RESPONSE OF SEVERAL STRAINS OF CORN (*Zea mays* L.) TO ZINC DEFICIENCY

by

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INTRODUCTION

Many reports of zinc deficiency in various crops have been made, since 1926. The deficiency was first identified within the United States in citrus orchards on peat soils of Florida. Zinc deficiencies of various crops have also been reported in soils of extremely leached areas which are continuously cultivated in central, north and northwestern Florida and on calcareous soils, particularly if they have been badly eroded or scalped.

Zinc is one of the few minor element deficiencies that has been positively identified in corn in more than one state. The deficiency has generally occurred on the western edge of the corn belt, in areas west of the Mississippi River, especially the areas of western Minnesota, the Dakotas, Kansas, Nebraska and Wisconsin. Zinc deficiency in corn has been particularly apparent during cold, wet springs. However, if the symptoms were not severe, they usually have disappeared as the weather warmed up and the soils dried out.

Loss of corn yield due to zinc deficiency has not been positively estimated. It may be expected that the yield reduction would become more significant as the soils gradually decrease their supply of minor elements and as corn yield levels continue to be increased. The practice of fertilizer placement and the increased use of more refined fertilizers may accentuate the zinc deficiency problem. Due to the potentially large areas in which zinc deficiency may be a problem, methods need to be developed to correct this situation. One possible method of overcoming small deficiencies is to breed varieties that are resistant or tolerant, that is less sensitive to low levels of zinc.

In this study the objectives were to determine the various characteristic zinc deficiency symptoms exhibited by genetically different lines of corn and whether these symptoms have any association to the levels of zinc and phosphorus in the plant tissue. Attempts were also made to determine differential accumulations of zinc and phosphorus as exhibited by some inbred lines and hybrids in growth chambers and in the field. Other objectives were, to determine whether high phosphorus limits the uptake of zinc, and whether genetic resistance or tolerance to zinc deficiency could be obtained in corn.

LITERATURE REVIEW

A number of studies concerned with the visual symptoms of zinc deficiency and toxicity have been reported during the past three decades. Zinc content of leaves and other plant parts has also been investigated in various crops. Barnette et al. (1936) described the symptoms shown by seedlings of corn as follows:

> "In effected soil areas symptoms of white bud begin to appear within a week or two after emergence of the seedlings. The full development of the chlorophyll in the older leaves of the seedlings scarcely takes place before light yellow streaks appear between the veins. Small white spots of inactive or dead tissues develop rapidly in the leaves, while small white areas that never have chlorophyll are present. The internodes of the plants are shortened and growth stunted."

Several reports also indicated that corn lines having the genetic factor for pigment production produced purple coloration of the leaves, when the zinc deficiency symptom was acute (Barnette et al., 1936; Thorne, 1957). Fruit growers often reported zinc deficiency expressed as little leaf, rossette, die back, bronzing, yellows and white bud. Peaches were often reported to be flattened or pointed and reduced in

size.

The essentiality of zinc for plant growth and development was shown by Chandler et al. (1931, 1932) working with peaches, by Johnston (1933), and by Parker (1934) working with citrus. Hoagland et al. (1935) and Chapman et al. (1937) were able to produce zinc deficiency symptoms in their controlled cultures, similar to those found in the field.

Some investigators suggested that the reduced growth of zinc deficient plants was due to the production or activity of growth reducing plant auxins. Skoog (1940) reported that only traces of auxin or no auxin could be extracted from zinc deficient plants as measured by diffusion into agar blocks. The auxin content of the control plants was in excess of that required for maximum stem elongation. The decrease of auxin in the zinc deficient plants took place before any zinc deficiency symptoms were apparent. Such plants when treated with zinc applications responded by synthesizing auxins in large concentrations within one to a few days, but resumption of normal growth was delayed for a longer period. Zinc deficient plants inactivated indole-3-acetic acid more rapidly than control plants. Also a higher oxidation capacity in zinc deficient plants was noted; this was believed to be correlated to auxin destruction. Skoog concluded that zinc was required for the maintenance of auxin in an active state rather than for its synthesis.

Tsui (1948) also studied auxin content and its relation to zinc deficiency on tomato (Lycopersicon esculentum Mill. var. John Baer). Tsui found two kinds of auxins and called them acid-stable and alkali-

labile, and alkali-stable and acid-labile. In normal plants the acid-stable and the alkali-labile types increased as the plants matured while the alkali-stable and the acid-labile types remained constant. Also, prior to the appearance of visual deficiency symptoms, the tryptophane content of the zinc deficient plants greatly decreased. Tsui concluded that zinc was required directly for the synthesis of tryptophane and indirectly for the synthesis of indo-acetic acid.

Quinlan-Watson (1951) working on oats (Avena sativa var. Algerian) and subterranean clover (Trifolium subterranean L.) had also indicated that zinc deficiency interfered with tryptophane synthesis. He further suggested that zinc was important in regulating aldolase activity. In zinc deficient plants, there was a breakdown of normal carbohydrate metabolism due to the decrease of aldolase.

Carbonic anhydrase had been said to be associated with zinc in plants. Wood and Sibly (1952), working with oats, reported that in zinc deficient plants, carbonic anhydrase was restricted by the blocking of metabolic reactions forming proteins, and not by the lack of sufficient zinc, to activate the apoenzyme. Other writers were unable to associate zinc with this enzyme (Kondo, Taizo and Chiba, 1952).

Reeds (1941) believed that the abnormalities of shoot growth appearance of apricot buds could be explained by the appearance and disappearance of phenolic compounds. With zinc deficient plants it was apparent that substances believed to be tannins were replaced by phloroglucinol, especially in the more active cells. The normal appearance of apical meristems were free of phenolic compounds. Reeds further reported that the principal effect of zinc deficiency on trees

appeared to be reflected in the condition of hypoplasis created, the polarization of cell content, and the restriction of cell multiplication in the apical region. In his subsequent work, Reeds (1946) reported that leaves of zinc deficient plants contained less sucrose and starch than normal non-deficient leaves but they contained more reducing sugars. He believed that one of the essential enzyme systems had failed or was blocked resulting in the accumulations of reducing sugars.

Zinc content of plant tissues has been investigated by various workers. There were indications that zinc readily accumulates in the leaves of many plants in considerable amounts. The great spread in zinc content of leaves would provide the basis for determining the status of a particular crop and also its critical level. Lyman and Dean (1942) reported a relatively decreased zinc content of the growing points of zinc deficient pineapple plants as compared to the zinc content of other plant tissue. The decrease of zinc content of the growing points was related to the zinc deficiency. Lyman and Dean further reported that merismetic tissues of normal plants contained the highest concentration of zinc.

Boawn and Viets (1952) reported zinc deficiency in Ranger alfalfa. The deficiency occurred on a very fine sandy loam that had been leveled for irrigation. The deficient plants were noticeably shorter than non-deficient plants growing on adjacent uncut areas. Zinc deficient plants had an average zinc content of 8.0 ppm, while samples of the plants showing normal growth averaged 13.8 ppm zinc.

Viets et al. (1953), working on corn, sampled leaves at tasseling time, reported that zinc deficient plants had leaf zinc content of

9.00-9.30 ppm and normal plants had an average of zinc content 31.10-36.60 ppm. They also reported that a zinc concentration of 15 ppm within the mature leaves (6th leaf from the base or 2nd leaf from node below upper ear node), when measured at time of pollen shedding, was sufficient to produce yields ranging from 100 to 125 bushels per acre without showing deficiency symptoms. However, Brown and Krantz (1966) in their investigation of source and placement of zinc and phosphorus for corn, noted that the best yielding treatment which did not show any zinc deficiency symptoms had a leaf zinc content of only 6.5 ppm.

Viets et al. (1954) reported zinc deficiency symptoms of interveinal chlorosis and death of leaf tissue in field grown Red Mexican beans. Visual deficiency symptoms were common in plants whose zinc content of mature leaves or plant tops were about 20 ppm. The chlorosis was restricted to the small veins and mesophylls when the zinc content of leaves was 12.8 ppm. When the zinc content was 11.4 ppm chlorosis appeared in the midribs and petioles as well.

Riceman and Jones (1956) observed zinc deficiency on subterranean clover (Trifolium subterraneum L.) thirty-three days after germination when grown in zinc free culture solution. The plant dry weight was less than 100 mg., and the zinc content was less than 1.5 ug. The last deficiency symptoms observed occurred 162 days after germination with plant dry weight and zinc content each in excess of 35 g. and 350 µg. respectively. They also reported that the zinc concentration of most affected plants on a plant dry matter basis lies between 15 to 20 ppm.

