl^2	+0.23	-0.011[e]	-0.010*	-0.007	-0.08[e]	-0.024
N^2	-2.27	-0.007[e]	-0.001	-0.012	-0.02	+0.011
s_b	±15.456	±0.0069	±0.0030	±0.0276	±0.047	±0.0257
P-S	+14.75	+0.003	+0.002	-0.002	+0.04	+0.026
P-Cl	-8.88	-0.002	-0.007[e]	+0.021	-0.01	+0.072[e]
P-N	+5.25	-0.002	-0.007[e]	+0.006	+0.00	-0.030
S-Cl	+28.75[e]	+0.018[e]	+0.006[e]	-0.009	+0.10[e]	+0.051[e]
S-N	+8.38	+0.018[e]	+0.003	+0.026	+0.08[e]	+0.054[e]
Cl-N	-30.50[e]	-0.004	-0.003	-0.037	-0.04	-0.096*
P-S-Cl	+23.00[e]	+0.011[e]	+0.003	-0.034	+0.01	-0.042[e]
P-S-N	-13.63	-0.009[e]	0.000	+0.011	-0.06	+0.001
P-Cl-N	+5.25	+0.011[e]	-0.008[e]	+0.018	-0.01	-0.011
S-Cl-N	-3.88	-0.009[e]	-0.008[e]	-0.012	-0.11[e]	+0.059[e]
s_b	±20.887	±0.0092	±0.0041	±0.0374	±0.064	±0.0347

e Regression coefficient greater than standard error (probably real).
* Regression coefficient significant (5 percent level).
** Regression coefficient highly significant (1 percent level).

Cl at a low level. The total P in the leaf blades was significantly increased by applied N (Table 9). The concentrations of the phosphate-P in the midribs and the total-P in the leaf blades at the time of tasseling varied from 333 to 854 ppm and from 0.32 to 0.55 percent, respectively (Table 10). The upper ends of the ranges closely approached the levels observed in experiment I, but the lower ranges are markedly less. The difference could be due to the general depressing effects of S and Cl, which were present as variables in experiment II. The grain response paralleled the increase in phosphate-P of the midribs with increasing P application (Figure 14a and 14c). It appears that a concentration above 830 ppm is needed for maximum yield of grain under the conditions of this experiment. This compares to a phosphate-P level of less than 600 ppm in experiment I. Ahmad (1966) and Fuehring (1966) reported upper ranges of 649 ppm and 514 ppm phosphate-P in the midribs at similar conditions, respectively. The increase in yield of stover and in total-P of leaf blades was small and no definite conclusion could be made except to imply that at least 0.52 percent P was needed. This is a very high level if compared to the levels reported in the literature. Tyner (1946) and Viets _et al_. (1954) reported a critical level of 0.295 percent P in the 6th corn leaf.

The positive and highly significant first order

Table 10. Observed P, S, Cl and N concentrations (dry basis) on the leaf at tasseling as affected by various combinations of levels of P, S, Cl and N.

Treat-ment No.	Treatment combinations				Phosphate-P of midribs	Total-P of blades	Total-S of blades	Water soluble Cl of blades	Total-N of blades	Nitrate-N of midribs
	P	S	Cl	N						
	Coded levels				ppm	%	%	%	%	ppm
1	-1	-1	-1	-1	480	0.43	0.16	0.36	2.58	641.0
2	+1	-1	-1	-1	616	0.47	0.18	0.28	2.48	543.0
3	-1	+1	-1	-1	333	0.32	0.13	0.28	1.78	538.0
4	+1	+1	-1	-1	428	0.37	0.14	0.28	1.88	532.8
5	-1	-1	+1	-1	574	0.44	0.15	0.48	2.36	768.6
6	+1	-1	+1	-1	499	0.39	0.16	0.52	2.08	1300.0
7	-1	+1	+1	-1	403	0.40	0.16	0.52	2.18	557.1
8	+1	+1	+1	-1	596	0.44	0.19	0.40	2.51	1287.0
9	-1	-1	-1	+1	726	0.49	0.18	0.52	2.81	3828.8
10	+1	-1	-1	+1	854	0.52	0.20	0.32	2.88	1712.4
11	-1	+1	-1	+1	620	0.53	0.19	0.52	2.86	1921.0
12	+1	+1	-1	+1	723	0.49	0.21	0.52	2.93	2587.0
13	-1	-1	+1	+1	630	0.48	0.22	0.44	2.78	772.0
14	+1	-1	+1	+1	714	0.50	0.17	0.56	2.86	1415.7
15	-1	+1	+1	+1	594	0.51	0.21	0.52	2.90	2524.0
16	+1	+1	+1	+1	712	0.55	0.18	0.51	2.78	2512.0
17	+2	0	0	0	564	0.47	0.22	0.52	2.58	608.9
18	-2	0	0	0	668	0.49	0.22	0.52	2.78	1116.3
19	0	+2	0	0	557	0.45	0.18	0.36	2.60	1152.9
20	0	-2	0	0	694	0.50	0.19	0.44	2.59	1600.7
21	0	0	+2	0	429	0.36	0.16	0.52	1.96	617.8

