ZINC PHOSPHORUS NITROGEN INTERRELATIONSHIPS IN MAIZE NUTRITION

By

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MAIZE NUTRITION

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AN ABSTRACT OF THE THESIS OF

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Title: Zinc-phosphorus-nitrogen interrelationships in maize nutrition.

A greenhouse experiment was conducted with maize grown on two calcareous soils with N, P, Zn, and method of placement as variables. Application of N resulted in increased Zn and P concentration in maize tops. Applied P tended to depress Zn levels of tops and the positive P-Zn effect indicated that the depressing effect of P on Zn was greater at low Zn levels. The positive N-P-Zn interaction tended to emphasize the effect at high N levels, but this was counteracted by the positive N-P interaction and the large first order N effect. The relationship between P and Zn application effects on maize depended on the relative levels of applied Zn and P as well as the levels of N in the system.

Mixing Zn in the soil was more efficient than banding in increazing Zn levels in the plant tissues, while mixing P in the AREC soil and banding P in the Bazouryeh soil were the most effective of the P application methods used. Applied Zn had little effect on P levels of tops but applied P had a generally negative effect on Zn concentration. The greater proportion of Zn and Mn translocated from roots to tops in the plants from the Bazouryeh soil as compared to the plants from the AREC soil was related to much greater Ca concentration of roots. However, a considerably greater proportion of P was translocated from roots to tops in the AREC soil. This leads to the postulation that excess Ca in the roots inactivates P and thus prevents P from inactivating as much Zn and Mn in the roots.

The Bazouryeh soil had greater tendency to fix P while the AREC soil tended to fix Zn to a greater extent. However, applied Zn and P did not have a mutually depressing effect on "available" P and Zn in the AREC soil after cropping. It was concluded that the effect of P on Zn in maize is associated with the plant root system, rather than the soil. It was also concluded that the general tendency of calcareous soils to be less Zn deficient than soils with pH levels near neutrality is probably related to the greater Ca levels resulting in inactivation of more P in the roots, thus allowing more Zn to be translocated to the tops.

TABLE OF CONTENTS

Page

LIST OF TABLES

Table Page

LIST OF FIGURES

I. INTRODUCTION

Maize is potentially a very important crop in the Middle East due to its efficiency of production of food and feed. Experimental grain yields of almost 18 metric tons per hectare of irrigated maize have been attained in Lebanon under soil and climatic conditions similar to many regions of the Middle East.

Numerous factors affect the growth and development of maize and interactions among macro and micronutrients have an important function. Experimental evidence has suggested that interaction of one growth factor with another, may be more important than the direct effect in many cases. Maize is sensitive to Zn deficiency and high levels of soil P decrease its uptake. Heavy P applications have resulted in P-induced Zn deficiency. The nature of this phenomenon is not well understood. Experimental work has suggested that it may be physiological in nature. Application of N has been reported to enhance the uptake of Zn but this effect has not been clearly understood.

A greenhouse experiment was conducted using a three layer technique (sand-soil-sand), involving two calcareous soils and including eight methods of nutrient placement. The experimental design was a rotatable, central composite, incomplete factorial. The purpose of the experiment was to study:

1. The overall effect of N, P and Zn as well as their interactions on yield of maize tops and on P and Zn composition.
2. The effect of the method of placement on yield and composition.
3. The nature of the P-Zn interaction.

II. REVIEW OF LITERATURE

In view of the importance of maize production considerable work has been carried out in relation to P and Zn nutrition of maize. The pertinent data are reviewed in the following pages.

The Zn-P Interrelationship

Stukenholtz et al. (1966) reported that P has a depressive effect on the uptake of Zn in maize. They concluded that this effect is physiological in nature occurring in the roots, where due to P accumulation, the translocation of Zn from the roots to nodal and internodal tissues is inhibited. Martin et al. (1965) found that application of P reduced the Zn concentration in tomato plant tissues grown in a greenhouse. They concluded that P induced Zn deficiency is related to soil temperature.

The effect of Zn application on yield of maize was studied by Ellis et al. (1964) who found an increase in yield from 7,504 to 8,680 pounds per acre with maize grown on a calcareous soil. In a greenhouse experiment with the same soil, application of 10 pounds of Zn per acre increased Zn concentration of the tops. In another greenhouse experiment the same authors found that application of 10 pounds of Zn increased the yield of field beans, but when high P levels were used in a field experiment involving beans, plants suffered from severe

P-induced Zn deficiency. They also concluded that the P-Zn interaction is related to the root system. Similar depressive effect of P on Zn has been reported by Langin _et al_. (1962).

Millikan (1963) supported the view that the depression in growth of maize in high P low Zn treatments was not due to a decrease in Zn concentration resulting from high applications of P, but that plants so treated had a high P/Zn ratio. Burleson _et al_. (1961) reported a severe P-induced Zn deficiency in _Phaseolus vulgaris_. They reported that Zn deficiency is favored in some crops by certain climatic conditions, being enhanced by cold and wet soils during the early part of the season by restricting root development chiefly to the zone of the fertilizer placement.

Watanabe _et al_. (1965) indicated that Zn concentrations in maize tissues were depressed at all levels of Zn with applied P. The addition of the first increment of P increased the yield due to correction of low supply of P. However, further additions of P had slight depressive action on Zn. Depressive P effect on Zn of maize has also been reported by Soltanpour (1963).

Thorne _et al_. (1942) reported that Zn deficiency of fruit trees in Utah is more common in acidic soils. No Zn deficiency was observed in calcareous soils. They also found that the Zn content of calcareous soils was twice as high as for non-calcareous soils. Similarly Alben and Boggs (1936) found that the basic United States soils had a greater Zn concentration than acid soils. Ravikovitch _et al_. (1961) reported that the EDTA extractable "available" Zn of some calcareous and non-calcareous soils of Israel was in the range of

1.9 to 13.3 ppm and that some of these at the lower end of the range were considered to be borderline with regard to possible Zn deficiency.

The Role of N in P and Zn Nutrition of Maize

In relation to the effect of N on the uptake of Zn, it has been reported by Thompson (1962) that increasing dressings of 40 to 120 pounds per acre of N tended to increase the concentration of Zn in the tissues. Similar results have been reported by Fuehring (1966), and Soltanpour (1963) as well as other workers. Viets _et al_. (1957) reported that Zn uptake from Ritzville fine sandy loam was enhanced by application of $ZnSO_4$ and the dry matter yield of milo was increased significantly. They also found that N application generally increased the uptake of both the applied and indigenous Zn, the effect depending on the change in pH. They generally explained the diverse effect of the N carriers on Zn uptake on the basis of changes in pH brought about by the carriers.

Method of Placement

Brown and Krantz (1966) in a greenhouse experiment using P and Zn deficient soils found that when Zn fertilizers materials were well mixed with the soil, $ZnSO_4$ and organic Zn sources such as Zn-EDTA and Rayplex-Zn were equivalent in their effectiveness for the correction of Zn deficiency. They furthermore reported that a small amount of mixing was effective for either Zn or P. Pumphrey _et al_. (1963) found that broadcasting and plowing under 5 pounds of Zn per acre as

$ZnSO_4$ was more effective in increasing the Zn uptake by maize, than banding at planting time with or without N, side dressing with or without N, or spraying when plants were 6 to 12 inches tall. Broadcasting was ineffective when not plowed under. Small amounts of N banded with $ZnSO_4$ increased its effectiveness. Ward *et al*. (1963), working with grain sorghum and maize, reported that P fertilizer applied in the row markedly reduced Zn concentration in maize. Increased soil compaction and soil moisture levels caused further depression on the uptake of Zn.

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III. MATERIALS AND METHODS

A greenhouse experiment was conducted in order to determine the overall effects of N, P and Zn as well as their interactions on maize nutrition. The effect of the method of placement and the nature of the P-Zn interaction were also studied.

Experimental Design

A central composite, rotatable, incomplete factorial design was used as described by Cochran and Cox (p. 349, 1957). This design allowed the study of the yield response for the three variables, (five levels for each), and for their interactions, with a total of fifteen treatment combinations. One of the treatments was repeated six times in order to make possible the determination of the experimental error. The levels of variables were coded as -1.68, -1, 0, +1, and +1.68 as required by the design. The levels used, were varied according to a logarithmic scale (to the base, 2, table 1). The statistical analysis was done by IBM 1620 computer.

Table 1. Applied N, P and Zn, and their levels.

Levels (log_2 scale)	Coded values	N	P	Zn
			ppm	
1	-1.68	34.8	34.8	9.3
2	-1	56.2	56.2	15.0
3	0	112.5	112.5	30.0
4	+1	225.0	225.0	60.0
5	+1.68	360.0	360.0	96.3

In order to study the effects of position of the applied nutrients in the rooting media on yield of dry matter and on P and Zn as well as Mn composition, eight methods of nutrient placement were used on each soil as follows:

ZxPx, ZmbPmb, ZbPb, ZlPl, ZxPl, ZbPl, ZlPx, and ZlPb

where:

Z = zinc

P = phosphorus

x = mixed with the soil

b = banded

mb = Zn and P mixed and banded

l = added to sand in solution

Thus, the entire experiment consisted of twenty pots (cans) for the composite design, two soils, and eight methods of placement making 320 individual pots.

Greenhouse Procedure

Two calcareous soils were screened through an 0.6 cm plastic sieve in order to avoid Zn contamination and were kept undried. Sand was collected from near the Beirut seashore and was thoroughly washed with tap water to eliminate the presence of salts, dried and stored.

Preparation of cans The sand was placed in each can, lined with a polyethylene bag, until the weight of can plus sand was 2,000 g. The cans were 15.5 cm in diameter and 24.5 cm in height. A 22 cm section of plastic garden hose (1.25 cm in diameter) was placed in the center of each can extending to a depth of about 1 cm from the bottom of the can. Field moist soil equivalent to 1,500 g of oven-dry soil was placed in each can. The nutrients were added to each soil according to the method of placement and to the treatment combinations (table 2).

Seeding On November 11, 1966, six seeds of maize were sown in each can. In cans where nutrients were banded in two bands of about 12 cm in length and 1.5 cm in depth, at 3.5 cm from the center, three maize seeds were placed on the soil surface directly above the banded nutrients. In cases where the nutrients were mixed with the soil, the seeds were placed in two rows, about 7 cm apart from each other. When seeding was completed, 400 g of clean sand were added to each can. The purpose of the upper sand layer was to cover the seeds and to provide a slow and even loss of water from the surface of the cans as suggested by Ozus and Hanway (1966) who have developed the "Three layer technique". Following the addition of the top layer of sand, enough distilled water was added to each can to bring the weight to 4,500 g. The amount of water added corresponded to approximately field capacity of the soils. In each subsequent irrigation, addition of water to growing plants was made by weighing each can in order not to exceed the total weight of 4,500 g. This was necessary for each can was a closed system having no drainage. The plants during the first two weeks were irrigated twice a week, but with the commencement of fast growth the plants were irrigated about every other day. The cans were arranged in the greenhouse in blocks of twenty with the treatment combinations being randomly assigned to each block.

A week after planting each can was thinned to one plant in each row. At this time, addition was made through the hose section of half

Table 2. Treatment combinations (coded levels) applied to each can as required by the statistical design.

Number of can	Variables N	P	Zn
		Coded levels	
1	-1	-1	-1
2	+1	-1	-1
3	-1	+1	-1
4	+1	+1	-1
5	-1	-1	+1
6	+1	-1	+1
7	-1	+1	+1
8	+1	+1	+1
9	+1.68	0	0
10	-1.68	0	0
11	0	+1.68	0
12	0	-1.68	0
13	0	0	+1.68
14	0	0	-1.68
15	0	0	0
16	0	0	0
17	0	0	0
18	0	0	0
19	0	0	0
20	0	0	0

of the nutrients to those cans requiring dissolved nutrients. The cans in each block were rotated once a week to compensate for the effects of microclimate differences of the greenhouse environment. On December 2, 1966, the balance of the nutrients in solution were added.

Plants were harvested on December 20, 1966. They were oven-dried at 70°C, weighed , ground through a 40-mesh sieve, and stored for chemical analysis. Plants grown on the P and Zn bands were harvested separately. The roots of plants grown under the ZmbPmb method of nutrient placement, were separated from the soil, cleaned with tap and distilled water, dried at 70°C, ground to pass a 40-mesh screen and then stored for the determination of total P, Zn, Mn and Ca. Finally, the soils of the ZxPx treatment were kept for the determination of residual "available" P and Zn.

Analytical Procedure

Total P of tops and roots was determined by digesting 0.5 g of dry matter in a nitric-perchloric acid system followed by color development of P in ammonium vanadate in the presence of a phosphoric and nitric acid system, as suggested by Jackson (pp. 153, 1958). The absorption was measured by a Fisher spectrophotometer.

Total Zn, Mn, and Ca of roots and tops were determined from the perchloric acid digests by means of a Perkin-Elmer 303 atomic absorption spectrophotometer.

"Available" P of soil was extracted by 0.5 M $NaHCO_3$, pH 8.5 (Olsen et al., 1954) and the color was developed in ammonium molybdatestannous chloride in excess HCl system (Jackson, p. 144, 1958).

"Available" Zn of soil was extracted three consecutive times from 5 g of soil by 0.05 M ethylenediaminetetraacetic acid (EDTA) at pH 9 as suggested by Viro (1955). The extracted Zn was determined by the atomic absorption spectrophotometer.

Exchangeable and soluble Ca was determined by extracting with ammonium acetate as suggested by Richards (p. 100, 1954).

IV. RESULTS AND DISCUSSION

Since much of the soil of the Middle East is calcareous in nature and since very high experimental yields have established maize as a crop with high potential in the area, further information on the nutrition of maize on calcareous soils is desirable.

Two calcareous soils were studied. One originating from the Agricultural and Educational Research Center of the American University of Beirut (AREC) located in the Beqa'a Plain. It was chosen because maize grown on this soil has shown very definite response to Zn application where P and B were applied along with high plant population levels[1]. This soil was medium in $CaCO_3$ level (table 3). The second soil (Bazouryeh) was chosen because of its highly calcareous nature and availability of information on its P relationships. The AREC soil has more exchangeable Ca but less ammonium-acetate-soluble Ca than the Bazouryeh soil where the total $CaCO_3$ is about double that of the AREC soil (table 3). The "available" Zn of both soils is about the same and the 3 ppm are considered as probably sufficient to meet plant needs, (Ravikovitch et al., 1961). However, the Bazouryeh soil was supplied with considerably lower levels of "available" P as compared to AREC soil. With these levels of P in both soils, response to applied P was likely to occur (Olsen et al., 1954).