Brown (1965), in his investigation of zinc content of hop leaves, discovered that healthy high producing hop plants had leaf zinc content

above 15 ppm at bloom stage. Leaves from plants with zinc deficiency symptom generally had zinc concentration below 12 ppm. The critical level for zinc in hop plant was said to be between 12 to 15 ppm.

High soil phosphate level or heavy phosphate fertilization appeared to accentuate zinc deficiency in various crops. Burleson et al, (1961) observed phosphorus-induced zinc deficiency in corn and sweet corn. They also obtained phosphorus-induced zinc deficiency in red kidney bean (Phaseolus vulgaris L) in their glass-house studies. Burleson (1965) working with fibre flax postulated that under the conditions of phosphorus-induced zinc deficiency the immobilization of zinc by phosphorus occurred within the roots and possibly at the root surfaces. Burleson's conclusion was similar to that of Laugin et al. (1962), who concluded that the interference of zinc absorption by plant roots in the presence of high concentrations of the other elements was due to root surface phenomenom. The element occurring in the highest concentration blocked the absorption of the less concentrated element. Several other investigators also reached similar conclusions (Millikan, 1947; Loneragen, 1951; Ellis et al., 1964; and Terman et al., 1966). De Remer et al. (1964), working on the nature of zinc deficiency in field beans, found that zinc deficiency was due to the inactivation of soil zinc by decomposing organic matter and the microflora. However, other writers found no significant interaction between high phosphorus and zinc absorption by plants. Boawn et al. (1954) and Boawn (1965), working on effect of phosphate fertilizers on zinc nutrition and on sugar beet-induced zinc deficiency respectively, believed that the occurrence of zinc deficiency could not be attributed to excess

phosphorus. Thorne (1957) and Seatz et al. (1959) reached similar conclusions.

Low temperature had been reported to accentuate zinc deficiency in crops. Ellis et al. (1964) reported that yield, zinc concentration in the plant tissue, and total zinc uptake by corn were decreased when soil temperature was decreased from 75 to 55° F. Total zinc uptake was reduced from 310 to 73 µg. per pot. This finding was based on the green-house study on Wisner clay loam using Michigan hybrid corn number 250. This report confirmed the observations of various workers who stated that low temperature and wet soils during the early part of the growing season increased zinc deficiency symptoms in crops.

Sugar beets had been reported to induce zinc deficiency in subsequent crops. It was believed that sugar beets altered the zinc nutritional status of the soil, such that corn or beans, following them in the cropping sequence would be severely zinc deficient (Boawn, 1965). No conclusion was stated but Boawn reported that the zinc deficiency could not be attributed to excess phosphorus or excessive removal of zinc by sugar beets. Ellis et al. (1964) found that yield of field beans was reduced approximately 50 per cent when the crop followed sugar beets grown in the Saginaw Bay area of Michigan on a calcareous Kawkawlin-Wisner loam to which 175 or 350 pounds of phosphorus per acre had been added. It was believed that the reduction in yield was due mainly to phosphorus-induced zinc deficiency.

Soil pH had also been reported as a factor that caused zinc deficiency in several crops. Camp (1945) reported that as the soil pH increased, zinc availability decreased. He defined the critical pH

value as ranging between 5.5 and 6.5. Massey (1957), working with 34 silt loam soils of Kentucky, found that zinc uptake by corn in pots was related to pH and to the amount of zinc extracted by him. The following formula was developed to estimate or predict potential zinc deficiencies:

$$\hat{Y} = 99.2 - 12.2\ X_1 + 10.9\ X_2$$

where X_1 is pH; X_2 is the extractable zinc in ppm of dry soil; and $\hat{Y}$ is the calculated zinc uptake. Where $\hat{Y}$ was greater than 40, no zinc deficiency would be obtained. Lower $\hat{Y}$ values would give zinc deficiency.

Apart from phosphorus, nitrogen has been reported to induce zinc deficiency. Reuther and Smith (1950) working on orange, and Ozanne (1955) working on subterranean clover reported nitrogen-induced zinc deficiencies. Viets et al. (1957) found that $NaNO_3$ decreased zinc uptake, but NH_4NO_3 and $(NH_4)_2SO_4$ increased it. Probably the phenomenon was related to the soil pH changes, or due to cation effects rather than nitrogen itself.

Control of zinc deficiency has been carried out with success. Barnette et al. (1936) obtained a good response of correcting zinc chlorosis of corn by the application of 10 to 20 pounds of zinc sulfate ($ZnSO_4 \cdot 7H_2O$) per acre on a Florida medium fine sand. Folia spraying using zinc sulfate has been widely used on various crops. Viets (1951) corrected zinc deficiency on corn using a spray containing 0.5% $ZnSO_4 \cdot 7H_2O$ and 0.25% $Ca(OH)_2$ while corn was six inches tall. However, Viets et al. obtained no response from corn having leaf zinc content of 15 ppm in their later study (1953), indicating that leaf zinc content of 15 ppm was adequate for development and growth. Zinc chelates applied to soils

have shown promise with certain crops. Boawn et al. (1957) compared zinc uptake from soils in pots when chelate, zinc sulfate, zinc oxide, zinc carbonate, zinc phosphate, zinc frits and blast-furnace slag were applied. Zinc chelate gave the best response. Brown and Kratz (1966) reported that where moderate mixing and incorporation of zinc fertilizer into the root zone was done, Zn SO_4 and organic sources such as Zn EDTA were equivalent in their effectiveness for the correction of zinc deficiency. However, if the fertilizer was banded under the seeds, Zn EDTA was more effective. Granulation or spot placement or both greatly reduce the effectiveness.

When volunteer weeds and grasses were allowed to grow for one or two years between corn crops, severity of zinc deficiency was reduced (Barnette et al., 1936). Alfalfa cover crops in orchards has been reported to prevent or decrease zinc deficiency. Millikan (1953) suggested that alfalfa roots might solubilized zinc and help other plants to obtain more.

Evidence for differential accumulation of elements by crops was reported by some investigators. Plant species could be classified as high or low chemical element accumulators. Sayre (1955) reported differences in element content between inbred lines of corn. Gorsline et al. (1961) reported that concentrations of calcium, magnesium and potassium were highly heritable. Thomas (1963), working on the chemical element accumulation in corn, reported that differential accumulation of elements in corn was under partial genetic control. He also reported that differential accumulation of some elements in leaf tissue was established early in the life of the plant, and that accumula-

tion in grain was not related to differential accumulation in leaf tissue on a limited sample of genotype. Massey and Loeffel (1966) believed that variation among inbred lines in the zinc content of corn kernel was due to variation in zinc translocation during grain formation. The high kernel zinc line exhibited a high uptake and high translocation, while the low kernel zinc line exhibited low uptake and low translocation.

MATERIALS AND METHODS

This study was divided into two parts, the growth chamber study and the field study.

Growth chamber study:

Ten inbred lines and twenty-four single crosses were used in this study. Nine seeds from each line were planted in washed sand contained in six-inch plastic pots. One week after sowing, the stands were thinned to six per pot. One pot of each line was treated every four days with 250 ml. of Hoagland solution[1], containing KNO_3 (5mm), $Ca(NO_3)_2$ (5mm), $MgSO_4$ (2mm), and KH_2PO_4 (1mm). Micronutrients containing 2μm $ZnSO_4 \cdot 7H_2O$ per liter of final solution were supplied with the macronutrient solution as suggested by Johnson et al.[2,3] Two sets of plants of each line were provided simultaneously with a similar nutrient solution containing 10 mm KH_2PO_4; pH of the solution was 5.5. Double dis-

[1]Hoagland, D. R., and W. C. Snyder. 1933. Proc. Amer. Soc. Hort. Sci. 30:288.

[2]Johnson, C. M., et al. 1957. Plant and Soil 8:337.

[3]See Appendix for details of elements used.

tilled water was provided as needed to bring the medium to field capacity at each treatment. The plants were kept in growth chambers at 30°C during the day and 20°C during the night and with a 16-hour light period. Relative humidity in the chambers was 39%. Light intensity was approximately 0.5 gram-cal./cm^2/ minute. Zinc deficiency symptoms on all lines were periodically noted throughout the study.