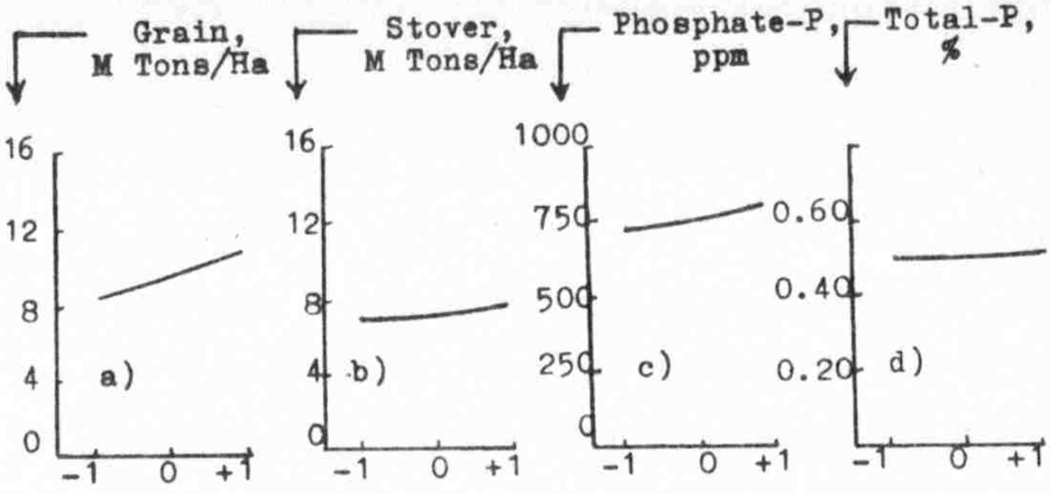
Table 10 (Continued).

Treat-ment No.	Treatment combinations P	S	Cl	N	Phosphate-P of midribs	Total-P of blades	Total-S of blades	Water soluble Cl of blades	Total-N of blades	Nitrate-N of midribs
	Coded levels				ppm	%	%	%	%	ppm
22	0	0	-2	0	657	0.51	0.19	0.24	2.54	672.6
23	0	0	0	+2	620	0.48	0.23	0.28	2.93	3120.0
24	0	0	0	-2	446	0.42	0.19	0.44	2.08	257.4
25	0	0	0	0	633	0.50	0.22	0.52	2.78	1182.3
26	0	0	0	0	636	0.45	0.20	0.71	3.00	1229.8
27	0	0	0	0	626	0.50	0.19	0.28	2.36	1065.5
28	0	0	0	0	448	0.42	0.17	0.32	2.24	617.8
29	0	0	0	0	448	0.46	0.20	0.42	2.69	614.8
30	0	0	0	0	518	0.49	0.21	0.40	2.64	1110.5
31	0	0	0	0	553	0.53	0.21	0.32	2.54	1281.0

effect of applied N on total S concentration in the leaf blades (Table 9) indicated that N fertilization increased total S concentration in the leaf blades at the time of tasseling. The total S concentrations varied from 0.13 to 0.23 percent (Table 10). Soltanpour (1963) reported almost the same range of total S and similar effects of applied S on grain at similar conditions. Since S application to the soil did not have much effect on the S concentration in the blades, the depressing effects of applied S on grain yield must be indirect. It appeared that when high levels of N and P are applied, levels of S greater than 0.2 percent in the leaves are probably detrimental to yields.