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[1] Fuehring, H.D. et al. 1967, to be published.

Table 3. Some chemical properties of soils studied.

Soil	$CaCO_3$ %	Ph	Ca[1] me/100g	Soluble Ca[2] me/100g	Exch.Ca[3] me/100g	EDTA Zn, ppm	0.5 M $NaHCO_3$ P, ppm
AREC	14	7.9	65.0	39.6	25.4	3.1	8.0
Bazouryeh	33	8.1	57.6	50.4	7.2	3.0	2.9

The results of varying N, P and Zn levels on dry matter yield of maize tops, as well as the P and Zn composition of tops will be discussed. Also the effect of the method of placement will be considered. Finally, the nature of the P-Zn interaction will be examined in the light of the experimental results.

General Interpretation of the Partial Regression Equation

The predicted yields were calculated from a regression equation (Cochran and Cox, p. 349, 1957), which was modified as follows to include the three-way interaction:

$$Y = b_0 + b_1x_1 + b_2x_2 + b_3x_3 + b_{11}x_1^2 + b_{22}x_2^2 + b_{33}x_3^2 + b_{12}x_1x_2 + b_{13}x_1x_3 + b_{23}x_2x_3 + b_{123}x_1x_2x_3$$

Where Y = yield of dry matter in grams

b_0 = mean

b_1, b_2 etc. = regression coefficients

x_1, x_2, x_3 = coded levels of N, P and Zn, respectively.

1 Ammonium acetate soluble Ca plus exchangeable Ca.

2 Ammonium acetate soluble Ca.

3 Exchangeable by difference.

The regression coefficients were calculated for the determination of the first order, squared, two-way, and three-way effects on yield of tops and on composition of P and Zn. The mean, b_0, represents the estimated yields or composition at $x_1 = 0$, $x_2 = 0$, and $x_3 = 0$ coded levels. A positive first order regression coefficient indicated that as the level of x_1, or x_2 or x_3 increased, there was a corresponding increase in the yield of dry matter, or composition of either of the elements studied. A negative first order coefficient, indicated the reverse. A positive squared effect, indicated an upward change of the slope of the response curve in the direction of increasing application rate of the element concerned, while a negative squared sign indicated the reverse. Finally, a positive two-way interaction indicated that the levels of the elements involved must be low or both high, depending on the effect of the first order terms and other interactions, to attain high yield. A negative two-way effect indicated that the supply of one of the elements concerned must be high in the soil, and low for the other element, if high yields are to be realized.

In order to facilitate the assessment of the overall effects of N, P and Zn on yield and composition; yields, Zn and P data were combined, respectively, for the eight methods of nutrient placement and for each soil (table 4).

Effect of N on Yield and on P and Zn Composition

Both soils responded positively to N application for yield of

Table 4. Regression coefficients for the yield, Zn, and P composition of tops of maize grown on two calcareous soils. Results of 8 placement treatments were combined.

Terms	AREC			Bazouryeh		
	Dry matter yield	Zn conc. of tops	P. conc. of tops	Dry matter yield	Zn conc. of tops	P conc. of tops
	g/pot	ppm	Percent	g/pot	ppm	Percent
b_0	4.092	41.909	0.2502	2.044	63.090	0.2354
N	$+0.808^{xx}$	$+5.258^{xx}$	$+0.0120^{xx}$	$+0.089^{e}$	$+ 8.757^{xx}$	$+0.0162^{xx}$
P	$+0.165^{xx}$	-1.122^{e}	$+0.0089^{x}$	$+0.135^{x}$	$- 0.898^{e}$	$+0.0238^{xx}$
Zn	−0.002	$+9.700^{xx}$	$+0.0036^{e}$	-0.048^{e}	$+15.690^{xx}$	$+0.0061^{x}$
s_b	±0.034	±0.525	±0.0024	±0.036	± 0.728	±0.0023
N^2	-0.201^{xx}	$+3.141^{xx}$	$+0.0293^{xx}$	-0.094^{x}	$+ 6.854^{xx}$	-0.0079^{x}
P^2	-0.072^{e}	$+0.543^{e}$	$+0.0134^{xx}$	−0.013	+ 0.155	+0.0008
Zn^2	-0.059^{e}	$+3.725^{xx}$	+0.0010	+0.021	$+ 6.447^{xx}$	-0.0133^{xx}
s_b	±0.033	±0.509	±0.0024	±0.035	± 0.707	±0.0022
NP	$+0.064^{e}$	+0.188	-0.0100^{x}	−0.010	$+ 2.063^{e}$	+0.0025
NZn	-0.064^{e}	$+1.138^{e}$	$+0.0050^{e}$	−0.018	$+ 2.912^{x}$	−0.0025
PZn	−0.039	$+1.438^{e}$	−0.0025	$+0.055^{e}$	$+ 5.213^{xx}$	-0.0050^{e}
NPZn	+0.029	$+1.538^{e}$	−0.0000	+0.025	$+ 5.588^{xx}$	0.0000
s_b	±0.045	±0.686	±0.0032	±0.047	± 0.951	±0.0029
R[1]	0.986	0.983	0.931	0.849	0.886	0.929

e Probably real because greater than standard error (s_b).

x Significant at 5% level.

xx Significant at 1% level.

1 Multiple correlation coefficient.

dry matter, but the effect was considerably greater for the AREC soil (table 4). The negative squared term for N for both soils indicated that the effect became less positive as the application rate increased. Application of N had a highly significant positive first order effect on both Zn and P concentration of tops for both soils, indicating an important role for N in the accumulation of Zn and P. Similar results were reported by Fuehring (1965), Soltanpour (1963), Stukenholtz et al. (1966), and Thompson (1962) as well as other workers. The squared term for N application on Zn concentration was highly significantly positive, indicating that N was increasingly effective in this respect as the level increased. The effect of N application on Zn concentration was more than half as great as the effect of Zn itself, and the same relationship was true for P concentration (table 4).

Viets et al. (1957) reported that N application generally increased the Zn uptake of either indigenous or applied Zn. They attributed this effect of N to pH changes brought about by the N carrier used. The N-Zn interaction effect on Zn concentration was positive for both soils indicating that the positive N effect on Zn application was greater at high Zn application levels than at low. Furthermore, the N-P-Zn three-way interaction effect on Zn concentration of tops of both soils, was positive, indicating that the N effect at high Zn levels was intensified if P was also at high levels. However, at low Zn levels the N interactions resulted in a general decrease in Zn concentration of tops which tended to cancel out the positive first order effect of N.

Effect of P on Yield and on P and Zn Composition

The first order effect of P application on dry matter yield was positive for both soils (table 4). The concentration of Zn of tops tended to be depressed as shown by the probably real negative regression coefficients for both soils. Moreover, the positive P-Zn interaction indicated that the depressive effect of P was greater at low levels of applied Zn. The depressive effect of P on Zn concentration in plant has been reported by Stukenholtz et al. (1966), Langin et al. (1962), Ellis et al. (1964), and Watanabe et al. (1965). Martin et al. (1965) found that P application reduced the Zn content of tomato plant tissues . Similar results were reported by Burleson et al. (1961) for *Phaseolus vulgaris*. The positive N-P-Zn three-way interaction in the present study further intensified the effect of P on Zn concentration of tops at high N levels. However, the general enhancing effect of N on Zn concentration would tend to offset the P effect on Zn. Thus, the relationship between P and Zn application effects on maize growth depends on the relative level of each as well as on the level of N in the system. Millikan (1963), supported the view that the lower yields of maize obtained from high P low Zn treatments was not due to the depressive P effect on Zn concentration but rather to a high P/Zn ratio.

Effect of Zn on Yield and on P and Zn Composition

Application of Zn had very little effect on dry matter yields.

However, the Zn concentration of tops was increased with applied Zn in both soils highly significantly (table 4). Also, the first order effect of Zn application on P concentration of tops was positive and probably real.

The Effect of the Method of Placement on Yield and on P and Zn Composition

The effect of the method of placement of P and Zn in maize nutrition has been discussed by various investigators. Pumphrey *et al.* (1963), Brown and Krantz (1966), and Stukenholtz *et al.* (1966) have reported that the method of placement is important in connection with maize production. Brown *et al.* (1962) emphasized that in view of the immobility of applied Zn in the soil, the method of application is very important.

The effect of P placement method. While both soils responded to application of P, the AREC soil gave the greatest yield response of maize tops with the Pl and Pb methods of application (figure 1), without, however, increasing the P concentration of tops. Mixing P with the soil increased the P level in the tops with increasing P application, but the yield remained constant. It appears that the effect of applied P on dry matter yield was indirect rather than on the plant P level itself. Neither does the effect of applied P in decreasing Zn in tops seems to be involved, since increasing yield and Zn concentration do not change in the same direction.

The Bazouryeh soil behaved differently in that applied P strongly increased P concentration of maize tops in the Pl and Pb

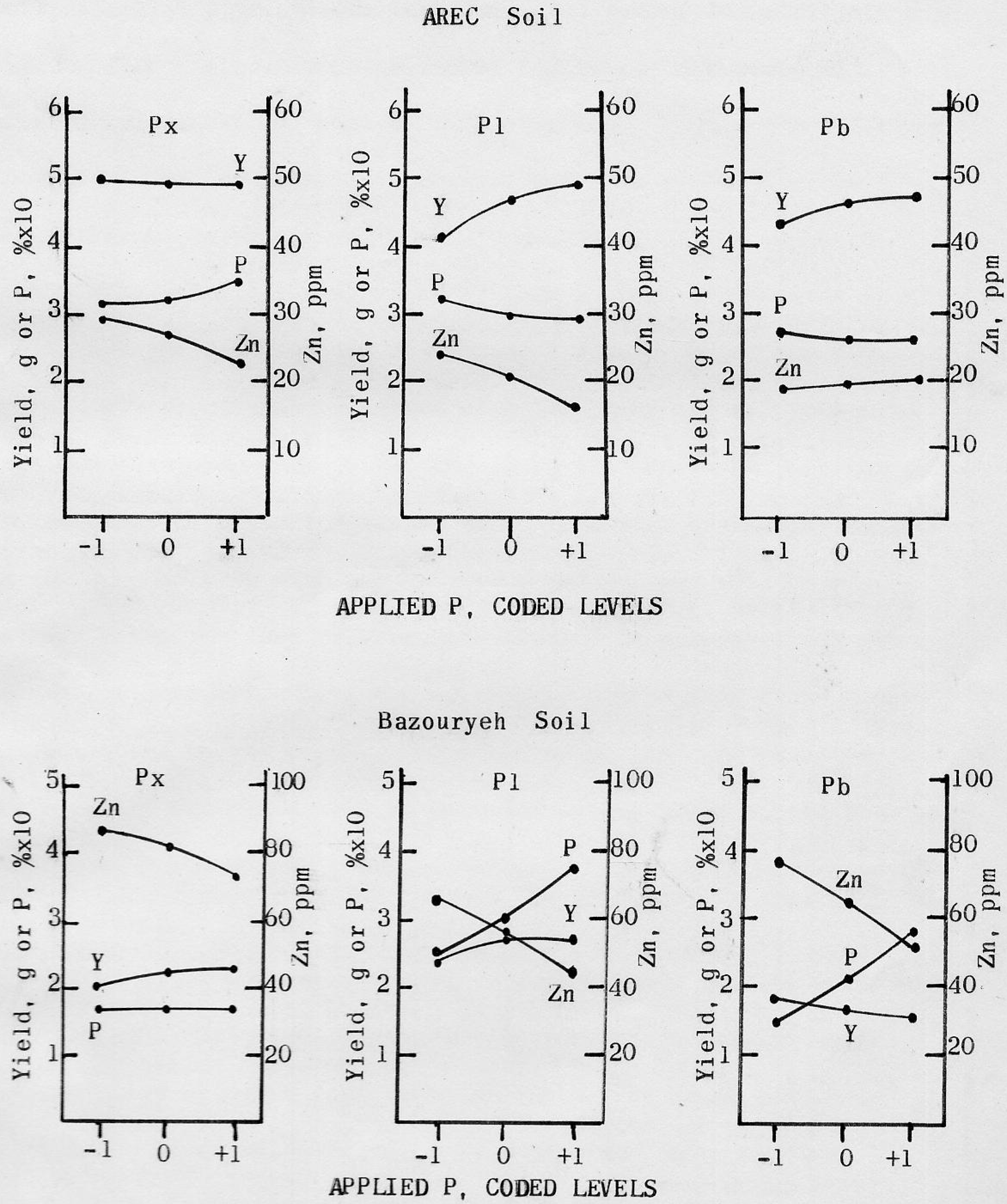

Figure 1. Effect of different methods and levels of P application on yield of dry matter and on Zn and P concentration of maize tops. The applied N and Zn were kept constant at the +1 and -1 coded levels, respectively.

methods, but not with the Px. Where P was mixed thoroughly in the soil, the highly calcareous Bazouryeh soil tended to inactivate P as will be shown later. Application of P strongly depressed Zn concentration with all methods of P placement. Again the differences in yield do not seem to be related directly to either P or Zn concentration in tops.

The effect of applied Zn (figure 2), was to increase Zn of tops about the same for all methods of P placement for the AREC soil, but the yields of tops increased with the Px method and tended to decrease with the Pb and Pl methods. In the Bazouryeh soil the effect on increased Zn concentration in maize tops with increasing applied Zn was considerable with the Px method and greater with Pb and Pl methods. However, the relationship between Zn concentration and dry matter yield of maize tops was negligible over a wide range of Zn concentration in the plants. This indicated that the relatively low yield on the Bazouryeh soil as compared to the yield of the AREC soil was probably not directly due to toxicity from the higher Zn levels in the plants.