Leaves of all the lines were sampled twenty-eight days after emergence for analysis by removing them at the collar attachment and drying them at 70°C to constant weight. The leaves were then weighed, ground to 40-mesh size, and redried at 70°C. Seeds from the same sources used in the study were similarly ground and dried. The roots of each line for both treatments were also examined at the end of the experiment.

One-gram samples of leaves of each treatment and the seed source were dry ashed by increasing the temperature from 200° to 400° to 600°C in two-hour steps. After ashing, the samples were dissolved in 0.1 N HCl, filtered through Whatman number 2 paper, washed thoroughly and adjusted to 25-ml. volume with 0.1 N HCl. Phosphorus was determined on one-ml aliquots by Elon-acid molybdate procedure.[1] The optical density of the color complex was determined at 660 mμ, using the Beckman Spectrophotometer model DB. Zinc was determined with the Perkins-Elmer model 303 Atomic Adsorption Spectrophotometer at 215 mμ.[2]

Field study:

Two tests of twenty-six single crosses and six double crosses

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[1]Fiske and Subbarow. 1915. J. Biol. Chem. 66:375.

[2]See Appendix for detail.

were planted on June 1, 1966, on the Kansas State University Agronomy Farm and the Ashland Agronomy Farm. A randomized complete block design with four replications was used. Each plot consisted of two rows, three feet apart and contained twelve plants spaced at one foot intervals within each row. No fertilizer treatment was applied to the test at the KSU Agronomy Farm. Two fertility treatments were applied to the test at the Ashland Agronomy Farm. A high level of phosphorus was applied to two replications using a rate of 100 pounds per acre of 45% double super phosphate. The other two replications in the test received 10 pounds per acre of elemental zinc in the form of zinc sulfate. A uniform rate of nitrogen, 100 pounds per acre, was applied to the entire test using ammonium nitrate. All fertility treatments were applied shortly after emergence of the seedlings.

At tasseling time, ten leaves were randomly sampled from each plot by removing them at the collar attachment. The leaves were taken from the first or second node above the ear shoot of each plant sampled. Zinc deficiency symptoms of each line were noted and ranked from 0 to 4; 0 indicating no visible zinc deficiency symptom. Zinc and phosphorus determinations were carried out following the same procedure that was outlined for the growth chamber study.

RESULTS AND DISCUSSION

Patterns of susceptibility and resistance:

The inbred lines and hybrid crosses of corn tested in this study exhibited different degrees and patterns of zinc deficiency symptoms under field and growth chamber conditions. In the growth chamber

studies, the earliest visual symptoms exhibited by the susceptible lines and crosses were either white chlorosis at the base of the shoot or purple coloration along the veins of the shoot followed by purple spots. Inbred lines K55 and K724 for example, showed the earliest zinc deficiency symptom of white bud which occurred one week after emergence. Inbred K786 also showed the white bud symptom, but scorching and necrosis of the affected part followed quickly afterwards. Susceptible single crosses also exhibited a similar pattern. As the zinc deficiency progressed, the severity of the symptoms again varied from line to line, Plate I, Fig. 1.

Single cross K63 x K740 for example, developed necrosis of the leaves followed by death of the plants. Many of the susceptible lines showed marked stunting, with enlargements of the nodes and shortening of the internodes, resulting in a rosette pattern which differed from the leaf chlorosis and necrosis. One line K55 exhibited such a rosette pattern, but later recovered and developed normal nodes and internodes towards the end of the experiment, Plate I, Fig. 2. Other lines, for example, H28, did not exhibit early zinc deficiency symptoms, either by chlorosis or stunting, Plate II, Fig. 1. However, towards the end of the experiment, purple coloration appeared, followed by necrosis of the leaves and death of the plants which occurred soon afterwards, Plate II, Fig. 2. Some single crosses also appeared to exhibit tendencies similar to K55 and H28. Table 1.

It was observed that single-cross combinations involving inbreds which produced purple coloration under severe zinc deficiency also exhibited purple coloration symptoms. H28, for example, produced purple

EXPLANATION OF PLATE I

Fig. 1. A view of one side of the growth chamber showing some lines and hybrids of corn under study. Note the various zinc deficiency symptoms exhibited by the plants. Pots were completely rerandomised in the growth chamber every four days.

Fig. 2. Inbred line K 55 in the growth chamber. The plants on the right were under high phosphorus treatment, and those on the left were under normal nutrient solution treatment. The photograph was taken just before the plants were harvested. Note that plants under both treatments had begun to recover. Young leaves started to turn green especially at the base. One plant under high phosphorus treatment began to elongate quickly and showed normal growth.

PLATE I

Fig. 1

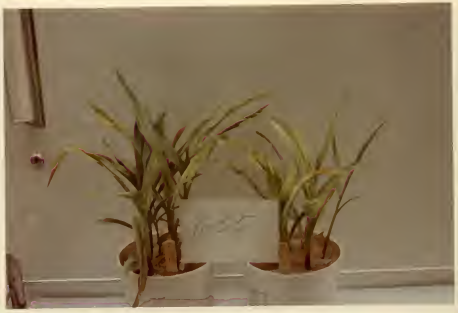

Fig. 2. K 55

EXPLANATION OF PLATE II

Fig. 1. Inbred line H 28 in the growth chamber four days before harvest. Plants on the right received high phosphorus treatment. Control plants were on the left. This line showed early resistance to zinc deficiency.

Fig. 2. Inbred line H 28 in the growth chamber, at the time of harvest. Both the control plants (left) and the plants under high phosphorus treatment exhibited severe zinc deficiency symptom, by producing purple coloration.

PLATE II

Fig. 1. H 28

Fig. 2. H 28

Table 1. Zinc and phosphorus level of leaves of 24 single crosses grown in growth chambers under normal nutrient solution and high phosphorus nutrient solution.

Entry no.	Hybrids	Zinc level (ppm)		Phosphorus level (%)		Symptom
		N.sol.	H.P.sol.*	N.sol.	H.P.sol.*	
1.	K201G x K55	6.33	4.65	0.20	0.57	R
2.	K201G x K786	6.78	6.79	0.23	0.59	ER
3.	H28 x K41	6.80	9.70	0.24	0.89	R
4.	K745 x K801	7.01	9.64	0.19	1.13	S
5.	K63 x K740	7.30	9.80	0.24	0.94	S
6.	H28 x K699	7.37	7.45	0.21	0.83	ER
7.	K698 x K699	7.59	9.29	0.28	1.04	S
8.	K166 x K55	7.67	6.60	0.33	0.71	LR
9.	K55 x K741	7.80	8.20	0.21	0.58	S
10.	K741 x H28	8.19	9.31	0.24	0.97	S
11.	K774 x MoIw	8.34	8.95	0.26	0.93	ER
12.	K41 x K742	8.40	8.10	0.28	0.38	S
13.	Ky211 x 33-16	8.57	8.96	0.29	0.99	S
14.	K798 x Ky27	9.64	9.99	0.29	1.12	S
15.	K745 x K802	9.72	7.44	0.24	0.80	S
16.	K61 x K740	9.72	7.59	0.32	1.04	S
17.	K724 x K731	9.80	8.90	0.21	0.63	S
18.	K731 x K776	10.40	9.60	0.22	0.97	S
19.	K55 x K699	10.40	11.00	0.34	0.62	S
20.	K810 x Ky209	10.48	8.23	0.37	1.13	S
21.	K729 x K166	10.57	7.81	0.25	1.04	S
22.	K730 x C149B	10.65	7.37	0.25	0.85	S
23.	K755 x K786	11.30	9.00	0.24	0.95	S
24.	H28 x K55	11.80	10.90	0.23	0.68	R

N.sol. = Normal nutrient solution
H.P.sol. = High phosphorus nutrient solution
* = Average of two replicates
R = Resistance
S = Susceptible
ER = Early resistance
LR = Late resistance

coloration under severe zinc deficiency, and generally any single cross having H28 as one of the parents produced purple coloration under severe zinc deficiency: K741 x H28, H28 x K699 etc., Plate III, Fig. 1. Table 1. Lines that produced yellow coloration probably do not have the genetic constituent for purple pigment production, both in inbreds and in single-cross combination. K166 and K745 x K802, Plate III, Fig. 2. Apart from observed deficiency symptoms, it was noted that susceptible plants had leaves which were brittle and soapy to the touch, especially at the leaf-collar attachment.