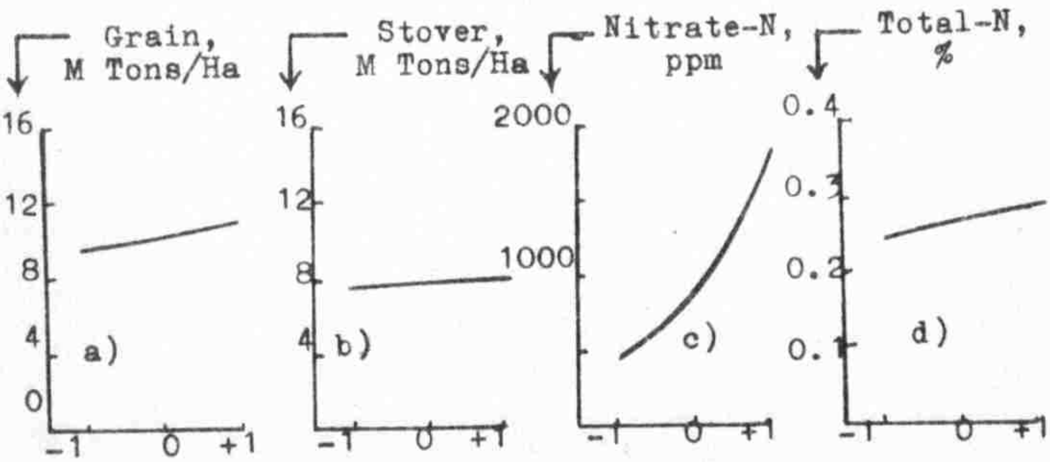
Applied Cl increased the water soluble Cl concentration in the blade at the time of tasseling as was implied by the positive and probably real first order effect of applied Cl (Table 9). The concentration of Cl in the blades varied from 0.24 to 0.71 percent (Table 10). Soltanpour (1963), working at similar conditions, reported an upper range of 0.84 percent Cl.

Applied N significantly increased the concentrations of the nitrate-N and phosphate-P in the midribs, and total-N, total-P and total-S in the leaf blades, as was indicated by the positive and highly significant first order coefficients of applied N (Table 9). The positive and negative effects of the two-way and three-way interactions on total N tended to cancel. High rates of applied N at low levels of P, S, and Cl increased the nitrate-N concentration in the midribs as was implied by the negative and significant Cl-N interaction, the negative and probably real P-S-Cl, and the positive and probably real P-Cl, S-Cl, and S-Cl interactions (Table 9). The nitrate-N concentration in the midribs varied from 533 to 3829 ppm (Table 10). The total-N concentration in the leaf blades ranged from 1.78 to 3.00 percent (Table 10). Soltanpour (1963), Soofi and Fuehring (1964), and Fuehring (1966) reported the ranges 1.28 to 2.30, 1.77 to 2.88 and 1.56 to 3.07 percent total-N in the leaf blades, respectively, under similar conditions. The curves for the grain yield, nitrate-N and total-N were all rising up to an N application of 300 kg per hectare (+1 coded level, Figure 15a, 15c 15d). It seemed that the critical levels were above 1000 ppm and 2.90 percent for nitrate-N and total N, respectively. This is in agreement with Benett _et al._ (1953) who reported a critical level range of 2.6 to 3.1 percent N in the corn leaf for 95 percent of maximum grain yield. However, Tyner (1946) and Viets _et al._ (1954) reported critical levels of 2.90 percent N. Dumenil (1961) explained this difference by observing that the critical level of N is not a point or a narrow range, but includes a considerable range of values depending on the levels of other nutrients in the leaves. The steepness of the nitrate-N curve implied that the nitrate-N concentration of the midribs was a very sensitive indicator of the N status of the plant.



Applied P, Coded Levels

Figure 14. Predicted grain yield (15.5% moisture) (a), air dry stover (b), phosphate-P (c), and total-P (d) as affected by levels of applied P. Levels of S and Cl were held constant at the -1 coded level and N at the +1 coded level.



Applied N, Coded Levels

Figure 15. Predicted grain yield (15.5% moisture) (a), air dry stover (b), nitrate-N (c), and total-N (d) as affected by levels of applied N. Levels of S and Cl were held constant at the -1 coded level and P at the +1 coded level.

V. SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

Two irrigated field experiments were established on a calcareous clay soil at AREC, Beqa'a Plain, North Lebanon, to study the individual effects and the interrelationships of P, Zn, B, S, Cl, N, and plant population on the yield and composition of maize. The variables P, Zn, B, and plant population comprised experiment I while the variables P, S, Cl, and N comprised experiment II. Each variable was studied at five levels. The nutrient variables were varied on a logarithmic scale to the base 2, while the plant population was varied on an arithmetic scale. Only one plot for each treatment was used except that the treatment receiving all the variables set at the third or "0" coded level was replicated seven times and the variation within the replications used to estimate the experimental error.

The experimental design used was a rotatable, central composite factorial. The experimental design permits the establishment of a partial third order regression equation which, using the coded values of the applied variables, indicated the individual effects of the variables and their interactions on the measured factor in terms of regression coefficients of the first order, second order, and third order types. The direct effects of the variables and their interactions on the yields of grain and stover and on leaf composition were determined.