The effect of Zn placement method. In both soils (figure 3) Zn mixed with the soil (Zx) tended to be more effective in raising Zn concentration in maize tops, than Zn applied in bands (Zb). Application of Zn in solution (Zl) to the sand layer was more effective in increasing Zn concentration than either the Zx or the Zb methods. Despite a wide range of Zn levels in the plants, the effect on yield of dry matter was slight. The effect of applied Zn on P concentration of tops was negligible in the AREC soil and in the

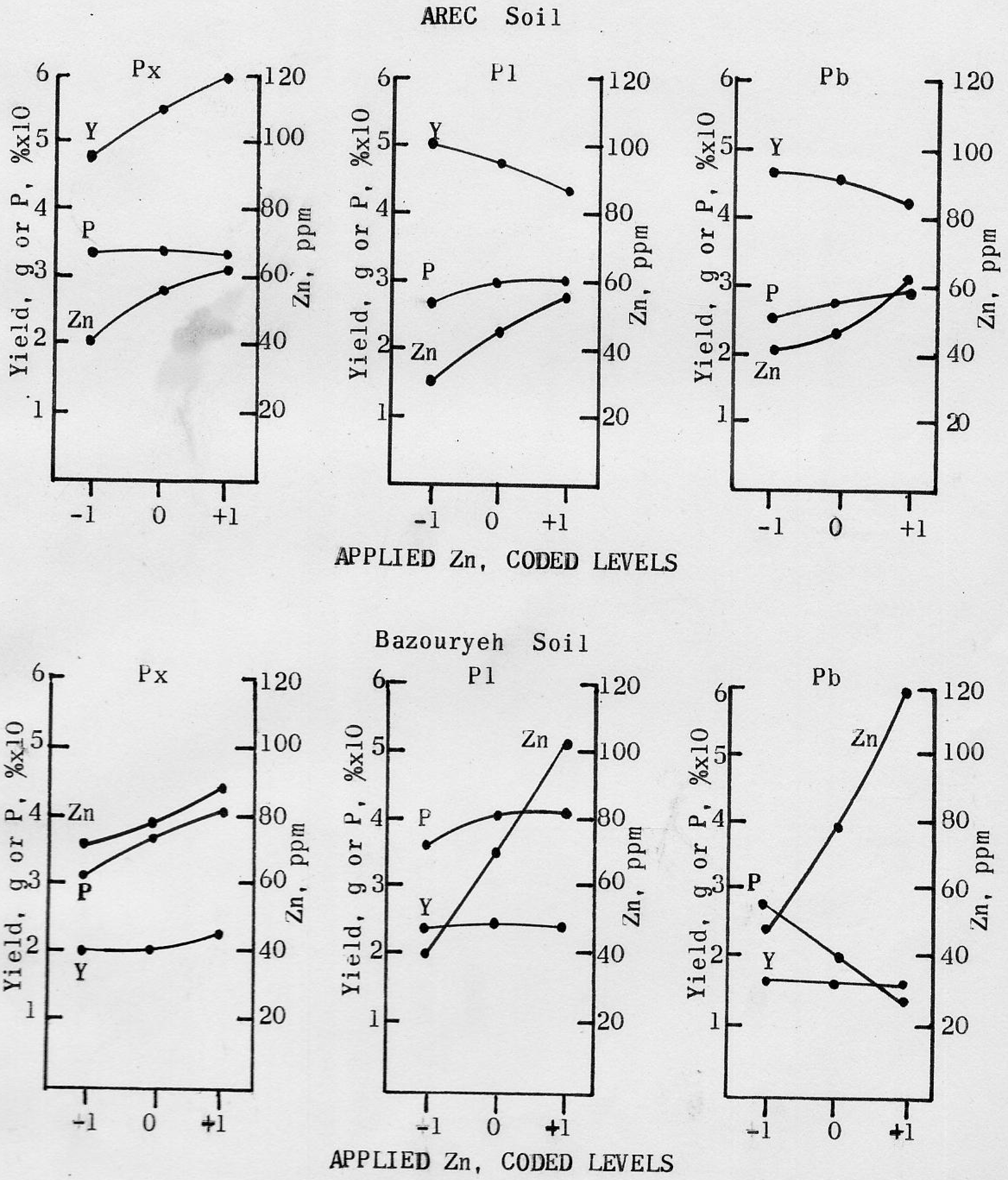

Figure 2. Effect of applied Zn on yield of dry matter and on P and Zn composition of maize tops under different methods of P application. The coded levels of P and N were kept constant at the -1 and +1 coded levels, respectively.

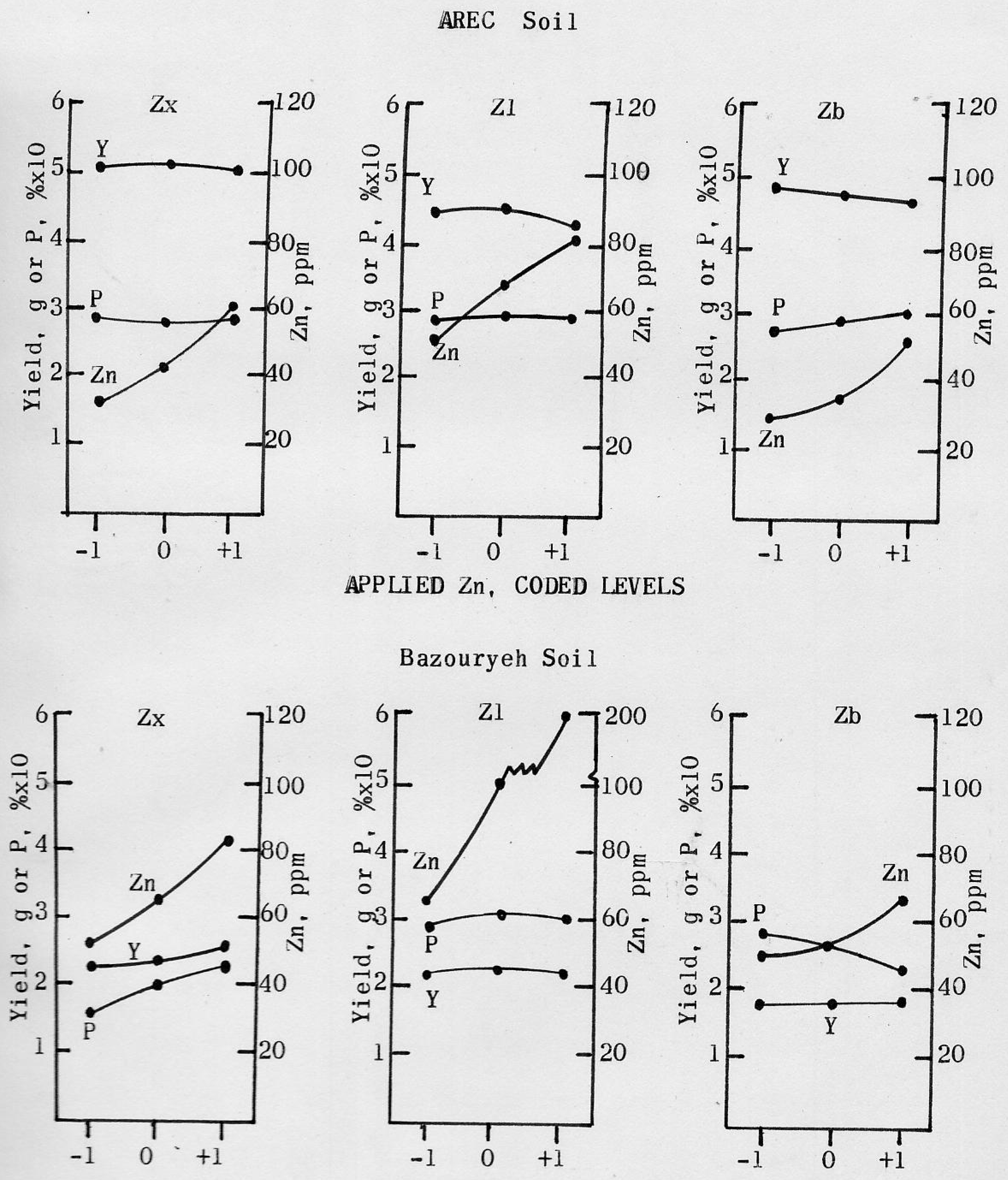

Figure 3. Effect of different methods and levels of Zn application on yield of dry matter, and on P and Zn concentration of maize tops. Applied N and P were kept constant at the +1 and -1 coded levels, respectively.

Bazouryeh soil ranged from an increasing effect with the Zx method to a decreasing effect with the Zb method. In both soils increasing P application resulted in somewhat greater reduction in Zn concentration with the Zx method of Zn placement as compared to the Zb or Zl methods (Figure 4).

<u>Effect of combined or separate application of Zn and P.</u> When the three placement methods where Zn and P were applied together and the five methods where Zn and P were applied separately were compared, it was found that in both soils applied P had a depressive effect on Zn concentration of maize tops (Figures 5 and 6). Applied Zn had very little effect on P concentration. The yield of dry matter was affected only slightly by the combined or separate application of the two elements. However, the Zn concentration of tops was considerably greater for the AREC soil when the two elements were applied separately as compared to combined application (figure 5). In the Bazouryeh soil the tendency was for somewhat lower Zn level when Zn and P were applied separately at high levels of N (figure 6).

It was concluded that the method of P and Zn application is an important factor in maize nutrition. Mixing Zn and P thoroughly in the soil seemed to be effective in increasing the P and Zn levels of maize tops from the AREC, but not in Bazouryeh soil, where the Pb method was more effective in increasing P levels in tops. This was probably due to its highly calcareous nature. Furthermore, the depressive effect of P on Zn of tops seems to be related to the method of application, but it appears to be independent of whether or not P and Zn were applied together or separately (figures 5 and 6).

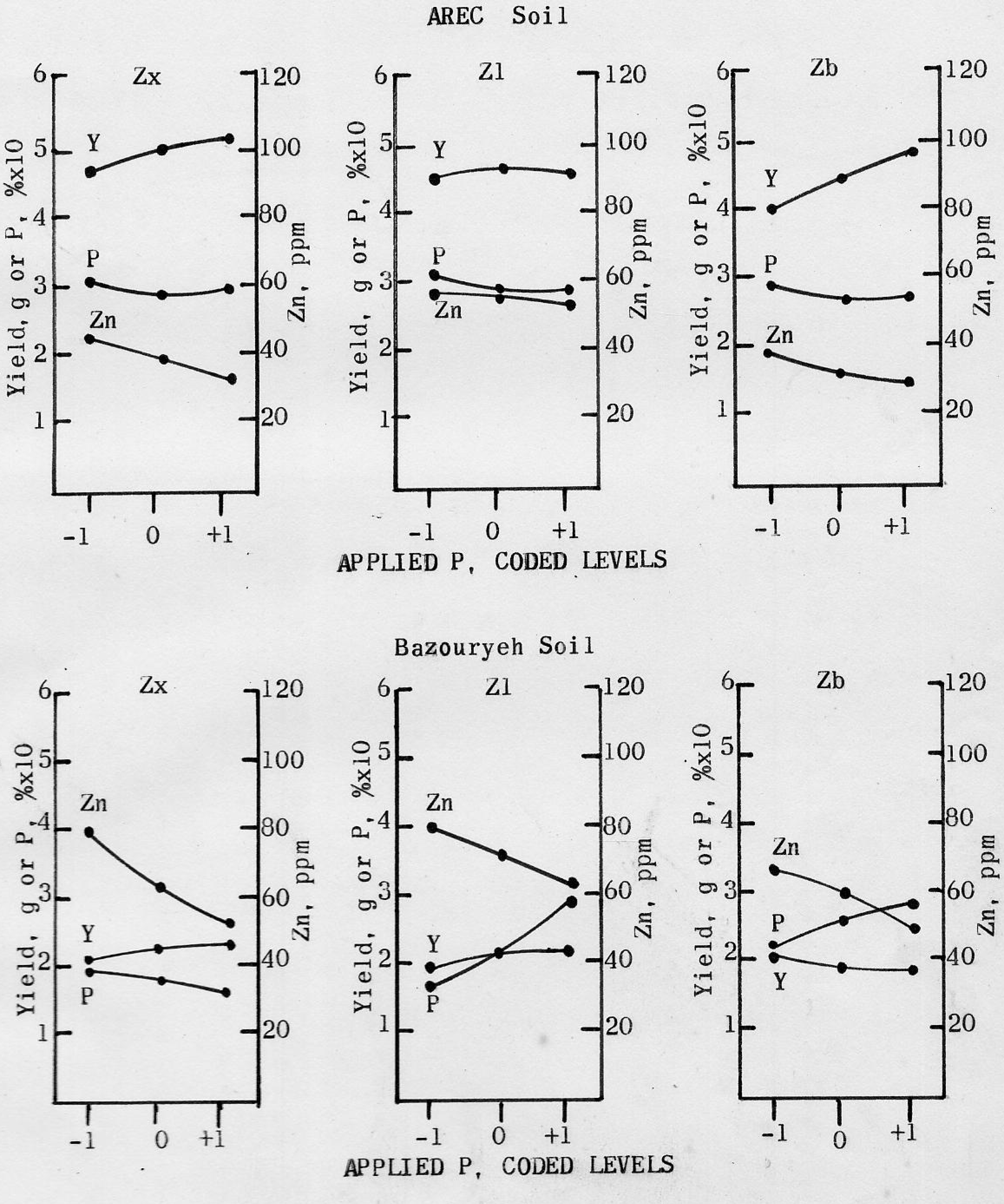

Figure 4. Effect of applied P on yield of dry matter and on P and Zn composition of maize tops under different methods of Zn application. Applied N and Zn were kept constant at the +1 and -1 coded levels, respectively.