A few inbreds and single crosses gave variable degrees of zinc deficiency symptoms even though provided with normal nutrient solution (Hoagland solution). Inbred K166 and single cross H28 x K699, for example, showed zinc deficiency symptoms both in the normal nutrient solution and in high phosphorus nutrient solution, although the degree of severity was more apparent in high phosphorus solution, Plate III, Figs. 1 & 2. Such response may indicate that what was termed normal nutrient solution (with 2 µm Zn) did not have enough or adequate zinc for these particular lines or hybrids, and hence resulted in the expression of zinc deficiency symptoms.

Similar zinc deficiency symptoms were also observed on lines grown in the field. Those lines that produced purple coloration under severe zinc deficiency in growth chambers also exhibited purple coloration in the field, Plate IV, Fig. 1. Stunting with enlarged, shortened internodes were also observed. In addition, chlorosis and necrosis of the leaves typical of zinc deficiency were encountered, Plate IV, Fig. 2.

EXPLANATION OF PLATE III

Fig. 1. Single cross H 28 x K 699 in the growth chamber at time of harvest. Very severe zinc deficiency exhibited by plants under high phosphorus treatment (right). Note the stunting of the plants and purple coloration produced. Control plants on the left also showed zinc deficiency symptom but no stunting.

Fig. 2. Inbred K 166 in the growth chamber at the time of harvest. Very severe zinc deficiency symptoms exhibited by the plants under high phosphorus treatment (right). Note stunting, chlorosis and necrosis of the leaves on the right. No purple coloration produced in this inbred. Control plants on the left exhibited slight zinc deficiency symptoms as shown by the chlorosis of the leaves in between the veins.

PLATE III

Fig. 1. H28 x K699

Fig. 2. K166

EXPLANATION OF PLATE IV

Fig. 1. Inbred line K148 showing severe zinc deficiency in the field. Note purple coloration of the leaves and stunting of the plant. Firing of the tassel can be seen.

Fig. 2. Inbred line K786 showing severe zinc deficiency in the field. Note chlorosis and necrosis of the leaves, in between the veins. Plants are stunted.

PLATE IV

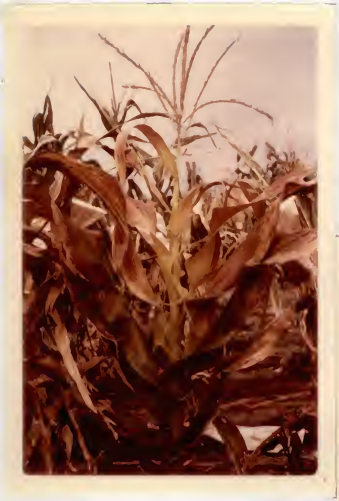

Fig. 1. K148

Fig. 2. K786

Root appearance and volume, in addition to the response of plant tops, may serve as an indicator of susceptibility or resistance to zinc deficiency. In the growth chamber studies, roots of susceptible lines had less volume and were decayed; while roots of normal plants were larger in volume and appeared very healthy, Plate V, Figs. 1 & 2. Roots of resistant lines had similar appearance and volume, whether grown in normal nutrient solution or high phosphorus solution, Plate VI. The appearance of the roots of the lines and hybrids included in this study, appeared to be consistent with the visual symptoms expressed by the plant tops. It was not determined whether the visual deficiency symptoms of plant tops were the result of the decaying of the roots or vice versa. Probably, the top symptoms and the decaying or degredation of the roots occurred simultaneously.

The time of the appearance of the zinc deficiency symptoms is important in evaluating a particular line or hybrid for susceptibility or resistance. In the growth chamber studies, based on the time of appearance and disappearance of the symptoms, lines and hybrids could be classified into four categories:

i) Susceptibility

These lines and hybrids showed zinc deficiency symptoms, one week to two weeks after emergence. The severity of the symptoms progressed to necrosis of the leaves and death of the plant parts. Many lines were stunted and developed a rosette pattern. Most of the lines studied belonged to this group, Tables1 & 2;

ii) Early resistance

A few lines and hybrids showed normal growth and development in

EXPLANATION OF PLATE V

Fig. 1. Roots of inbred K786, susceptible line, showing a decrease in root volume and decaying of the root tips under high phosphorus treatment (right). Control plants had roots which were larger in volume and appeared healthy (left).

Fig. 2. Roots of single cross K729 x K166, showing a marked decrease in root volume and decaying of the root tips under high phosphorus treatment (right). Control plants had larger root volume and vigorousness (left).

PLATE V

Fig. 1. K786

Fig. 2. K729 x K166

EXPLANATION OF PLATE VI

Fig. 1. Roots of inbred K41, a resistant line, showing no marked decrease in root volume under high phosphorus treatment (left). Roots in both treatments appeared normal.

Fig. 2. Roots of inbred H28, early resistant line, showing slight decrease in volume under high phosphorus treatment (right). Roots under high phosphorus showed signs of decaying. Roots of the control plants are shown on the left.

PLATE VI

Fig. 1. K41

Fig. 2. H28

the early part of the experiment, in both the normal and high phosphorus nutrient solutions. However, towards the end of the experiment, these lines and hybrids, when under zinc stress, suddenly exhibited symptoms followed quickly by necrosis of the leaves and death of the plants soon after. The plants showed no marked stunting, and the dead plants had almost the same height as the control plants. The root volume appeared to be equal in both treatments, but it appeared that the roots of the plants in the high phosphorus solution had started to decay, Plate VI, Fig. 2; Tables 1 & 2.

Table 2. Zinc and phosphorus level of leaves of 10 inbreds grown in growth chambers under normal nutrient solution and high phosphorus nutrient solution.

Entry no.	Inbreds	Zinc level (ppm) N.sol.	Zinc level (ppm) H.P.sol.*	Phosphorus level (%) N.sol.	Phosphorus level (%) H.P.sol.*	Symptom
1.	K724	5.70	5.10	0.52	1.10	S
2.	K742	7.10	7.80	0.39	0.98	S
3.	K786	7.20	8.10	0.79	0.88	S
4.	K41	8.00	6.40	0.32	0.63	R
5.	K731	8.90	7.10	0.14	0.64	R
6.	K166	9.26	9.72	0.19	1.07	S
7.	H28	10.20	8.80	0.38	1.10	ER
8.	K148	11.58	13.27	0.42	0.94	S
9.	K723	11.75	7.15	0.36	0.94	S
10.	K55	12.90	12.60	0.44	0.69	LR

N. sol. = Normal nutrient solution
H.P. sol. = High phosphorus nutrient solution
* = Average of two replicates
R = Resistant
S = Susceptible
ER = Early resistance
LR = Late resistance

iii) Late resistance.

Some lines and hybrids showed the reverse of ii; susceptibility was indicated in the early part of the experiment, but plants recovered and showed resistance later, increasing in height and resuming growth and development. Plate I, Fig. 2; Tables 1 & 2.

iv) Resistance.

A few inbreds and single crosses grew well (no visible zinc deficiency symptoms) in either high phosphorus or normal nutrient solution, Plate VII, Fig. 1. The roots also showed healthy growth, Plate VI, Fig. 1; Tables 1 & 2.

It should be noted that single crosses of inbred lines with one parent having early resistance and the other late resistance exhibited a high degree of resistance to zinc deficiency throughout the experiment, Plate VII, Fig. 2; Table 1.

Similar responses to zinc deficiency were observed in the field as mentioned previously. K55, classified as a late resistant line, had necrosis of the lower, older leaves and shortening of the internodes of the lower part of the stem in the field test. The development of the upper part of the stem appeared normal with normal, green leaves, Plate VIII, Fig. 1. K55 was obviously susceptible to zinc deficiency in the early part of its life cycle but resumed normal growth towards the end of its life cycle. The reverse case was found in line H28, Plate VIII, Fig. 2. This line was resistant to zinc deficiency in the early part of its life cycle, thus exhibiting normal green leaves at the bottom part of the plant. In the later stages of development, H28 displayed zinc deficiency symptoms by exhibiting purple coloration of the leaves

EXPLANATION OF PLATE VII

Fig. 1. Inbred K41, a resistant line, in the growth chamber. Plants under high phosphorus treatment (right), and plants under normal nutrient treatment (left), both showed no apparent zinc deficiency symptom.