A leaf sample was collected at the time of tasseling. The leaves were immediately separated into a midrib sample and a blade sample. The grain and stover were harvested after five months from the time of planting and reported as yields of grain at 15.5 percent moisture and air-dry stover, respectively.

Applied P with Zn, B, and plant population as variables had a probably real enhancing first order effect on yield of grain and a significantly positive first order effect on yield of stover. There was a greater response to P as the levels of Zn, B, and plant population were increased, indicating more P requirement at those conditions. Phosphorus fertilization at high levels of applied S, Cl, and N depressed grain and enhanced stover production. The net effect of applied Zn on yield of grain tended to be more positive as the levels of P, B, and Pop were increased. The effect of Zn application on yield of stover was negative as compared to its net positive effect on grain yield. The first order effect of applied B on yield of grain was negative, but the overall effect of B on grain was determined by the levels of applied Zn, P, and plant population. High levels of applied P and plant population balanced the effects of large amounts of applied

B. The first order effect of plant population on grain yield was positive and highly significant. Grain yield response to increasing levels of plant population was greater at high soil fertility levels. Grain yield response to applied S was determined to a large extent by the levels of applied P and N. Application of S at high levels of applied P, N, and Cl depressed yield of grain and increased the yield of stover. For grain production, it appeared that either P or S were required in high amounts, but not both. The effects of applied Cl on grain yield were negligible. Application of N increased the yield of stover to a considerably greater extent than the yield of grain. High levels of applied N, when the soil levels of P, S, and Cl were high, greatly increased stover production at the expense of grain formation.

The grain yield regression equations were solved for the optimum combination for maximum grain yield when the variables are held between the arbitrary limits of -1.5 and +1.5 coded levels. The optimum combination was -0.1, +1.5, -1.5, and +1.5 with a maximum grain yield of 16.7 metric tons per hectare for P, Zn, B, and Pop, respectively. The combination was -1.5, +1.5, +1.5, and +1.5 with a maximum grain yield of 14.8 metric tons per hectare for P, S, Cl, and N, respectively. However, when the data of the experiments were combined with previous work, the optimum combination was +1 N, +1 P, -1 S, -1 Cl, +1 Zn, +1 B, and +1 Pop, when calculated within the arbitrary limits of -1 to +1 coded levels (Fuehring _et al_., 1968).

Application of P with Zn, B, and Pop as variables significantly increased the concentrations of phosphate-P in the midribs and total-P in the leaf blades. Application of P with S, Cl, and N as variables tended to increase the concentrations of the phosphate-P in the midribs. Applied S and Cl tended to depress the phosphate-P concentrations in the midribs. Applied N significantly increased the concentrations of the phosphate-P in the midribs and the total-P in the leaf blades. Tissue-P concentration in the two experiments were in about the same range but were differently related to maize yields depending on the levels of the other variables. The phosphate-P of the midribs seemed to be a more sensitive measurement of P supply than the total-P of the leaf blades. Application of Zn significantly increased the Zn concentrations in the leaf blades but high levels of plant population significantly decreased it. The significantly positive three-way Zn-B-Pop interaction in Zn concentration implied that the significantly negative Zn-B interaction was enhanced at low plant population and cancelled out at a high plant population. It appeared that Zn concentrations in the leaf blades at tasseling of 50 to 75 ppm were required for high grain yields. Applied B significantly increased the B concentrations in the midribs but high plant population levels tended to depress the B concentrations. The relationship between grain yield and B concentration in the midribs seemed to depend on the level of soil P. The total-S concentrations in the leaf blades were significantly increased by applied N. Applied S did not have much effect on the total-S concentration in the blades, and it seemed that the depressing effect of applied S on grain was indirect. At high levels of applied N and P, levels of S in leaf blades greater than 0.2 percent appeared to be detrimental to yield. Applied Cl tended to increase the water soluble Cl concentrations in the blades. Applied N significantly increased the concentrations of nitrate-N and phosphate-P in the midribs and total-N, total-P, and total-S in the leaf blades. The curves for the grain yield, nitrate-N and total-N were all rising up to a N application of +1 coded level and it seemed that the critical levels were greater than 1000 ppm and 2.9 percent for nitrate-N and total-N, respectively. It appeared that the nitrate-N of the midribs was a very sensitive indicator of the N status of maize plants.