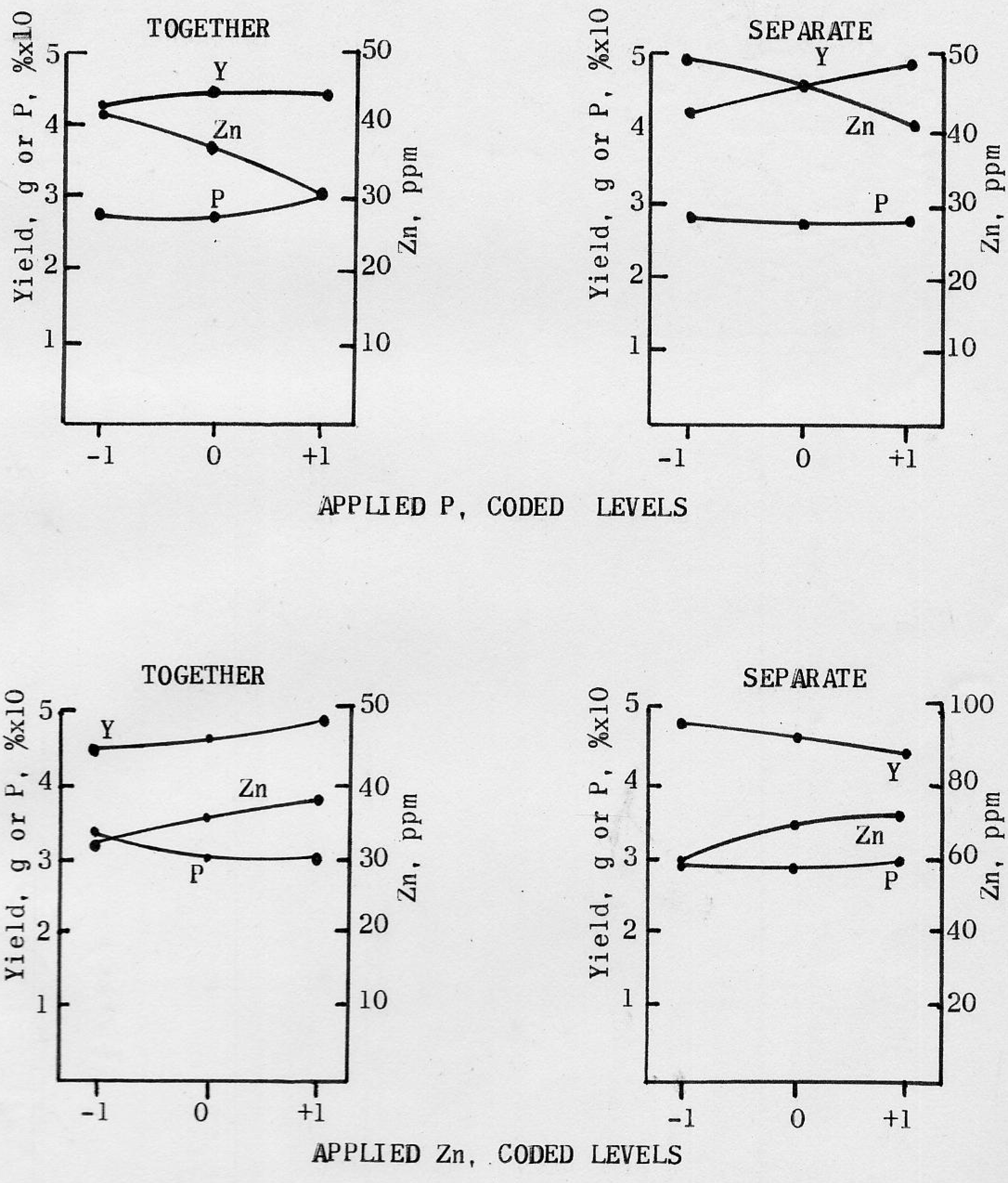

Figure 5. Effect of together or separate application of P and Zn on yield and on Zn and P concentrations of maize tops grown on the AREC soil. The applied N, P, and Zn were kept at the +1, +1, and -1 levels, respectively, when not varied.

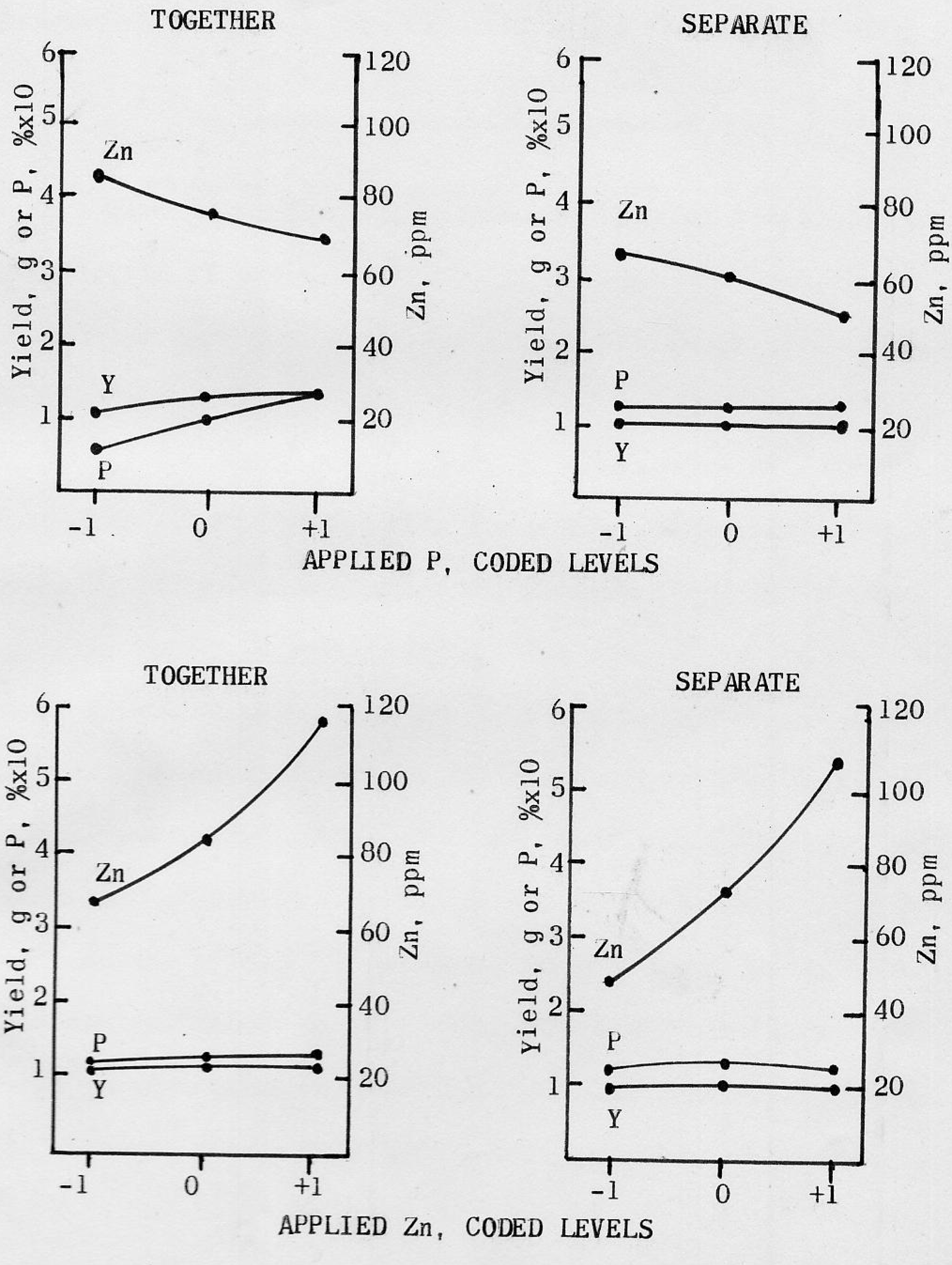

Figure 6. Effect of together or separate application of P or Zn on dry matter yield and on P and Zn concentrations of maize tops grown on the Bazouryeh soil. The applied N, P, and Zn were kept constant at the +1, +1, and -1 coded levels, respectively, when not varied.

Stukenholtz et al. (1966) reported that the curbing effect of P on Zn levels of maize is independent of the relative position of the two elements in the soil, thus substantiating the above finding.

The Nature of the P-Zn Interaction

A number of studies have shown an effect of P application on the Zn nutrition of maize. Ellis et al. (1964) and Stukenholtz et al. (1966) reported that the depressive effect of P on Zn concentration of maize is related to the root system.

In the following pages, the P-Zn interaction will be discussed in relation to plants and to soils for a more comprehensive understanding of the interrelationship between these two elements.

The P-Zn interaction in maize plants. Analysis of the maize roots from the ZmbPmb treatment and comparison to the analysis of the maize tops from the same placement treatment, afforded information on the accumulation and translocation of P, Zn, Mn and Ca (figures 7 and 8). The levels were chosen to show the effect of increasing P at a low Zn level, and the effect of increasing Zn at a low P level. The highly calcareous Bazouryeh soil produced maize plants with much greater Ca concentration in both roots and tops than in the plants from the less calcareous AREC soil. The proportion of Ca translocated from roots to the tops was about the same in both soils. The P concentration in the roots of the plants from the Bazouryeh soil was greater in general than that of those from the AREC soil, and the rate of accumulation with increasing applied P was also considerably greater (figure 7). However, the P level of the tops was considerably greater

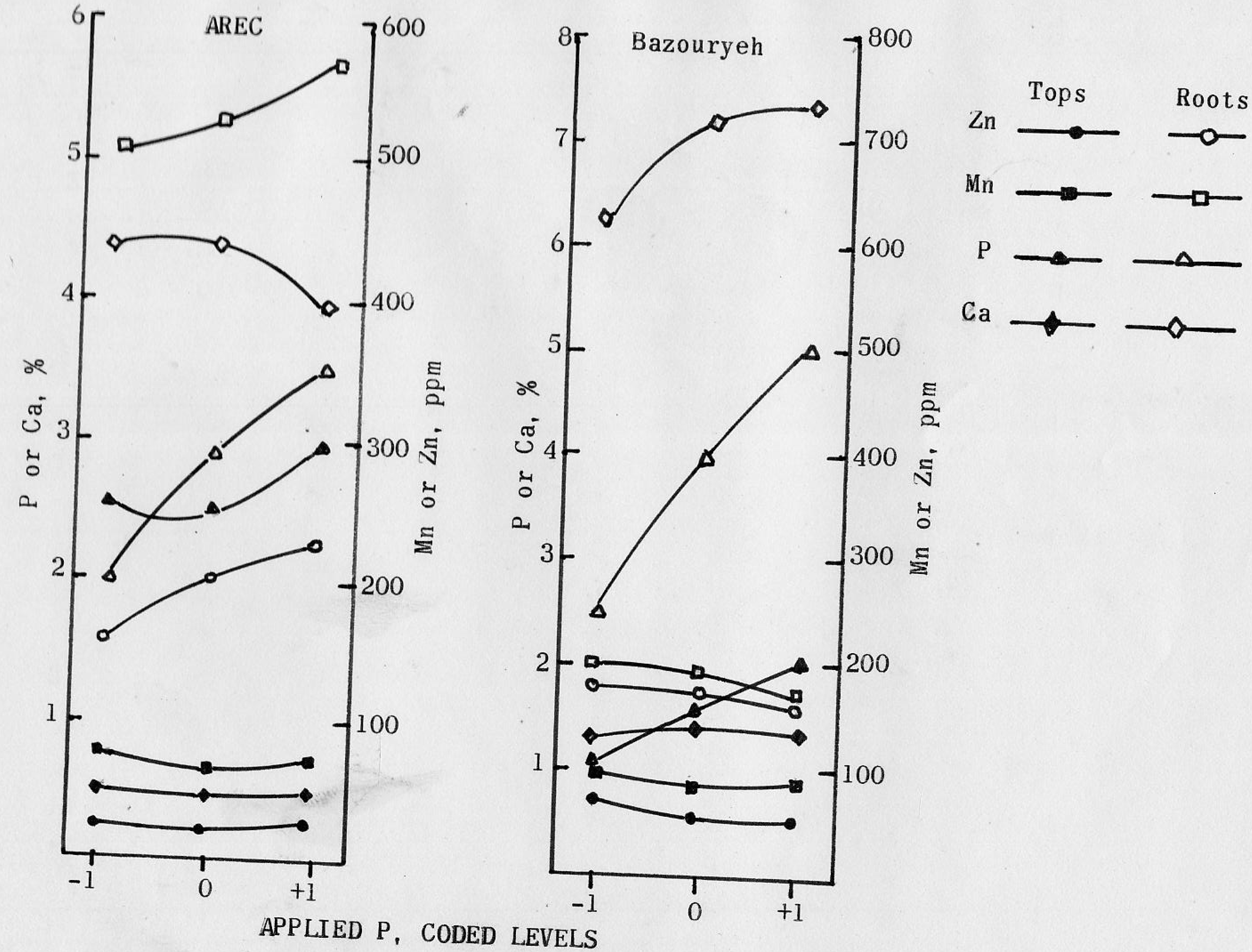

Figure 7. Effect of applied P on Zn, Mn, Ca and P concentrations of maize tops. Applied N and Zn are kept constant at the +1 and -1 coded levels, respectively.

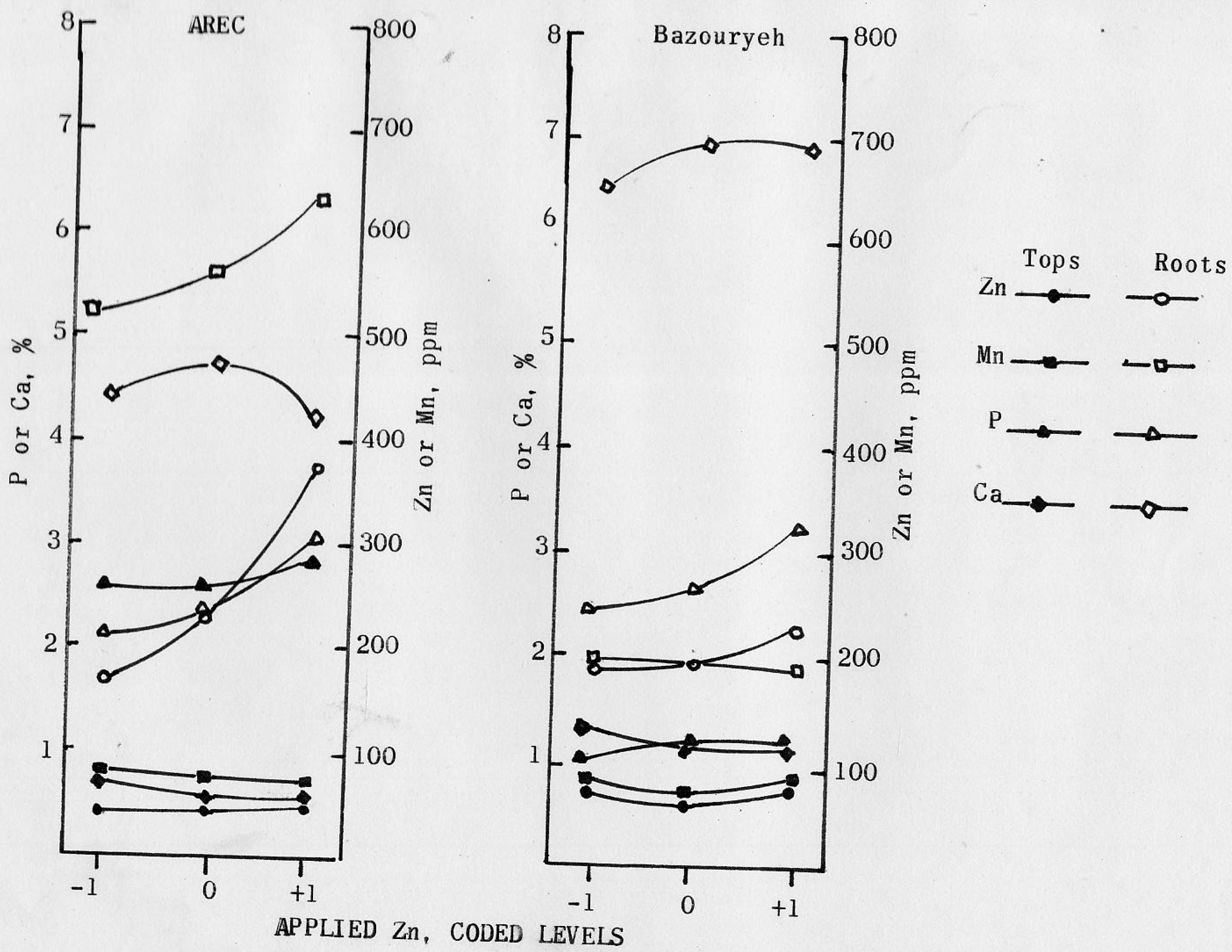

Figure 8. Effect of applied Zn on Zn , Mn, Ca and P concentrations of maize tops. The applied N and P are kept constant at the +1 and -1 coded levels, respectively.