Fig. 2. Single cross H28 x K55 after being removed to the green house. Plants on the right were under high phosphorus treatment. Control plants on the left. This single cross is a cross between early resistant parent (H28) and a late resistant parent (K55). This single cross is highly resistant to zinc deficiency.

PLATE VII

Fig. 1. K41

Fig. 2. H28 x K55

EXPLANATION OF PLATE VIII

Fig. 1. Inbred K55, a late resistant line, growing in the field. Note necrosis of the lower leaves and the healthy green leaves on the top portion of the stem.

Fig. 2. Inbred H28, an early resistant line, growing in the field. Note purple coloration of the upper leaves, whereas leaves on the lower part of the plant remained green.

PLATE VIII

Fig. 1. K55

Fig. 2. H28

on the upper portion of the plant. Zinc deficiency symptoms produced in the growth chambers on several lines and hybrids of corn were similar to those found in the field where zinc deficiency was known to occur; therefore, the results of growth chamber studies gave a good indication of the performances of the lines in the field.

Resistance to zinc deficiency or phosphorus-induced zinc deficiency appeared to be under genetic control. The actual mechanism of the genetic control was not determined in this study. However, it appeared that a complimentary effect of two genotypes may result in an expression of resistance as in the case of K55 x H28. Table 1. Other lines appeared to have the resistance to zinc deficiency controlled by recessive genes. For example, single cross K742 x K731 was susceptible to zinc deficiency, but the parent K731 inbred was resistant, Tables 1 and 2 respectively.

Accumulation of zinc and phosphorus:

In this part of the study, the objective was to determine whether genetically different sources of corn exhibited differential accumulation of zinc and phosphorus. If no significant difference among lines exists, then any line may be used as representative of corn for studies relating to accumulation of these elements, and results would be applicable in general.

Analytic results of zinc and phosphorus present in leaves sampled at tasseling time from the field indicated that there is differential accumulation of both zinc and phosphorus. Zinc content ranges from an average of 11.12 ppm to 27.05 ppm on dry weight basis. Similarly, accumulations of phosphorus also varied from genotype to geno-

type. The phosphorus content of the leaves ranged from 0.28 to 0.33 per cent in the lines studied, Table 3. Analysis of variance of these lines, Tables 4 and 5, indicated that differential accumulation of zinc and phosphorus by the lines under study was significant at 1% level. The L.S.D. of zinc and phosphorus were 5.48 ppm and 0.02% respectively, Tables 3, 4, and 5. The analysis of variance thus confirmed that genetically different lines of corn exhibited different accumulations of zinc and phosphorus. Based on the levels of zinc and phosphorus of the leaves, lines could be classified as low, intermediate, or high zinc or phosphorus accumulators. The results also indicated that there is no association between the levels of zinc and phosphorus in the leaf tissue. High zinc lines exhibited both low phosphorus and high phosphorus accumulations. Similarly, low zinc lines also had high and low phosphorus levels. For example, single cross K786 x K41 had zinc level of 11.12 ppm and phosphorus level of 0.28%. Single cross H28 x K786, on the other hand, had zinc level of 16.60 ppm and phosphorus level of 0.33%, the highest phosphorus level of any of the lines or crosses studied. Single cross K55 x K41 had the highest zinc content and also a high phosphorus level, 0.30%, Table 3. The cross K786 x K41 could be classified as a low zinc accumulator, and K55 x K41 as a high zinc accumulator. In this experiment more lines and crosses had zinc content of 20 to 22 ppm, and thus the intermediate range could be said to be around 20 to 22 ppm zinc.

In the growth chamber studies, differential accumulations of zinc and phosphorus by the lines were also apparent. Based on the normal nutrient solution treatment, zinc levels of the inbreds (on dry

Table 3. Zinc and phosphorus levels of 26 single crosses and 6 double crosses grown in Kansas State University Agronomy Farm.

Entry no.	Hybrids	Av. zinc (ppm)	Av. Phosphorus (%)	Symptom*
1.	K786 x K41	14.12	0.28	1.00
2.	H28 x K786	16.60	0.33	2.50
3.	K766 x K767	17.99	0.27	2.25
4.	K755 x K786	18.33	0.29	2.25
5.	38-11x H10	19.04	0.29	2.75
6.	(H28 x K41) x (K755 x K786)	19.07	0.29	2.25
7.	H30 x K809	19.13	0.29	2.25
8.	H28 x K41 (I)	19.46	0.29	1.00
9.	Hy x P8	19.69	0.30	3.00
10.	K730 x CI49B	19.82	0.32	2.25
11.	K201 x MwF9	19.93	0.31	1.75
12.	(H28 x K41) x (K713 x Oh7B)	19.97	0.30	2.25
13.	H28 x K41 (II)	20.01	0.29	1.25
14.	Hy x K155	20.72	0.31	3.50
15.	K724 x K731	20.79	0.31	1.75
16.	K729 x MoIw	21.85	0.32	2.25
17.	K41 x K742	21.90	0.28	2.00
18.	K766 x Ky116	22.04	0.30	1.75
19.	(K713x Oh7B) x (K755 x K786)	22.25	0.30	2.00
20.	K762 x K766	22.35	0.27	1.50
21.	K731 x K776	22.78	0.31	2.00
22.	WF9 x N6	22.89	0.28	2.00
23.	(K55 x H28) x (H28 x K41)	22.92	0.31	1.50
24.	K55 x CI64	23.18	0.29	2.50
25.	MoIw x N72	23.33	0.29	2.00
26.	K55 x K786	23.63	0.30	2.75
27.	(K55 x H28) x (K755 x K786)	24.29	0.30	2.50
28.	K55 x K741	24.29	0.30	2.50
29.	H28 x K55	24.49	0.31	1.00
30.	(K55 x H28) x (K713 x Oh7B)	25.00	0.31	2.25
31.	K55 x K699	25.88	0.29	3.00
32.	K55 x K41	27.05	0.30	1.50
	L.S.D.	5.48	0.02	

*Ranking of zinc deficiency symptom (0-4). Average of 4 replicates.

Table 4. Analysis of variance of zinc content of leaves sampled at tasseling time from lines grown at the Kansas State University Agronomy Farm.

Source of variation	df	SS	MS	F
Replications	3	970.072	323.357	
Treatments	31	965.105	31.132	2.05**
Error	93	1410.746	15.169	

**Significant at 1% level.

Table 5. Analysis of variance of phosphorus content of leaves sampled at tasseling time from lines grown at the Kansas State University Agronomy Farm.

Source of variation	df	SS	MS	F
Replications	3	0.00057	0.00019	
Treatments	31	0.02389	0.00077	2.32**
Error	93	0.03083	0.00033	

**Significant at 1% level.

weight basis) ranged from 5.70 to 12.90 ppm, and phosphorus levels ranged from 0.14 to as high as 0.79%. Single crosses also showed variations in their accumulations of zinc and phosphorus, being 6.33 to 11.80 ppm and 0.19 to 0.37%, respectively. Tables 1 and 2. Due to insufficient replications for the normal nutrient solution treatment, no analysis of variance was made for differential accumulations of zinc and phosphorus for inbreds and single crosses. However, a trend of differential accumulation was obtained with one replicate, indicating that the lines involved probably differ in their capacities to accumulate both the elements under study.

Zinc and phosphorus interaction:

Studies in the growth chambers were carried out to determine the capacity of phosphorus to induce zinc deficiency symptoms in several lines and crosses of corn. It has been postulated by various writers that high phosphorus limits the uptake of zinc in several crops. Other writers did not find any interaction between high phosphorus and zinc uptake.

Results indicated that various lines and crosses of corn exhibited differential response of zinc uptake as influenced by high phosphorus level. The phosphorus content of leaves of the inbreds, under high phosphorus treatment, showed marked increase when compared with the phosphorus level under normal nutrient treatment. This indicates that as the level of phosphorus in the soil increases, the amount of phosphorus uptake by the plants increases. The same pattern of phosphorus uptake was observed on single crosses, Tables 1 and 2. Influence of high phosphorus level upon zinc uptake varied from line to line. Based on the zinc content of leaves obtained under high phosphorus treatment, the response of the lines and crosses under study could be classified into three groups:

i) Zinc uptake was inhibited by high phosphorus. Inbred line K723, for example, yielded 11.75 ppm zinc when grown in normal nutrient solution but only 7.15 ppm zinc when grown in high phosphorus nutrient solution, Table 2. Similarly, single cross K730 x CI49B had zinc content of 10.65 ppm in normal nutrient solution, but only 7.37 ppm under high phosphorus treatment, Table 1.

ii) Zinc uptake increased as the level of phosphorus was in-

creased. Inbred line K148, for example, showed an increase in zinc uptake, from 11.58 ppm in normal nutrient solution, to 13.27 ppm in high phosphorus nutrient solution, Table 2. Similarly, single cross H28 x K41 had zinc content of 6.80 ppm under normal nutrient treatment, but had higher zinc level under high phosphorus treatment, that of 9.70 ppm, Table 1.

iii) No apparent change in zinc level under high phosphorus treatment. Inbred K55, for example, had zinc content of 12.90 ppm under normal nutrient treatment and 12.60 ppm under high phosphorus treatment, Table 2. Single cross H28 x K699 had zinc content of 7.37 ppm in normal nutrient solution and 7.45 ppm under high phosphorus treatment, Table 1.