Since either high levels of P or S, but not both, were required for high levels of grain production, it is recommended that fertilizers containing S, such as ordinary superphosphate should not be used under conditions similar to those in the Beqa'a Plain. There was a considerable positive effect of applied Zn at high levels of grain yield, while the overall effect of applied B on grain yield depended on the level of applied P and plant population. However, the amounts of Zn and B applied were far in excess of the amounts taken up by the plant and tended to be uneconomic. It is recommended that further work be done with regard to obtaining more efficient response to Zn and B. Spraying Zn and B directly on the plants offers the greatest possibility, but the amounts required and timing of application are not known. There was a large grain yield response to plant population at high soil fertility levels and it is recommended that the levels of plant population be adjusted to result in an ear weight of about 200 to 250 g. It is recommended that levels of applied N be considered in relation to the amount of N contained in the crop at the expected yield levels and on the history of the area to be planted with regard to the probable supplying power for N. Levels of applied P should be considered in relation to soil test values.

In general further work is required in relation to the effects of soil levels and applied rates of N, P, and micronutrients needed for grain yields of maize in the range of 15 to 20 metric tons per hectare.

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A P P E N D I X

Table 11. Analysis of variance for yields of grain (15.5% moisture), stover (air-dry), and grain-stover ratio as affected by various combinations of coded levels of applied P, Zn, 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		
Grain yield m tons/ha								
S.S.	14342919	37807385	45652219	11712225	4006019	8196742	9.5	70.37
M.S.		9451846*	4565221	2928056	667669*	1366123		
Stover yield m tons/ha								
S.S.	15751914	27038516	54662154	4716825	57653639	13448000	15.77	59.98
M.S.		6759629	5466215	1179206	9608939*	2241333		
Grain-stover ratio								
S.S.	2681141	406286	1138469	48325	785089	302971	17.07	66.98
M.S.		101571	113846	12081	130848	50495		

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

* Significant at 5 percent level.

Table 12. Analysis of variance for yields of grain (15.5% moisture), stover (air-dry), and grain-stover ratio as affected by various combinations of coded levels of applied P, S, Cl and N.

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									
S.S.	6592528	935974	2130284	1069630	819585	1637054	2456640	15.13	83.46
M.S.		233993	213028	267407	136597	272842	204720		
Stover yield m tons/ha									
S.S.	7786717	1625356	2173357	743582	3050732	193688		7.88	59.82
M.S.		406339**	217335*	185895*	508455**	32281			
Grain-stover ratio									
S.S.	3541109	1094392	555756	421175	1121186	348600		18.26	64.88
M.S.		273598*	55575	105293	186864	58100			

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.

** Significant at 1 percent level.

Table 13. Analysis of variance for concentration of phosphate-P and total-B of midribs and total-Zn and total-P of blades as affected by various combinations of coded levels of applied P, Zn, 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		
Phosphate-P in midribs									
S.S.	196279	640020	667406						
M.S.		160005*	66740	12678	38666	14192		9.03	78.76
Total-B in midribs									
S.S.	822077	569821	133240	16650	36394	65971	102365	4.79	95.18
M.S.		142455**	13324	4162	6065	10995	8530		
Total-Zn in blades									
S.S.	5037944	1504377	1326794	300530	1701086	205157		10.56	64.80
M.S.		376094**	132679	75133	283514*	34193			
Total-P in blades									
S.S.	36877	15016	10959	2025	2733	6142	8876	4.97	91.10
M.S.		3754	1095	506	455	1023	739		

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.

** Significant at 1 percent level.

Table 14. Analysis of variance for concentration of phosphate-P of midribs, total-P and total-S of blades as affected by various combinations of coded levels of applied P, S, Cl and N.

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		
Phosphate-P in midribs								
S.S.	4073894	2283143	556238	121155	694543	418814	15.14	80.99
M.S.		570786*	55623	30288	115757	69802		
Total-P in blades								
S.S.	8847	4005	1578	643	1793	829	7.76	77.64
M.S.		1001*	157	161	299	138		
Total-S in blades								
S.S.	1939	578	645	228	329	160	8.16	81.52
M.S.		144*	64	57	55	27		

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

* Significant at 5 percent level.

Table 15. Analysis of variance for concentration of water soluble Cl and total-N of blades and nitrate-N of midribs as affected by various combinations of coded levels of applied P, S, Cl and N.

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		
Water soluble Cl in blades									
S.S.	38847	10115	7212	2823	5300	13397	18697	29.41	79.17
M.S.		2529	721	706	883	2233	1558		
Total-N in blades									
S.S.	337104	192057	54286	25258	26249	39254	65503	8.86	91.18
M.S.		48014*	5428	6314	4375	6542	5459		
Nitrate-N in midribs									
S.S.	221480	133703	45745	8647	21845	11539		4.63	89.59
M.S.		33426**	4574	2162	3641	1923			

1 Pooling sum 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.

** Significant at 1 percent level.