in those from the AREC soil indicating that the translocation of P from roots to tops was much greater. The reason for the greater P accumulation in the maize roots from the Bazouryeh soil is probably related to the much higher accumulation of Ca. This implies an immobilization of P by Ca. A study of the levels of Zn and Mn in maize tops and roots of both soils (figure 7) indicated considerably greater translocation of both Zn and Mn in the Bazouryeh soil plants. This in turn is probably related to the previously postulated inactivation of P by Ca. Assuming that active P in the roots interferes with the translocation of Zn and Mn from roots to tops, this inactivation would possibly explain the greater Zn and Mn concentrations in the tops of the Bazouryeh soil plants as compared to the AREC soil plants.

The P-Zn interaction in soils. The generally "available" Zn level in soil was higher in the Bazouryeh soil than in the AREC soil (mean terms, table 5), and the first order term for Zn was considerably more positive indicating less fixation of Zn than in the AREC soil. The interaction effects in both soils were very similar with P-Zn being positive and N-P-Zn negative in both soils (table 5). Thus a low N level enhanced the decreasing effect of P on available Zn at low Zn levels. However, the negative N-P and N-Zn interactions were also involved and tended to cancel out when P is at high levels and Zn at low levels. The net effect depended on the magnitude of the various regression coefficients involved. Thus, both applied N and P had considerable influence on residual "available" Zn, but the effect depended on the relative levels of Zn, N and P involved.

Table 5. Regression coefficients for residual "available" P and Zn of the two soils studied.

Terms	AREC		Bazouryeh	
	P, ppm	Zn, ppm	P, ppm	Zn, ppm
Mean	28.53	17.02	15.78	20.50
N	-0.42	-0.42[e]	-0.64[e]	-1.55[xx]
P	+16.73[xx]	+0.61[x]	+7.44[xx]	0.00
Zn	+1.52[x]	+10.88[xx]	-0.02	+15.93[xx]
s_b	±0.49	±0.23	±0.33	±0.11
N^2	-2.79[xx]	+1.77[xx]	-2.34[xx]	-1.49[xx]
P^2	+4.95[xx]	+1.99[xx]	+1.45[xx]	-0.85[xx]
Zn^2	-1.62[x]	+1.43[xx]	+2.06[xx]	+8.14[xx]
s_b	±0.47	±0.22	±0.32	±0.10
NP	-2.15[x]	-1.68[xx]	-0.93[e]	-2.91[xx]
NZn	-0.58	-1.63[xx]	+0.20	-1.51[xx]
PZn	+2.90[xx]	+0.80[x]	-2.38[xx]	+1.19[xx]
NPZn	-3.48[xx]	-2.68[xx]	+0.45[e]	-0.91[xx]
s_b	±0.64	±0.30	±0.43	±0.14
R[1]	0.982	0.932	0.960	0.876

[e] Greater than standard error (s_b) so probably real.

[x] Significant at 5% level.

[xx] Highly significant at 1% level.

[1] Multiple correlation coefficient.

The relatively large highly significantly positive P-Zn interaction effect on "available" P of the AREC soil indicated a decreasing effect for applied Zn when P was at low levels. The highly significantly negative N-P-Zn interaction indicated that high application of N cancelled out the above effect.

The highly calcareous Bazouryeh soil had the opposite result in that the P-Zn interaction was highly significantly negative in effect on "available" P. The Bazouryeh soil had about half the general available P level of the AREC soil, and the first order effect of P was also about half that of the AREC soil. Therefore the P-Zn interaction effect was occurring at a considerably different level of "available" soil P.

The effect of applied N on the residual "available" Zn levels in both soils depended on the interactions with P and Zn all of which were highly significantly negative (table 5). Thus, the net N effect at high levels of applied P and low levels of applied Zn was positive for the AREC soil and negative for the Bazouryeh soil, depending on the relative magnitude of the various regression coefficients. It could be postulated that the greater amount of "active" Ca in the Bazouryeh soil (table 3) resulted in greater inactivation of P. This chain of events is supported by the positive effect of applied P on residual "available" P which was much greater for the less calcareous AREC soil indicating less fixation in the soil.

However, the chain of events proposed above is probably more complex than indicated, since applied Zn and P do not have a mutually depressing effect in the AREC soil as expected if co-precipitation alone were involved. Therefore, the fixation of Zn in the soils appears to generally be related to some other factor than the amount of P present in the soil in available form.

The differences found in the Ca, P and Zn in plants grown on the two soils may help to explain the occurrence of the Zn deficiencies found in many soils with pH levels in the general range of 6.4 to 7.6. Thorne et al. (1942) reported that Zn deficiency symptoms of fruit trees in Utah were more likely to occur in non-calcareous soils. Alben and Boggs (1936) reported that the Zn content of basic United States soils examined was generally higher than the Zn content of acid soils. Of 53 California Zn deficient soils 68 percent had a pH range of 7.0 to 8.0 (Brown et al., 1962). Soils in the pH range of 6.4 to 7.6 would tend to have high levels of "available" P as compared to soils of lower or higher pH and also would range from non-calcareous to only slightly calcareous. Therefore, under these conditions applied P would be more apt to induce Zn deficiency in maize, probably by inactivating Zn in the root system rather than in the soil.

V. SUMMARY AND CONCLUSIONS

A greenhouse experiment was conducted with maize grown on two calcareous soils, using a three layer technique. The purpose was to study the effect of varying N, P, and Zn and the method of placement on yield and on P and Zn composition of maize tops. The nature of the P-Zn interrelationship was also studied.

Application of N increased the P and Zn concentrations of tops in both soils, and this effect was almost as great as the direct effect of P on P and about half as great as the direct effect of Zn on Zn. This indicated the importance of N in Zn and P nutrition of maize plants. The positive effect of N on Zn concentration of tops increased at high Zn levels as shown by the positive N-Zn interaction and was intensified at high P levels as shown by the positive three-way N-P-Zn interaction. The response to applied N was greater in the AREC soil as compared to the Bazouryeh soil where the yields of tops were considerably lower.

Application of P tended to depress the Zn concentration of tops from both soils and the positive P-Zn interaction indicated that the effect was greater at low levels of Zn.

In relation to the effect of the method of placement, it was found that in the AREC soil the Pl and Pb methods gave the greater yield response to the application of P, but the P levels remained about the same. When P was mixed with the soil the P levels in plant tissues were increased but the yield remained constant.

In Bazouryeh soil banded P (Pb) and P added to sand (Pl) were effective in increasing P concentration, while P mixed with the soil was less effective probably due to P fixation in this highly calcareous soil.

In both soils Zn mixed (Zx) was more effective in increasing the Zn level in plants than the Zb method, but the Zl method was more effective than either of the above. Applied Zn had a small effect on P levels of plants, ranging from an increasing effect with the Zx method in the AREC soil to a decreasing effect with Zb method in the Bazouryeh soil. Increased P applications resulted in somewhat greater reduction in Zn concentration with the Zx method than with the Zb or Zl methods.

It was found that the translocation of Zn and Mn from roots to tops was greater in plants from the Bazouryeh soil as compared to the AREC soil plants but P translocation was greater in the AREC soil. The higher Ca and P concentration of the roots of the Bazouryeh soil plants led to the postulation that Ca inactivates P in the roots thus reducing the tendency for P to inactivate Zn and Mn. Consequently, more Zn and Mn are translocated to the tops. This finding is supported by the overall depressive effect of P application on Zn in maize tops. However, while the AREC soil tended to fix less P and more Zn than the Bazouryeh soil, applied P and Zn did not have a mutually depressive effect on available soil P and Zn as expected if co-precipitation was involved. This indicated that the effect of P on Zn in maize was associated to much greater extent with the root system than with the soil.

The availability of P tends to be greater at soil pH levels approaching neutrality. Also, the literature shows that many severely Zn deficient soils are near neutrality in reaction. It is postulated from this and from the results of the study reported here that plants grown in such soils are more likely to suffer from P-induced Zn deficiency, while in more calcareous soils plants are less susceptible to P-induced Zn deficiency because of P inactivation by Ca in the roots.

Study of the mineralogical composition of the soil in relation to P-Zn interaction may result in further clarification of this point. It is also suggested that further study of the P-Zn relationships should involve determination of the form of P, Zn, Ca and Mn present in various plant parts in order to find out where and how the various interactions involved are taking place.

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APPENDICES

Table 6. Regression coefficients for yield of dry matter of maize tops grown on the Bazouryeh soil under different methods of nutrient placement.

	ZxPx	ZmbPmb	ZbPb	Z1P1	ZxP1	ZbP1	Z1Px	S1Pb
Terms				g/pot				
Mean	2.190	1.778	1.574	3.048	2.418	2.067	1.670	1.635
N	+0.099	-0.150[x]	+0.107[xx]	+0.347[x]	-0.016	+0.117[e]	+0.108[e]	+0.104
P	+0.178[x]	+0.153[x]	-0.042	+0.057	+0.311[x]	+0.170[e]	+0.198[x]	+0.045[e]
Zn	+0.011	+0.099[e]	-0.056	-0.013	-0.066	-0.052	-0.085[e]	-0.012
s_b	±0.114	±0.059	±0.061	±0.098	±0.111	±0.096	±0.061	±0.039
N^2	-0.122[e]	-0.111	-0.009	-0.294[x]	-0.130[e]	-0.076	+0.039	-0.041[e]
P^2	-0.141[e]	+0.118	+0.012	-0.158[e]	+0.017	+0.011	+0.002	+0.039[e]
Zn^2	+0.414[xx]	+0.013	+0.137[x]	-0.295[x]	-0.088	+0.002	+0.084[e]	-0.103[x]
s_b	±0.111	±0.057	±0.059	±0.095	±0.108	±0.093	±0.059	±0.038
N-P	-0.060	-0.100[e]	-0.081[e]	+0.123	+0.064	-0.077	+0.092[e]	-0.032
N-Zn	+0.244[e]	-0.023	-0.247[x]	-0.165[x]	-0.108[x]	+0.042	-0.005	+0.117[e]
P-Zn	+0.140	-0.021	+0.116[e]	+0.031	+0.005	+0.210[e]	-0.034	-0.011
N-P-Zn	-0.109	-0.049	-0.055	+0.093	+0.117	+0.062	+0.057	-0.023
s_b	±0.149	±0.077	±0.081	±0.128	±0.145	±0.125	±0.080	±0.051
R[1]	0.829	0.834	0.847	0.878	0.661	0.712	0.830	0.774

[e] Probably real because greater than standard error (s_b).

[x] Significant at 5% level.

[xx] Significant at 1% level.

[1] Multiple correlation coefficient.

Table 7. Regression coefficients for yield of dry matter of maize tops grown on the AREC soil under different methods of nutrient placement.

	ZxPx	ZmbPmb	ZbPb	ZlPl	ZxPl	ZbPl	ZlPx	ZlPb
Terms				g/pot				
Mean	4.508	4.120	3.829	3.568	4.131	4.278	4.261	4.071
N	$+1.169^{xx}$	$+0.914^{xx}$	$+0.753^{x}$	$+0.591^{x}$	$+0.767^{xx}$	$+0.869^{x}$	$+0.984^{x}$	$+0.545^{xx}$
P	$+0.228^{xx}$	$+0.207^{xx}$	$+0.139^{e}$	+0.038	$+0.267^{xx}$	-0.019	$+0.191^{e}$	$+0.263^{xx}$
Zn	$+0.213^{xx}$	$+0.093^{e}$	+0.085	-0.093	-0.036	-0.078	+0.039	-0.238^{x}
s_b	±0.071	±0.088	±0.120	±0.105	±0.058	±0.116	±0.136	±0.089
N^2	$+0.247^{x}$	-0.249^{e}	-0.260^{e}	-0.203^{e}	-0.308^{xx}	-0.223^{e}	+0.016	-0.008
P^2	-0.182^{e}	-0.061	+0.046	+0.031	-0.071^{e}	-0.239^{e}	+0.058	-0.189
Zn^2	-0.145^{e}	+0.033	+0.020	-0.042	-0.005	+0.062	-0.274^{e}	-0.171^{e}
s_b	±0.069	±0.086	±0.116	±0.102	±0.056	±0.112	±0.132	±0.087
N-P	+0.058	-0.021	+0.134	$+0.141^{e}$	$+0.126^{e}$	$+0.269^{e}$	$+0.184^{e}$	-0.375^{x}
N-Zn	-0.059	+0.023	-0.062	-0.073	-0.311^{x}	$+0.166^{e}$	+0.140	-0.345^{x}
P-Zn	$+0.180^{e}$	-0.051	+0.009	+0.041	-0.012	-0.318^{e}	+0.111	-0.251^{e}
N-P-Zn	+0.065	+0.005	+0.077	+0.104	-0.083^{e}	-0.241^{e}	$+0.513^{x}$	-0.197^{e}
s_b	±0.093	±0.115	±0.157	±0.137	±0.075	±0.151	±0.178	±0.118
R^1	0.957	0.966	0.918	0.901	0.924	0.947	0.941	0.912

e Probably real because greater than standard error (s_b).

x Significant at 5% level.

xx Significant at 1% level.