Due to these variations in the response of the various lines of corn under study, analysis of variance for zinc under high phosphorus treatment on both inbreds and single crosses showed no significant interaction between phosphorus and zinc. This indicates that high phosphorus may not limit the uptake of zinc in some lines of corn. The inbreds and single crosses showed significant response at 5% level, thereby indicating that inbreds and single crosses react differently under high phosphorus level, Tables 6 and 7. Analysis of variance on inbreds and single crosses confirmed the statements mentioned earlier.

It appears that the conflicting reports in the literature relating to the uptake of zinc as influenced by high phosphorus level in soils in which various crops were grown, may have been due to genetic differences among lines or crosses of the crops involved.

Table 6. Analysis of variance of zinc content of leaves as influenced by high phosphorus level on 10 inbreds grown in growth chambers.

Source of variation	df	SS	MS	F	
Replications	1	0.606	0.606	0.155	NS
Phosphorus level	1	2.621	2.621	0.670	NS
Inbreds	9	153.879	17.100	4.373	*
Phosphorus level x Inbreds	9	19.524	2.170	0.555	NS
Error	9	35.150	3.910		

*Significant at 5% level
NS = Nonsignificant

Table 7. Analysis of variance of zinc content of leaves as influenced by high phosphorus level on 24 single crosses grown in growth chambers.

Source of variation	df	SS	MS	F	
Replications	1	2.17	2.17	1.23	NS
Phosphorus level	1	1.29	1.29	0.73	NS
Single crosses	23	109.76	4.77	2.71	*
Phosphorus level x Single crosses	23	46.87	2.04	1.16	NS
Error	23	40.37	1.76		

*Significant at 5% level
NS = Nonsignificant

Resistance to phosphorus-induced zinc deficiency was observed in several lines and hybrids of corn under study. Resistance as well as susceptibility was found in all the groups of lines as classified according to their responses to high level of phosphorus: groups (i), (ii)

and (iii) discussed above. Group (i) where zinc uptake decreased as phosphorus was increased contained resistant lines as well as lines which exhibited susceptible symptoms. Inbred K41 showed a reduction in zinc uptake from 8.00 ppm to 6.40 ppm, and yet this line was one of the most resistant inbred lines found in this investigation, Table 2. Similarly, single cross K201G x K55 (classified resistant) had a zinc level of 6.33 ppm in normal nutrient solution, but only 4.65 ppm under high phosphorus treatment, Table 1. Other lines and crosses in this group were classified as susceptible, for example, K723, K724, (Table2) and K730 x CI49B, K729 x K166, (Table 1).

Resistant and susceptible lines were also found in group (ii) where an increase of zinc uptake occurred when phosphorus was increased. Inbred K148, in which zinc uptake increased from 11.58 ppm to 13.27 ppm, showed severe zinc deficiency stress, Table 2. Similarly, single cross K63 x K740, in which zinc content increased from 7.30 ppm to 9.80 ppm, exhibited zinc deficiency symptoms, Table 1.

Thus, it appeared that a change in zinc uptake under high phosphorus level will not necessarily result in the expression of zinc deficiency symptoms. Because of these variations in the responses of the lines, resistance to zinc deficiency could not be correlated with the levels of zinc present in the leaf tissue.

Zinc deficiency symptoms in the field were noted and ranked, from 0 to 4. A ranking of 0 indicates that there was no visible effect due to zinc deficiency and a ranking of 4 means that the zinc deficiency symptom was severe. In this phase of the study the objective was to determine the relationship between the expression of deficiency symptoms

and the levels of zinc present in the leaf tissue, and if possible, to establish a critical level of zinc, below which zinc deficiency could be expected to occur.

Results of the observations of the lines indicated that nearly all the lines exhibited zinc deficiency symptoms, although the degree of the deficiency varied from line to line. It was also observed that the lines which showed only slight symptoms recovered; that is, the symptoms disappeared. Those lines which had the ranking of 1.50 or below were classified as resistant lines. It was noted too, that those single crosses which were resistant in the growth chamber study were also resistant in the field. Single crosses, H28 x K41 and H28 x K55, had the ranking of 1.00 and 1.50, respectively, Table 3; but again, zinc deficiency symptoms could not be correlated to the levels of zinc in the leaf tissue. The hybrid K786 x K41 had the lowest zinc content of 14.12 ppm, yet its field reaction was resistant. K55 x K699 had the second highest zinc content of 25.88 ppm but had the highest symptom ranking of 3.00, Table 3. Therefore, no minimum or critical level could be established for these lines and crosses as a group below which zinc deficiency symptoms were consistently observed. Thus, the critical level of about 15 ppm for corn, as reported by several writers (Ellis et al., 1964; Viet et al., 1963), is applicable only to the particular lines or hybrids of corn investigated by those writers. This study also confirmed the finding of Brown and Krantz (1966) who reported that the best yielding treatment which did not show any zinc deficiency symptom had a low zinc content. Similarly, in this study, the single cross that had the lowest zinc content was classified resistant. The actual reason

that lines with high zinc content may exhibit zinc deficiency symptoms, can only be postulated at this juncture. It may be possible that even though there was a relatively high content of zinc in the plant tissue, the zinc was inactivated or tied up. Therefore, zinc was made unavailable for use by the plants and hence the zinc deficiency symptoms.

Field studies were also conducted to determine the effects of applied phosphorus and applied zinc on the uptake of zinc and phosphorus. It was of interest to see whether application of zinc to the soil just after the emergence of seedlings in the field would reduce zinc deficiency symptoms, when compared to the same lines grown under applied phosphorus, on the same location.

Due to insufficient data (the samples of one of the two replicates that received applied phosphorus were lost) no statistical analysis could be carried out and interpretations of the data may not be reliable. However, it appeared that zinc content varied from hybrid to hybrid under each treatment. Zinc content under phosphorus treatment ranged from 14.99 ppm to 32.25 ppm. The range of zinc content under zinc treatment appeared to increase from 16.00 ppm to 34.26 ppm, though this may not represent a statistically significant increase. Contents of zinc and phosphorus of leaves of the hybrids included in the test showed that they varied in their response to applied phosphorus and zinc. There were indications that certain crosses showed no increase of zinc uptake even under applied zinc, but under applied phosphorus both zinc and phosphorus content showed marked increase. K786 x K41, for example, had zinc content of 16.00 ppm and phosphorus content of 0.31% under zinc treatment, but increased to 21.23 ppm of zinc and 0.35% of phos-

phorus under treatment, Table 8. Other hybrid combinations showed less zinc, but more phosphorus uptake under phosphorus treatment and high zinc content but low phosphorus content under zinc treatment. H28 x K786 had zinc content of 18.74 ppm and 0.33% phosphorus under zinc treatment; but where phosphorus was applied, it had 16.34 ppm zinc and 0.35% phosphorus, Table 8. In this particular cross, high phosphorus reduced the uptake of zinc and high zinc reduced the uptake of phosphorus. Some other hybrids showed no marked change of zinc and phosphorus for either zinc or phosphorus treatment. K766 x Ky116 gave zinc contents of 27.77 ppm and 28.13 ppm under zinc and phosphorus treatments respectively. Phosphorus contents of this cross under both treatments remained constant at 0.28%, Table 8. Hybrids K55 x K741, H28 x K55, K55 x K699 and K55 x K41 gave high phosphorus uptake at high zinc levels and low zinc induced low phosphorus uptake, Table 8. Thus, it appeared that high phosphorus and high zinc in certain cross combinations reduced the uptake of zinc and phosphorus, respectively. Other crosses showed no effect on the uptake of zinc or phosphorus when phosphorus and zinc fertilizers were added to the soil.

Deficiency symptoms have no association with the levels of zinc and phosphorus in the plant tissue. K786 x K41, under zinc treatment, showed very slight stress even though the level of zinc was only 16.00 ppm. However, this line showed severe zinc deficiency response under the phosphorus treatment, even though the level of zinc had increased to 21.23 ppm. Other crosses, for example, H28 x K55, gave zinc level decrease under phosphorus treatment but remained resistant. In general, when the hybrids were considered as a group, it appeared that zinc

Table 8. Zinc and phosphorus content of leaves and zinc deficiency symptoms of 26 single crosses and 6 double crosses grown at Ashland Farm of Kansas State University.

Entry no.	Hybrids	Zinc content (ppm) Zn.treat.*	Zinc content (ppm) P.treat.	Phos. content (%) Zn.treat.*	Phos. content (%) P.treat.	Zinc def. ranking*i Zinc*	Zinc def. ranking*i Phos.*
1.	K786 x K41	16.00	21.23	0.31	0.35	0.5	3.0
2.	H28 x K41 (I)	17.75	15.00	0.31	0.32	0.0	0.5
3.	H28 x K41 (II)	17.81	25.25	0.33	0.28	0.5	0.5
4.	H28 x K786	18.74	16.34	0.33	0.35	1.5	1.5
5.	Hy x K155	20.05	18.00	0.29	0.31	3.5	2.0
6.	38-11x H10	20.46	21.11	0.29	0.26	2.0	3.0
7.	Hy x P8	21.70	23.04	0.36	0.35	2.0	3.0
8.	H30 x K809	21.78	18.25	0.33	0.31	1.0	1.5
9.	(K55 x H28) x (H28 x K41)	22.19	19.48	0.30	0.31	3.0	1.5
10.	K729 x MoIw	23.08	26.49	0.35	0.35	3.0	3.0
11.	K41 x K742	24.81	24.32	0.29	0.28	2.0	2.0
12.	K731 x K776	25.22	25.37	0.31	0.28	1.5	1.5
13.	K730 x CI49B	25.58	21.22	0.35	0.30	2.0	1.5
14.	K724 x K731	25.84	23.73	0.34	0.35	3.5	4.0
15.	(K55 x H28) x (K713x Oh7B)	26.24	18.35	0.32	0.29	1.0	1.0
16.	K766 x K767	26.25	31.44	0.25	0.25	1.5	2.5
17.	K201 x MWF9	26.39	23.91	0.30	0.29	0.0	2.0
18.	K762 x K766	27.49	21.83	0.26	0.28	2.0	3.0
19.	(H28 x K41) x (K713x Oh7B)	27.61	14.99	0.31	0.31	1.5	1.5
20.	(K55 x H28) x (K755xK786)	27.71	28.36	0.30	0.31	2.5	2.5
21.	K766 x Kyll6	27.77	28.13	0.28	0.28	0.5	2.0
22.	K755 x K786	27.78	24.66	0.33	0.30	1.5	1.5
23.	K55 x CI64	27.93	32.25	0.30	0.29	1.5	1.5
24.	MoIw x N72	28.62	27.31	0.31	0.33	2.5	3.0
25.	WF9 x N6	28.95	27.91	0.31	0.29	2.5	2.5
26.	K55 x K786	29.45	22.48	0.31	0.31	2.0	2.0
27.	K55 x K41	30.03	19.31	0.34	0.29	0.5	1.0
28.	(H28 x K41) x (K755x K786)	30.88	17.05	0.32	0.30	1.5	1.0
29.	(K713xOh7B) x (K755x K786)	31.12	18.25	0.30	0.24	1.5	2.0
30.	K55 x K741	31.44	28.60	0.32	0.29	3.0	3.0
31.	K55 x K699	31.76	30.33	0.30	0.27	1.0	2.5
32.	H28 x K55	34.26	25.19	0.36	0.32	0.5	0.5

*Average of two replicates
i Zinc deficiency symptom ranking from 0 to 4

fertilizers applied to the soil reduced the occurrence of zinc deficiency symptoms and applications of phosphorus fertilizers increased the expressions of zinc deficiency symptoms.

Dry weight and high phosphorus:

This phase of the study involved the measurements of the dry weight of leaves harvested from the inbred lines and single cross hybrids grown in growth chambers. The dry weights of leaves were from the six plants in each treatment, taken 28 days after emergence of the seedlings. These results are presented in Table 9.

In general, the results indicate that for inbreds and single crosses, there were marked decreases of dry weights under high phosphorus treatment. Dry weights of inbreds under normal nutrient treatment ranged from 2.41 grams to 8.20 grams; the range under high phosphorus treatment was from 1.41 grams to 6.66 grams. Similarly, the range of dry weights of single crosses was 2.00 to 6.97 grams in the normal nutrient solution, and 2.44 to 5.88 grams in the high phosphorus treatment, Table 9. However, the dry weights of most single crosses in the normal and high phosphorus nutrient solutions generally appeared to be somewhat higher than the inbreds. This is, at least in part, due to the hybrid vigour exhibited by the hybrids. Susceptible lines, showed either marked reduction of dry weight in the high phosphorus treatment or no difference in dry weights for both the normal nutrient treatment or high phosphorus treatment. K166 had 5.33 grams in the normal nutrient solution, but only 2.98 grams in the high phosphorus solution. Susceptible single crosses also showed similar reduction in dry weights. For example, K745 x K801 had 6.97 grams under normal nutrient

treatment, but only 3.94 grams under high phosphorus treatment, Table 9. This indicates that plants under normal nutrient solution were vigorous, with just a slight zinc deficiency symptom (K166, Plate 3, Fig. 2). In those cases in which susceptible lines had almost the same dry weight, it appeared that the plants under both normal nutrient treatment and high phosphorus treatment, exhibited severe zinc deficiency symptoms. For example, inbred K724 had dry weight of 3.66 grams and 2.98 grams, a decrease of only 0.68 gram. Single cross K698 x K699 had dry weights of 4.50 grams and 4.21 grams under normal nutrient treatment and high phosphorus treatment, respectively. A decrease of only 0.29 gram, Table 9. Resistant lines had slight decrease in dry weight under high phosphorus treatment, a decrease which was probably not to be significant. K41 had dry weight of 4.53 grams under normal nutrient solution and 4.40 grams under high phosphorus treatment. K201G x K55 had dry weight of 6.15 grams and 5.88 grams under normal nutrient treatment and high phosphorus treatment, respectively, Table 9.

Table 9. Dry weight of leaves of 10 inbreds and 24 single crosses taken 28 days after emergence of the seedlings. Growth chamber study.

Entry no.	Inbreds	Dry weight (gram)		Reaction type
		Normal solution	High phosphorus solution*	
1.	K55	2.41	1.63	LR
2.	K723	2.48	1.41	S
3.	K148	2.51	1.65	S
4.	H28	3.08	2.31	ER
5.	K724	3.66	2.98	S
6.	K742	3.90	3.14	S
7.	K786	4.03	2.20	S
8.	K41	4.53	4.40	R
9.	K166	5.33	2.98	S
10.	K731	8.20	6.66	R

Table 9. continued

Entry no.	Hybrids	Dry weight (gram)		Reaction type
		Normal solution	High phosphorus solution*	
1.	K755 x K786	2.00	3.04	S
2.	K810 x Ky209	3.47	3.25	S
3.	K741 x H28	3.83	3.42	S
4.	K41 x K742	4.09	3.50	S
5.	K61 x K740	4.14	2.44	S
6.	K724 x K731	4.16	2.82	S
7.	K55 x K699	4.31	4.15	S
8.	K698 x K699	4.50	4.21	S
9.	K774 x MoIw	4.52	4.45	ER
10.	K63 x K740	4.69	2.94	S
11.	K55 x K741	4.75	3.37	S
12.	K729 x K166	4.72	3.31	S
13.	K745 x K802	4.79	3.43	S
14.	K731 x K776	4.80	3.29	S
15.	K798 x Ky27	4.82	3.75	S
16.	Ky211 x 33-16	4.87	4.03	S
17.	H28 x K41	4.88	4.05	R
18.	H28 x K55	4.90	4.60	R
19.	H28 x K699	5.29	3.57	ER
20.	K166 x K55	5.60	3.90	LR
21.	K201G x K786	5.75	4.88	ER
22.	K730 x CI49B	5.86	3.74	S
23.	K201G x K55	6.15	5.88	R
24.	K745 x K801	6.97	3.94	S

* = Average of two replicates
R = Resistant
ER = Early resistant
LR = Late resistant
S = Susceptible

Analysis of variance of inbreds indicates that high phosphorus level decreased the dry weight of the plants under study; differences due to phosphorus were significant at the 1% level, Table 10. Also inbreds responded differently under both normal and high phosphorus solutions and were significant at the 1% level. However, the inter-

action of inbreds with levels of phosphorus showed no significant difference, indicating that the inbred lines were ranked in the same relative order on a dry weight basis on both levels of phosphorus. The analysis of variance of single crosses showed a significant difference between levels of phosphorus, indicating that there generally was a decrease in dry weight of plants when under high phosphorus treatment. All sources of variance except replications were at the 1% level of significance, Table 10. However, in the single cross analysis, the interaction between single crosses and phosphorus level was significant, indicating the single crosses were not ranked in the same relative order at both levels of phosphorus.