1 Multiple correlation coefficient.

Table 8. Regression coefficients for total P concentration ofmaize tops grown on the Bazouryeh soil under different methods of nutrient placement.

	ZxPx	ZmbPmb	ZbPb[1]	ZlPl	ZxPl	ZbPl	ZlPx	ZlPb
Terms				Percent				
Mean	0.1381	0.1716	0.2264	0.3048	0.2748	0.3579	0.2447	0.1575
N	+0.0027	-0.0006	+0.0009	+0.0483[x]	+0.0201[x]	+0.0453[xx]	+0.0073[e]	+0.0165[x]
P	+0.0126[e]	+0.0153[e]	+0.0133[e]	+0.0848[xx]	+0.0213[x]	+0.0346[xx]	+0.0179[xx]	-0.0016
Zn	+0.0109[e]	-0.0004	+0.0017	+0.0272[x]	-0.0111[e]	+0.0014	+0.0076[e]	+0.0037[e]
s_b	±0.0074	±0.0078	±0.0053	±0.0082	±0.0079	±0.0081	±0.0045	±0.0036
N^2	-0.0077[e]	-0.0042	-0.0228[xx]	-0.0155[e]	-0.0098[e]	+0.0216[x]	-0.0061[e]	+0.0035[e]
P^2	+0.0092[e]	-0.0150[e]	+0.0045	+0.0403[xx]	-0.0158[e]	-0.0127[e]	-0.0164[x]	+0.0134[x]
Zn^2	+0.0057	-0.0055	+0.0021	-0.0344[xx]	-0.0229[x]	-0.0261[x]	-0.0158[x]	-0.0078[e]
s_b	±0.0072	±0.0076	±0.0051	±0.0079	±0.0077	±0.0078	±0.0043	±0.0035
N-P	-0.0054	+0.0084	-0.0253[xx]	+0.0720[xx]	-0.0193[e]	+0.0027	-0.0083[e]	+0.0020
N-Zn	+0.0074	-0.0196[e]	-0.0135[e]	-0.0025	-0.0153[e]	+0.0050	-0.0053	+0.0063[e]
P-Zn	+0.0091	-0.0156[e]	-0.0040	-0.0160[e]	+0.0110[e]	+0.0038	-0.0145[e]	-0.0085[e]
N-P-Zn	+0.0251[x]	-0.0086	-0.0200[x]	+0.0145[e]	+0.0053	-0.0080	+0.0050	-0.0010
s_b	±0.0097	±0.0103	±0.0069	±0.0107	±0.0104	±0.0105	±0.0058	±0.0047
R^2 [2]	0.797	0.794	0.873	0.905	0.900	0.877	0.859	0.916

e Probably real because greater than standard error (s_b).

x Significant at 5% level.

xx Significant at 1% level.

1 Harvested from P band.

2 Multiple correlation coefficient.

Table 9. Regression coefficients for total P concentration of maize tops grown on the AREC soil under different methods of nutrient placement.

Terms	ZxPx	ZmbPmb	ZbPb[1]	ZlPl	ZxPl	ZbPl	ZlPx	ZlPb
				Percent				
Mean	0.2182	0.2145	0.2435	0.2440	0.2532	0.2398	0.4158	0.1533
N	+0.0039[x]	+0.0116[xx]	+0.0235[e]	+0.0263[xx]	+0.0197[xx]	+0.0229[e]	+0.0074	+0.0131[x]
P	+0.0189[xx]	+0.0157[xx]	+0.0161	+0.0217[xx]	+0.0045	+0.0074[e]	-0.0074	-0.0017
Zn	-0.0200[xx]	+0.0067[x]	+0.0052	+0.0213[xx]	+0.0113[e]	+0.0033	+0.0258[e]	-0.0168[x]
s_b	±0.0013	±0.0018	±0.0113	±0.0045	±0.0047	±0.0074	±0.0102	±0.0051
N^2	-0.0462[xx]	+0.0241[xx]	+0.0520[xx]	+0.0384[xx]	+0.0221[xx]	+0.0218[x]	-0.0022	+0.0277[xx]
P^2	-0.0355[xx]	+0.0289[xx]	+0.0091	+0.0138[x]	+0.0156[x]	+0.0089[e]	-0.0025	+0.0061
Zn^2	+0.0192[xx]	+0.0009	+0.0131	+0.0202[xx]	-0.0057[x]	-0.0045	-0.0283[x]	+0.0013
s_b	±0.0013	±0.0017	±0.0109	±0.0043	±0.0045	±0.0072	±0.0099	±0.0049
N-P	-0.0229[xx]	+0.0041[e]	-0.0073	+0.0018	-0.0256[xx]	-0.0277[x]	-0.0076	-0.0031
N-Zn	+0.0171[xx]	-0.0038[e]	-0.0097	+0.0037	-0.0094[e]	-0.0045	+0.0248[e]	+0.0129[e]
P-Zn	-0.0218[xx]	+0.0059[x]	+0.0150[e]	+0.0155[x]	-0.0101	-0.0103[e]	-0.0254[e]	+0.0136[e]
N-P-Zn	-0.0016	-0.0111[xx]	-0.0058	+0.0058[e]	+0.0009	+0.0055	-0.0188[e]	+0.0091[e]
s_b	±0.0017	±0.0023	±0.0148	±0.0058	±0.0061	±0.0096	±0.0133	±0.0066
R^2	0.953	0.979	0.877	0.965	0.888	0.885	0.733	0.712

e Probably real because greater than standard error (s_b).
x Significant at 5% level.
xx Significant at 1% level.
1 Plants harvested from the P band.
2 Multiple correlation coefficient.

Table 10. Regression coefficients for total Zn concentration of maize tops grown on the Bazouryeh soil under different methods of nutrient placement.

Terms	ZxPx	ZmbPmb	ZbPb[1]	ZlPl	ZxPl	ZbPl	ZlPx	ZlPb
				ppm				
Mean	70.62	47.92	46.26	75.42	37.61	58.34	71.06	97.89
N	$+11.40^{xx}$	$+8.21^{xx}$	$+1.47^{e}$	$+20.31^{xx}$	$+6.81^{x}$	$+9.57^{xx}$	-2.65^{e}	$+19.21^{xx}$
P	-8.34^{xx}	-2.88^{e}	-0.08	-1.59	-2.39^{e}	-4.04^{x}	-4.22^{e}	$+12.21^{xx}$
Zn	$+8.88^{xx}$	$+9.31^{xx}$	$+3.12^{e}$	$+24.76^{xx}$	$+5.56^{x}$	-0.38	$+17.19^{xx}$	$+61.04^{xx}$
s_b	±2.20	±1.68	±1.08	±2.84	±1.83	±1.48	±2.57	±1.32
N^2	$+12.59^{xx}$	$+2.94^{e}$	-2.44^{e}	+1.79	$+5.56^{x}$	$+3.49^{e}$	$+9.32^{x}$	$+23.04^{xx}$
P^2	-0.14	$+6.14^{e}$	-1.55^{e}	$+3.63^{e}$	$+2.35^{e}$	-3.18^{e}	$+3.14^{e}$	-8.07^{xx}
Zn^2	$+2.28^{e}$	$+10.33^{xx}$	$+5.53^{xx}$	$+12.54^{xx}$	+1.64	+0.29	$+5.10^{e}$	$+15.61^{xx}$
s_b	±2.14	±1.63	±1.04	±2.75	±1.78	±1.44	±2.49	± 1.28
N-P	+0.41	+1.81	-9.88^{xx}	$+12.69^{x}$	-2.10	+0.33	$+4.78^{e}$	+1.38
N-Zn	-5.11^{e}	-4.01^{e}	-7.65^{xx}	$+13.89^{x}$	$+9.83^{xx}$	$+13.68^{xx}$	-2.87	$+12.54^{xx}$
P-Zn	-0.24	-2.09	-0.78	$+10.11^{x}$	$+3.83^{e}$	+1.10	+0.53	$+22.19^{xx}$
N-P-Zn	$+3.29^{e}$	$+9.64^{xx}$	$+1.90^{e}$	$+11.24^{x}$	$+5.20^{e}$	$+2.55^{e}$	-4.53^{e}	$+8.21^{xx}$
s_b	±2.88	±2.20	±1.40	±3.71	±2.39	±1.94	±3.36	±1.73
R^2	0.954	0.832	0.741	0.893	0.832	0.884	0.687	0.868

[e] Probably real because greater than standard error (s_b).

[x] Significant at 5% level.

[xx] Significant at 1% level.

[1] Plants harvested from P band.

[2] Multiple correlation coefficient.

Table 11. Regression coefficients for total Zn concentration of maize tops grown on the AREC soil under different methods of nutrient placement.

Terms	ZxPx	ZmbPmb	ZbPb[1]	ZlPl	ZxPl	ZbPl	ZlPx	ZlPb
				ppm				
Mean	31.06	27.18	23.95	45.57	35.41	35.00	81.38	56.04
N	-0.460	+5.08^{xx}	+3.10^{x}	+1.11	+10.15^{xx}	+5.19^{e}	+4.98^{e}	+12.98^{x}
P	-6.86^{xx}	-2.61^{xx}	+0.64	-5.97^{x}	+1.86	+0.56	-0.99	+4.48^{e}
Zn	+9.95^{xx}	+1.17^{xx}	+13.96^{xx}	+2.03^{xx}	+5.96^{x}	+6.64^{x}	+5.81^{e}	+10.97^{x}
s_b	±0.75	±0.25	±0.68	±1.93	±1.99	±2.09	±3.36	±3.60
N^2	+6.77^{xx}	+5.73^{xx}	-0.52	+0.29	+5.13^{x}	+0.95	+6.14^{e}	+0.48
P^2	+1.77^{e}	-0.94^{x}	+6.15^{xx}	+1.37	+0.99	-1.25	-4.46^{e}	+0.67
Zn^2	+3.39^{xx}	+1.93^{x}	+20.74^{xx}	+9.40^{xx}	+2.11^{e}	+2.15^{e}	-8.76^{e}	-1.15
s_b	±0.72	±0.24	±0.66	±1.87	±1.94	±2.03	±3.26	±3.49
N-P	-1.02^{e}	-0.93^{e}	-2.76^{x}	+1.34^{e}	+5.58^{e}	-2.01	+4.08	-2.84
N-Zn	-2.79^{x}	+1.70^{xx}	+4.16^{xx}	-8.11^{x}	+4.56^{e}	+1.84	+1.40	+6.21^{e}
P-Zn	-1.96^{e}	-0.10	-1.09^{e}	-6.22^{e}	+4.28^{e}	+9.56^{x}	+8.18^{e}	-1.24
N-P-Zn	-2.64^{x}	-0.80^{e}	-0.99^{e}	+3.26^{e}	+11.81^{xx}	+0.64	+4.55^{e}	-3.56
s_b	±0.98	±0.32	±0.88	±2.52	±2.61	±2.73	±4.39	±4.71
R^2	0.830	0.952	0.921	0.931	0.902	0.778	0.868	0.715

[e] Probably real because greater than standard error (s_b).

[x] Significant at 5% level.

[xx] Significant at 1% level.

[1] Plants harvested from P band.

[2] Multiple correlation coefficient.

Table 12. Analysis of variance for dry matter yield of maize tops grown on the Bazouryeh soil under different methods of nutrient placement.

		ZxPx	ZmbPmb	ZbPb	ZlPl	ZxPl	ZbPl	ZlPx	ZlPb
						g/pot			
d.f.	Total	19	19	19	19	19	19	19	19
	First order	3	3	3	3	3	3	3	3
	Higher order	7	7	7	7	7	7	7	7
	Lack of fit	4	4	4	-	4	-	-	4
	Error	5	5	5	9	5	9	9	5
S.S.	Total	6.705	1.855	1.638	5.880	4.504	2.273	1.469	0.847
	First order	0.571	0.762	0.225	1.688	1.384	0.618	0.794	0.177
	Higher order	4.025	0.524	0.946	2.850	0.579	0.533	0.216	0.328
	Lack of fit	1.214	0.333	0.315	-	1.704	-	-	0.240
	Error	0.894	0.234	0.151	1.341	0.836	1.122	0.459	0.101
M.S.	First order	0.190	0.254	0.075	0.563	0.461	0.206	0.270^{x}	0.059
	Higher order	0.575	0.075	0.135	0.407	0.083	0.076	0.031	0.047
	Lack of fit	0.304	0.083	0.078	-	0.426	-	-	0.060
	Error	0.178	0.047	0.030	0.149	0.167	0.125	0.052	0.020
Coefficient of variation, %		19.3	12.2	11.0	12.7	16.9	17.1	13.5	8.7

x Statistically significant at 5% level.

Table 13. Analysis of variance for dry matter yield of maize tops grown on the AREC soil under different methods of nutrient placement.

		ZxPx	ZmbPmb	ZbPb	ZlPl	ZxPl	ZbPl	ZlPx	ZlPb
		g/pot							
d.f.	Total	19	19	19	19	19	19	19	19
	First order	3	3	3	3	3	3	3	3
	Higher order	7	7	7	7	7	7	7	7
	Lack of fit	4	-	-	-	4	-	-	4
	Error	5	9	9	9	5	9	9	5
S.S.	Total	23.76	14.05	11.15	7.21	13.32	15.67	19.82	11.09
	First order	19.98	12.11	8.10	4.91	9.02	10.41	13.73	5.48
	Higher order	1.74	0.98	1.28	0.94	2.35	3.62	3.82	3.74
	Lack of fit	1.68	-	-	-	1.72	-	-	1.32
	Error	0.35	0.95	1.76	1.36	0.23	1.63	2.27	0.55
M.S.	First order	6.66^{xx}	4.03^{xx}	2.70^{xx}	1.64^{xx}	3.01^{xx}	3.47^{xx}	4.57^{xx}	1.83^{xx}
	Higher order	0.25	0.14	0.18	0.13	0.34^{x}	0.52	0.55	0.53^{x}
	Lack of fit	0.42^{x}	-	-	-	0.43^{x}	-	-	0.33
	Error	0.069	0.105	0.196	0.151	0.046	0.182	0.252	0.109
Coefficient of variation, %		5.8	7.9	11.6	10.8	5.2	9.9	11.8	8.1

^{x} Statistically significant at 5% level.

^{xx} Statistically significant at 1% level.

Table 14. Analysis of variance for total P concentration of maize tops grown on the Bazouryeh soil under different methods of nutrient placement.

		ZxPx	ZmbPmb	ZbPb[1]	ZlPl	ZxPl	ZbPl	ZlPx	ZlPb
						Percent			
d.f.	Total	19	19	19	19	19	19	19	19
	First order	3	3	3	3	3	3	3	3
	Higher order	7	7	7	7	7	7	7	7
	Lack of fit	-	-	4	4	-	4	4	-
	Error	9	9	5	5	9	5	5	9
S.S.	Total	0.02054	0.02048	0.02722	0.28567	0.03740	0.08558	0.02105	0.01053
	First order	0.00390	0.00318	0.00246	0.14026	0.01345	0.04442	0.00595	0.00397
	Higher order	0.00913	0.00974	0.01825	0.09391	0.01684	0.02136	0.00957	0.00485
	Lack of fit	-	-	0.00461	0.04700	-	0.01535	0.00418	-
	Error	0.007511	0.007558	0.001890	0.004589	0.007105	0.004453	0.001352	0.001712
M.S.	First order	0.00130	0.00106	0.00082	0.04672[xx]	0.00445[x]	0.01481[xx]	0.00198[x]	0.00132[x]
	Higher order	0.00130	0.00139	0.00261[x]	0.01342[xx]	0.00241	0.00305	0.00136[x]	0.00069
	Lack of fit	-	-	0.00115	0.01175[xx]	-	0.00384	0.00104	-
	Error	0.000830	0.000839	0.000378	0.000917	0.000789	0.000890	0.000270	0.000190
Coefficient of variation,%		20.90	16.90	8.60	9.90	10.20	13.10	6.70	8.80

x Statistically significant at 5% level.
xx Statistically significant at 1% level.
1 Plants harvested from P band.

Table 15. **Analysis of variance for total P concentration of maize tops grown on the AREC soil under different methods of nutrient placement.**

		ZxPx	ZmbPmb	ZbPb[1]	Z1P1	ZxP1	ZbP1	Z1Px	Z1Pb
						Percent			
d.f.	Total	19	19	19	19	19	19	19	19
	First order	3	3	3	3	3	3	3	3
	Higher order	7	7	7	7	7	7	7	7
	Lack of fit	4	4	4	4	4	4	4	4
	Error	5	5	5	5	5	5	5	5
S.S.	Total	0.07455	0.02730	0.07133	0.05451	0.03024	0.03039	0.06617	0.04168
	First order	0.01058	0.00582	0.01146	0.02208	0.00734	0.00811	0.01058	0.00621
	Higher order	0.05709	0.02029	0.04322	0.02854	0.01645	0.01561	0.02485	0.01486
	Lack of fit	0.00675	0.00097	0.00790	0.00253	0.00496	0.00115	0.02362	0.01886
	Error	0.000121	0.000210	0.008743	0.001352	0.001486	0.005526	0.007117	0.001744
M.S.	First order	0.00353[xx]	0.00194[xx]	0.00382	0.00736[xx]	0.00244[x]	0.00270	0.00353	0.00207[x]
	Higher order	0.00815[xx]	0.00289[xx]	0.00617	0.00408[xx]	0.00235[x]	0.00223	0.00355	0.00212[x]
	Lack of fit	0.00168[xx]	0.00024[x]	0.00198	0.00063	0.00124	0.00028	0.00590	0.00471[xx]
	Error	0.000024	0.000042	0.001748	0.000270	0.000297	0.001105	0.001423	0.000348
Coefficient of variation,%		2.30	5.30	17.20	6.70	6.80	13.80	9.10	12.20

x Statistically significant at 5% level.

xx Statistically significant at 1% level.

1 Plants harvested from P band.

Table 16. Analysis of variance for total Zn concentration of maize tops grown on the Bazouryeh soil under different methods of nutrient placement.

		ZxPx	ZmbPmb	ZbPb[1]	ZlPl	ZxPl	ZbPl	ZlPx	ZlPb
						ppm			
d.f.	Total	19	19	19	19	19	19	19	19
	First order	3	3	3	3	3	3	3	3
	Higher order	7	7	7	7	7	7	7	7
	Lack of fit	-	4	4	4	4	4	4	4
	Error	9	5	5	5	5	5	5	5
S.S.	Total	7072.7	7366.5	3759.9	26380.0	4011.6	4339.9	13448.1	100661.9
	First order	3802.4	2217.6	162.2	14034.5	1133.1	1476.7	4376.1	57965.3
	Higher order	2623.4	2880.3	1899.4	7003.3	1645.0	1912.6	1964.4	17934.5
	Lack of fit	-	2075.5	1619.6	4794.6	1004.4	800.8	6657.7	24642.9
	Error	647.0	193.2	78.7	547.7	229.0	149.7	449.8	119.2
M.S.	First order	1267.5^{xx}	739.2^{xx}	54.1	4678.2^{xx}	377.7^{xx}	492.2^{xx}	1458.7^{xx}	19321.8^{xx}
	Higher order	374.8^{x}	411.5^{xx}	271.3^{xx}	1000.5^{xx}	235.0^{x}	273.2^{x}	280.6	2562.1^{xx}
	Lack of fit	-	518.9^{xx}	404.9^{xx}	1198.6^{xx}	251.1^{x}	200.2^{x}	1664.4^{xx}	6160.7^{xx}
	Error	71.9	38.6	15.7	109.5	45.8	29.9	89.9	23.8
Coefficient of variation, %		12.0	13.0	8.6	13.9	18.0	9.4	13.3	4.9

x Statistically significant at 5% level.

xx Statistically significant at 1% level.

1 Plants harvested from P band.

Table 17. Analysis of variance for total Zn concentration of maize tops grown on the AREC soil under different methods of nutrient placement.

		ZxPx	ZmbPmb	ZbPb[1]	ZlPl	ZxPl	ZbPl	ZlPx	ZlPb
		ppm							
d.f.	Total	19	19	19	19	19	19	19	19
	First order	3	3	3	3	3	3	3	3
	Higher order	7	7	7	7	7	7	7	7
	Lack of fit	4	4	4	4	4	4	4	4
	Error	5	5	5	5	5	5	5	5
S.S.	Total	4259.8	1144.5	11293.4	11486.7	4970.5	3101.2	7223.7	9274.9
	First order	1997.9	463.9	2800.7	7747.5	1940.5	973.5	812.9	4221.9
	Higher order	934.5	572.7	6787.6	2215.4	2097.1	901.7	2927.6	516.4
	Lack of fit	1289.4	103.7	1673.9	1271.0	661.1	927.3	2713.5	3651.9
	Error	37.90	4.18	31.2	252.7	271.8	298.6	769.74	884.70
M.S.	First order	665.9[xx]	154.6[xx]	933.6	2582.5[xx]	646.8[xx]	324.5[x]	270.9	1407.3[x]
	Higher order	133.5[xx]	81.8[xx]	969.7	316.5[x]	299.6[x]	128.8	418.2	73.7
	Lack of fit	322.4[xx]	25.9[xx]	418.5	317.8[x]	165.7	231.8	678.4	912.9
	Error	7.57	0.837	6.20	50.50	54.40	59.70	153.94	176.94
Coefficient of variation, %		8.90	3.30	10.40	15.60	20.80	22.10	15.20	23.70

x Statistically significant at 5% level.

xx Statistically significant at 1% level.

1 Plants harvested from P band.

Table 18. Yield of dry matter of maize tops grown on the Bazouryeh soil under different methods of nutrient placement.

N	P	Zn	ZxPx	ZmbPmb	ZbPb	ZlPl	ZxPl	ZbPl	ZlPx	ZlPb
Levels						g/pot				
2	2	2	2.03	1.78	1.56	1.70	1.72	2.06	1.68	1.51
4	2	2	1.89	1.55	2.62	2.87	2.14	2.38	1.85	1.63
2	4	2	2.18	2.08	1.49	1.50	2.00	1.99	2.04	1.59
4	4	2	2.23	1.65	2.00	2.79	2.22	1.74	2.34	1.68
2	2	4	1.45	1.66	1.59	2.08	2.35	1.59	1.65	1.01
4	2	4	2.73	1.53	1.44	2.21	1.87	1.82	1.57	1.69
2	4	4	2.59	2.07	1.77	1.64	2.19	2.11	1.64	1.23
4	4	4	3.19	1.35	1.51	2.63	2.43	2.28	2.15	1.69
5	3	3	1.79	1.43	1.59	2.74	2.01	2.19	1.85	1.58
1	3	3	2.05	1.75	1.41	2.05	2.38	1.52	1.51	1.53
3	5	3	1.97	2.67	1.52	3.09	3.65	2.71	1.96	1.86
3	1	3	1.77	1.81	1.59	2.45	1.58	1.49	1.19	1.71
3	3	5	2.99	1.67	2.09	2.42	1.82	1.97	1.73	1.57
3	3	1	3.88	2.22	1.73	2.35	2.81	2.19	1.89	1.19
3	3	3	2.82	1.67	1.50	3.20	1.85	2.59	1.59	1.48
3	3	3	2.38	2.09	1.48	3.48	2.38	1.99	2.00	1.71
3	3	3	1.98	1.67	1.89	3.28	2.05	2.14	2.00	1.56
3	3	3	2.41	1.99	1.66	2.83	2.99	2.01	1.52	1.48
3	3	3	1.76	1.59	1.52	2.96	2.57	2.21	1.47	1.81
3	3	3	1.76	1.61	1.39	2.47	2.61	1.45	1.46	1.71

Table 19. Yield of dry matter of maize tops grown on the AREC soil under different methods of nutrient placement.

N	P	Zn	ZxPx	ZmbPmb	ZbPb	ZlPl	ZxPl	ZbPl	ZlPx	ZlPb
Levels						g/pot				
2	2	2	2.14	2.57	2.58	2.92	2.32	3.39	2.71	2.28
4	2	2	5.08	4.57	4.24	4.13	4.28	3.92	4.99	4.67
2	4	2	2.52	3.13	2.86	2.89	2.47	3.04	3.61	3.29
4	4	2	5.44	5.02	4.76	4.25	5.27	5.61	4.58	4.97
2	2	4	2.50	2.68	3.07	2.99	2.59	3.07	3.35	2.66
4	2	4	4.95	4.75	4.18	3.50	3.65	5.22	4.15	4.46
2	4	4	3.35	3.02	3.07	2.72	3.03	2.42	2.65	3.46
4	4	4	6.29	5.03	5.03	4.20	4.26	4.68	6.23	2.97
5	3	3	5.07	4.75	4.05	3.90	4.65	4.89	6.06	4.73
1	3	3	2.27	2.07	1.88	1.81	2.61	2.28	2.63	3.66
3	5	3	3.90	4.30	3.90	3.52	4.74	3.42	4.69	4.57
3	1	3	3.79	3.59	3.76	3.52	3.87	3.66	4.25	2.80
3	3	5	4.25	4.54	3.83	3.17	4.58	4.25	3.54	3.27
3	3	1	3.66	3.89	3.68	3.46	4.39	4.54	3.51	4.21
3	3	3	4.50	4.22	3.92	3.64	3.82	4.68	4.55	3.84
3	3	3	4.16	3.52	3.71	3.99	4.09	3.85	3.73	4.49
3	3	3	4.95	4.38	4.14	3.13	4.28	4.77	4.96	3.89
3	3	3	4.43	4.02	4.37	4.28	3.96	3.57	3.66	3.69
3	3	3	4.65	4.61	2.86	3.20	4.41	3.97	5.00	4.01
3	3	3	4.41	3.96	4.01	3.20	4.10	4.84	3.63	4.44

Table 20. Total P concentration of maize tops grown on the Bazouryeh soil under different methods of nutrient placement.

N	P	Zn	ZxPx	ZmbPmb	ZbPb[1]	ZlPl	ZxPl	ZbPl	ZlPx	ZlPb
Levels						Percent				
2	2	2	0.120	0.129	0.164	0.156	0.202	0.257	0.134	0.151
4	2	2	0.175	0.118	0.188	0.153	0.261	0.315	0.175	0.163
2	4	2	0.181	0.143	0.235	0.174	0.251	0.297	0.224	0.149
4	4	2	0.141	0.200	0.238	0.401	0.212	0.398	0.212	0.173
2	2	4	0.159	0.170	0.161	0.339	0.150	0.217	0.226	0.161
4	2	4	0.143	0.115	0.211	0.268	0.249	0.327	0.226	0.202
2	4	4	0.156	0.156	0.296	0.235	0.222	0.304	0.238	0.129
4	4	4	0.219	0.100	0.165	0.510	0.265	0.393	0.225	0.174
5	3	3	0.098	0.184	0.186	0.352	0.280	0.535	0.251	0.204
1	3	3	0.097	0.151	0.146	0.214	0.213	0.380	0.201	0.142
3	5	3	0.175	0.179	0.235	0.665	0.290	0.419	0.229	0.210
3	1	3	0.116	0.095	0.252	0.217	0.169	0.302	0.165	0.192
3	3	5	0.154	0.177	0.241	0.201	0.176	0.336	0.179	0.147
3	3	1	0.117	0.151	0.232	0.258	0.243	0.309	0.218	0.135
3	3	3	0.146	0.137	0.217	0.334	0.285	0.339	0.259	0.147
3	3	3	0.113	0.166	0.247	0.321	0.271	0.362	0.263	0.164
3	3	3	0.139	0.223	0.238	0.330	0.319	0.385	0.249	0.170
3	3	3	0.189	0.175	0.211	0.278	0.233	0.318	0.248	0.140
3	3	3	0.129	0.175	0.200	0.299	0.285	0.336	0.223	0.150
3	3	3	0.119	0.151	0.244	0.259	0.256	0.394	0.227	0.172

[1] Plants harvested from P band.

Table 21. Total P concentration of maize tops grown on the AREC soil under different methods of nutrient placement.

N	P	Zn	ZxPx	ZmbPmb	ZbPb[1]	ZlPl	ZxPl	ZbPl	ZlPx	ZlPb
Levels						Percent				
2	2	2	0.313	0.257	0.283	0.259	0.244	0.186	0.321	0.258
4	2	2	0.315	0.254	0.334	0.324	0.319	0.316	0.274	0.262
2	4	2	0.416	0.239	0.269	0.288	0.310	0.289	0.324	0.212
4	4	2	0.333	0.297	0.314	0.337	0.279	0.286	0.322	0.167
2	2	4	0.256	0.252	0.301	0.258	0.286	0.221	0.374	0.193
4	2	4	0.333	0.278	0.336	0.315	0.395	0.311	0.502	0.212
2	4	4	0.278	0.302	0.370	0.326	0.308	0.261	0.351	0.165
4	4	4	0.257	0.300	0.353	0.413	0.318	0.262	0.373	0.208
5	3	3	0.382	0.301	0.449	0.385	0.332	0.329	0.449	0.249
1	3	3	0.335	0.254	0.326	0.325	0.269	0.272	0.449	0.155
3	5	3	0.385	0.326	0.316	0.312	0.309	0.275	0.448	0.185
3	1	3	0.271	0.256	0.216	0.259	0.255	0.253	0.448	0.096
3	3	5	0.276	0.214	0.251	0.359	0.254	0.246	0.373	0.095
3	3	1	0.288	0.210	0.304	0.248	0.254	0.206	0.377	0.159
3	3	3	0.208	0.209	0.207	0.258	0.256	0.229	0.471	0.147
3	3	3	0.218	0.226	0.227	0.227	0.255	0.231	0.422	0.150
3	3	3	0.218	0.219	0.246	0.233	0.224	0.277	0.377	0.146
3	3	3	0.220	0.212	0.199	0.227	0.256	0.284	0.372	0.146
3	3	3	0.221	0.213	0.275	0.261	0.255	0.202	0.402	0.193
3	3	3	0.221	0.210	0.308	0.257	0.278	0.216	0.437	0.148

[1] Plants harvested from P band.

Table 22. Total Zn concentration of forty days old maize tops grown on the Bazouryeh soil under different methods of nutrient placement.

N	P	Zn	ZxPx	ZmbPmb	ZbPb[1]	ZlPb	ZxPl	ZbPl	ZlPx	ZlPb
Levels						ppm				
2	2	2	64.9	38.7	25.1	52.8	44.4	71.8	99.0	70.0
4	2	2	107.9	76.9	60.3	71.1	47.7	74.9	47.3	48.4
2	4	2	55.4	59.3	61.9	38.7	56.9	61.6	83.5	86.6
4	4	2	86.9	66.2	50.0	62.8	31.0	55.8	69.0	37.7
2	2	4	93.5	73.0	54.5	74.2	40.1	37.8	119.8	113.7
4	2	4	102.9	56.6	51.5	103.1	61.9	85.4	74.7	109.4
2	4	4	69.9	46.7	80.6	55.6	47.1	21.8	124.5	186.2
4	4	4	94.1	76.1	45.7	180.0	81.3	80.9	80.4	220.3
5	3	3	121.7	80.3	41.3	123.0	65.2	72.9	134.8	280.7
1	3	3	93.4	48.2	20.7	75.5	29.8	57.0	63.9	100.5
3	5	3	56.4	60.7	19.3	87.7	22.1	44.5	59.8	95.9
3	1	3	86.7	85.9	47.8	122.0	54.7	47.7	103.9	109.3
3	3	5	101.0	119.6	55.8	174.8	44.0	65.7	127.3	302.4
3	3	1	55.8	50.7	51.3	85.4	28.8	46.1	47.5	36.8
3	3	3	69.9	49.2	49.6	82.5	31.1	56.6	75.6	98.0
3	3	3	81.7	53.1	44.7	62.0	38.6	66.1	58.4	95.7
3	3	3	67.6	47.5	50.1	72.9	42.8	52.9	59.8	88.6
3	3	3	78.8	38.9	49.8	86.7	28.2	64.4	79.9	99.2
3	3	3	63.8	41.5	46.2	79.5	42.3	54.0	78.8	93.6
3	3	3	61.4	54.5	40.0	62.2	44.6	57.1	73.1	102.7

[1] Plants harvested from P band.

Table 23. Total Zn concentration of maize tops grown on the AREC soil under different methods of nutrient placement.

N	P	Zn	ZxPx	ZmbPmb	ZbPb[1]	ZlPl	ZxPl	ZbPl	ZlPx	ZlPb
Levels						ppm				
2	2	2	43.1	33.6	37.1	31.6	31.1	26.8	73.9	25.8
4	2	2	33.5	41.1	43.9	47.1	56.0	35.2	68.6	43.9
2	4	2	24.6	26.4	44.2	33.8	41.3	12.1	53.5	49.9
4	4	2	21.5	33.4	43.9	41.6	41.3	19.9	46.3	70.9
2	2	4	76.8	32.8	39.9	98.9	50.5	27.1	94.5	12.3
4	2	4	66.6	50.3	67.3	68.9	46.4	40.3	76.6	69.5
2	4	4	61.0	28.4	46.6	63.2	30.6	48.1	88.6	45.7
4	4	4	36.2	39.0	59.0	51.6	96.1	55.8	105.2	77.3
5	3	3	59.1	48.9	25.0	59.3	57.7	57.7	120.8	81.5
1	3	3	34.5	33.0	27.3	39.4	26.6	31.7	72.2	52.1
3	5	3	27.6	20.6	46.0	44.9	30.5	41.8	68.4	58.1
3	1	3	37.7	23.6	44.0	59.9	30.4	35.2	64.6	76.6
3	3	5	42.6	40.2	130.0	130.4	41.8	49.1	41.5	102.5
3	3	1	31.9	30.2	42.6	19.8	25.4	47.1	67.2	21.9
3	3	3	32.3	28.1	21.8	37.2	50.0	25.9	70.2	64.4
3	3	3	34.5	28.4	20.1	51.3	35.3	42.7	80.7	42.0
3	3	3	29.6	27.9	25.3	37.2	35.0	26.6	85.0	41.9
3	3	3	29.7	26.4	26.3	49.5	30.7	43.5	64.3	61.9
3	3	3	27.5	26.7	23.0	43.8	34.8	31.8	94.9	74.2
3	3	3	33.9	26.4	25.9	53.4	29.3	37.1	93.9	48.6

[1] Plants harvested from P band.

Table 24. Total Mn concentration of maize tops grown on the Bazouryeh soil under different methods of nutrient placement.

N	P	Zn	ZxPx	ZmbPmb	ZbPb[1]	ZlPl	ZxPl	ZbPl	ZlPx	ZlPb
Levels						ppm				
2	2	2	52.5	54.4	57.9	48.9	55.6	87.6	61.2	57.9
4	2	2	77.7	88.2	69.3	46.4	72.2	108.2	70.0	69.7
2	4	2	63.7	49.4	100.0	51.8	65.7	93.3	63.2	44.3
4	4	2	87.4	90.9	60.0	77.1	60.7	98.7	73.9	60.0
2	2	4	60.8	67.3	75.8	64.0	46.0	44.3	58.9	51.7
4	2	4	91.7	58.6	75.8	60.7	51.9	70.9	89.1	84.0
2	4	4	53.4	64.8	74.5	46.7	53.5	67.3	74.1	51.4
4	4	4	81.3	63.7	66.9	79.7	71.2	74.5	84.3	65.3
5	3	3	75.0	82.1	52.0	95.9	63.0	70.6	97.1	77.5
1	3	3	62.0	50.3	65.2	59.6	47.9	66.5	62.4	60.3
3	5	3	63.9	75.8	68.1	77.1	68.9	72.4	83.7	67.5
3	1	3	66.6	89.9	85.6	56.1	64.9	80.1	81.4	75.4
3	3	5	52.1	88.1	93.9	47.6	45.7	68.6	62.0	62.0
3	3	1	57.8	64.9	67.5	63.2	92.9	86.7	78.8	76.1
3	3	3	54.4	56.1	68.5	58.6	91.6	73.1	72.7	66.3
3	3	3	59.1	86.9	55.9	58.0	81.9	74.2	63.8	79.9
3	3	3	57.9	68.1	66.2	73.4	77.5	61.9	69.5	75.7
3	3	3	62.6	75.4	65.8	58.1	73.2	69.2	84.9	75.9
3	3	3	53.4	91.4	66.2	57.2	81.2	75.8	63.8	88.5
3	3	3	64.9	76.6	66.0	44.4	80.4	64.6	60.5	69.5

[1] Plants harvested from P band.

Table 25. Total Mn concentration of maize tops grown on the AREC soil under different methods of nutrient placement.

N	P	Zn	ZxPx	ZmbPmb	ZbPb	ZlPl	ZxPl	ZbPl	ZlPx	ZlPb
Levels						ppm				
2	2	2	59.9	48.3	70.9	69.0	52.0	60.7	57.6	35.8
4	2	2	88.0	86.5	91.5	109.8	83.0	98.2	58.3	84.8
2	4	2	50.7	43.9	75.0	51.0	66.4	67.2	63.8	40.6
4	4	2	68.5	84.4	98.9	91.7	84.8	88.0	66.6	55.6
2	2	4	63.4	42.4	50.5	47.4	66.8	65.8	44.1	53.7
4	2	4	95.0	57.1	80.7	103.4	97.8	68.2	83.3	86.2
2	4	4	52.7	53.6	60.5	67.9	45.4	72.2	55.4	58.0
4	4	4	78.8	64.9	92.4	102.9	93.2	86.7	67.9	66.9
5	3	3	83.7	83.1	89.4	98.3	121.2	83.7	79.6	79.0
1	3	3	43.2	57.6	69.7	58.5	62.6	66.9	44.7	46.1
3	5	3	54.1	51.0	97.0	72.7	65.0	68.8	50.2	65.7
3	1	3	48.5	60.0	66.0	120.2	83.9	98.7	72.9	62.9
3	3	5	48.5	47.6	100.8	73.5	72.7	69.7	63.3	49.2
3	3	1	61.5	49.9	72.4	68.0	78.8	80.3	84.6	55.9
3	3	3	55.7	31.0	62.3	71.5	87.6	60.9	52.7	47.3
3	3	3	42.4	57.1	89.7	45.4	78.0	59.3	55.5	66.8
3	3	3	38.4	41.7	87.6	72.7	63.9	75.9	54.6	58.9
3	3	3	41.2	53.9	59.9	54.2	69.0	71.1	58.6	42.7
3	3	3	52.6	49.0	96.3	72.6	66.6	62.7	54.6	42.9
3	3	3	52.6	51.5	87.5	65.8	74.5	83.0	47.7	50.7

Table 26. EDTA extractable Zn and 0.5 M $NaHCO_3$ extractable P of soils treated with ZxPx method of nutrient placement.

N	P	Zn	AREC P	AREC Zn	Bazouryeh P	Bazouryeh Zn
Levels			ppm			
2	2	2	17.0	9.2	7.8	9.6
4	2	2	11.2	9.0	8.4	13.1
2	4	2	39.0	9.0	28.7	16.9
4	4	2	38.5	12.8	23.8	12.4
2	2	4	11.5	32.2	10.2	31.9
4	2	4	17.3	35.2	9.8	33.0
2	4	4	59.0	48.9	19.8	47.6
4	4	4	42.0	31.5	17.5	33.4
5	3	3	23.5	22.1	10.3	16.4
1	3	3	16.7	17.3	11.3	20.6
3	5	3	73.7	18.8	35.8	20.3
3	1	3	10.3	21.9	7.30	20.3
3	3	5	22.3	30.0	26.6	82.5
3	3	1	24.4	7.5	20.0	9.0
3	3	3	31.5	18.7	16.8	20.1
3	3	3	29.3	16.5	14.5	19.9
3	3	3	27.0	17.3	16.5	20.2
3	3	3	27.3	16.5	17.0	20.6
3	3	3	27.0	16.6	15.0	21.0
3	3	3	29.3	17.3	14.3	20.4

Table 27. Total Mn, Zn, Ca and P concentrations of roots grown under ZmbPmb method of nutrient placement.

N	P	Zn	AREC Mn	AREC Zn	AREC P	AREC Ca	Bazouryeh Mn	Bazouryeh Zn	Bazouryeh P	Bazouryeh Ca
Levels			ppm		Percent		ppm		Percent	
2	2	2	472	140	0.158	2.87	157	127	0.142	9.39
4	2	2	455	115	0.212	3.48	168	152	0.142	5.39
2	4	2	321	94	0.180	2.96	133	116	0.138	5.77
4	4	2	540	165	0.380	2.45	143	134	0.440	7.14
2	2	4	369	129	0.137	5.19	194	132	0.135	9.79
4	2	4	644	360	0.294	3.75	154	236	0.256	5.03
2	4	4	739	331	0.207	4.20	180	192	0.276	8.62
4	4	4	401	142	0.196	2.68	142	224	0.196	6.35
5	3	3	675	364	0.298	7.70	273	316	0.669	11.68
1	3	3	401	167	0.247	1.62	160	151	0.136	7.15
3	5	3	354	163	0.189	3.79	151	132	0.188	6.60
3	1	3	470	122	0.177	2.85	217	146	0.133	9.51
3	3	5	350	282	0.184	2.80	167	153	0.142	8.76
3	3	1	492	258	0.250	3.11	140	157	0.375	4.04
3	3	3	310	100	0.153	3.57	134	167	0.155	7.04
3	3	3	264	109	0.150	3.27	160	172	0.216	9.35
3	3	3	470	126	0.186	3.98	210	186	0.167	9.38
3	3	3	399	115	0.170	4.75	179	133	0.139	8.16
3	3	3	547	132	0.187	3.18	164	147	0.149	7.70
3	3	3	391	130	0.210	4.82	178	167	0.176	7.42

Table 28. Total N concentration of maize tops grown on the AREC soil under ZbPl and ZbPb methods of nutrient placement.

N	P	Zn	ZbPb[1]	ZbPl
Levels			Percent	
2	2	2	2.55	1.65
4	2	2	2.95	3.35
2	4	2	2.97	1.66
4	4	2	3.00	2.95
2	2	4	2.47	1.36
4	2	4	2.53	3.60
2	4	4	2.40	1.46
4	4	4	2.80	3.37
5	3	3	2.65	3.92
1	3	3	1.95	1.60
3	5	3	3.07	1.96
3	1	3	3.20	1.99
3	3	5	3.25	1.85
3	3	1	2.89	1.75
3	3	3	2.78	2.19
3	3	3	2.75	1.56
3	3	3	2.70	1.77
3	3	3	2.90	1.90
3	3	3	2.40	1.50
3	3	3	2.70	1.50

[1] Plants harvested from P band.