Table 10. Analysis of variance of dry weight of leaves from 10 inbreds and 24 crosses grown in the growth chambers as influenced by high phosphorus.

Source of variance	df	SS	MS	F	
Replication	1	0.27	0.27	2.455	NS
Phosphorus level	1	7.68	7.68	69.818	**
Inbreds	9	70.65	7.85	71.363	**
Phosphorus level x Inbreds	9	2.41	0.27	2.455	NS
Error	9	0.97	0.11		
		Single Crosses			
Replication	1	0.02	0.02	1.43	NS
Phosphorus level	1	18.19	18.19	129.93	**
Single cross	23	40.86	1.78	12.71	**
Phosphorus level x Single cross	23	13.65	0.59	4.21	**
Error	23	3.28	0.14		

NS = Nonsignificant
** = Significant at 1% level

Dry weight reduction could not be correlated to the levels of zinc in the leaf tissue. K148 had higher levels of zinc, from 11.58 ppm to 13.27 ppm under high phosphorus treatment, Table 2; but the dry weight was decreased from 2.51 grams to 1.65 grams, Table 9. Similarly, for single cross K745 x K801 had zinc level increased from 7.01 ppm to 9.64 ppm, Table 1, under high phosphorus treatment; yet there was a reduction of dry weight from 6.97 grams to 3.94 grams, Table 9. Also a reduction of zinc level did not necessarily result in marked reduction of dry weight of the leaves. K41 had zinc level reduced from 8.0 ppm to 6.4 ppm under high phosphorus treatment, Table 2; and yet the dry weight showed no apparent reduction, Table 9. Similarly, single cross H28 x K55 had zinc level reduced from 11.8 ppm to 10.0 ppm under high phosphorus treatment, Table 1; yet there was no significant decrease in the dry weight, Table 9. Thus, a change in zinc level in the leaf tissue under high phosphorus treatment did not necessarily change dry weight yield of the leaves.

Zinc and phosphorus contents in some seed source:

Seeds from some of the same sources used in this study were used for the determination of zinc and phosphorus of corn seed. The objective was to determine whether there are any variations zinc and phosphorus in the seeds, and whether these levels are associated with zinc and phosphorus uptake by the resulting plants.

Results indicated that zinc content of the seed sources varied among lines and crosses, while phosphorus level showed no marked variations. The zinc contents of seeds ranged from 15.3 ppm to 31.2 ppm. Phosphorus contents ranged from 0.06% to 0.10%, Table 11. It should be

noted that H28, an early resistant line, had the highest zinc content in the seeds, 31.5 ppm. It is postulated that zinc was translocated from the seeds during germination and in the early part of its life. The line probably was unable to take up more zinc from the soil, especially while under high phosphorus treatment; thus, the susceptible reaction in the later part of its life resulted. K55, a late resistant line, had the lowest seed zinc content, indicating that at this level of zinc it was inadequate for translocation to the plants. However, later when root developments were adequate, K55 was able to take up zinc even under high phosphorus treatment, resulting in recovery from the zinc deficiency symptoms in the later part of its life. Single cross H28 x K55, a resistant single cross, had also a high seed zinc content of 28.0 ppm. It appeared that this line was able to make use of the zinc from the seeds in the early part of its life, and then obtained zinc from the soil, even under high phosphorus treatment, in the later part of its life.

Variation among lines in zinc content of the seed source was thought to be due to differential translocation of zinc during seed formation from the stalk and the leaves. The variation in zinc translocation was reported by Massey and Loeffel (1966) while working on interstrain variation in zinc content of corn.

Table 11. Zinc and phosphorus contents of some seeds from the same seed sources used in the experiments.

Entry no.	Seed source	Zinc (ppm)	Phosphorus (%)
1.	K55	15.34	0.08
2.	K731	17.50	0.06
3.	K786	18.45	0.08
4.	H28 x K41	19.34	0.06
5.	K55 x K741	19.72	0.10
6.	K55 x K699	20.21	0.06
7.	K41 x K742	20.21	0.08
8.	K755 x K786	21.21	0.07
9.	K63 x K740	22.31	0.09
10.	K724 x K731	23.44	0.06
11.	K742	24.59	0.10
12.	K724	25.42	0.07
13.	H28 x K55	28.01	0.08
14.	K731 x K776	28.65	0.07
15.	K41	29.43	0.07
16.	H28	31.47	0.06

SUMMARY AND CONCLUSIONS

In the present study, investigations were carried out in growth chamber and field tests. For growth chamber studies, high phosphorus (10 x normal level) was applied to twenty-four single crosses and ten inbred lines of corn to evaluate their response to phosphorus-induced zinc deficiency. Various zinc deficiency symptoms exhibited by the lines were noted, dry weight of the leaves taken, phosphorus and zinc levels of the leaves taken twenty-eight days after emergence were determined. Roots of those lines grown in the growth chambers were examined and abnormalities noted.

A field study was conducted to determine the differential accumulation of zinc and phosphorus in twenty-six single-cross and six

double-cross lines. No fertilizers were supplied in this study. Another field test including the same single and double crosses was conduoted where two replications received phosphorus treatment and the other two received zinc treatment. The fertilizers were applied to the soil, just after the emergence of the seedlings. The objective of this phase of the study was to determine the uptake of zinc and phosphorus under phosphorus treatment and the uptake of zinc and phosphorus under zinc treatment. Samples of leaves from the fields were taken from each line at tasseling time; zinc and phosphorus were determined.

The degree of zinc deficiency symptoms varied from line to line. Typical zinc deficiency symptoms were characterized by white buds, followed by stunting of the plants resulting in rosette pattern. Chlorosis and necrosis of the leaves were observed. Inbreds that produced purple coloration under severe zinc deficiency symptom also induced the production of purple coloration when in single cross combination. It was noted that some inbred lines showed early resistance to zinc deficiency but were susceptible in later stages of growth (H28). Other lines showed the reverse effect, that is susceptible in the early stages of growth and resistant later (K55). A single cross of these lines resulted in high resistance to zinc deficiency (H28 x K55). A similar pattern of resistance to zinc deficiency was observed in lines grown in the field. Thus, it was concluded that growth chamber studies gave a good indication of the potential performance of these particular inbred lines and crosses of corn under field conditions. Root development and root volume are other factors that may be used to describe zinc deficiency symptoms in corn. Susceptible lines, K786, K729 x K166 etc., had de-

creased root volume and decayed root-tips under zinc stress. Resistant lines, K41, H28 x K55, showed normal root growth and development, which was consistent with the reaction of the plant tops of these lines under stress.

Differences in zinc and phosphorus accumulations were found in the lines studied, both in the growth chambers and the fields. No association was found to indicate that high phosphorus limits zinc uptake from soil. Some lines and crosses, such as K148 and K55 x K741 showed increases in zinc level when phosphorus level was increased; yet these lines expressed severe zinc deficiency symptoms. This indicated that zinc was either inactivated in the plant tissues or was tied up in a form that was unavailable for use, resulting in the expression of zinc deficiency symptoms. Due to the different responses of the lines and crosses under study, a critical level of zinc in the soil for corn could not be established, below which zinc deficiency symptoms would occur. Zinc levels within plant parts seemed to be increased when zinc was applied to the soil, and severity of zinc deficiency symptoms appeared to be reduced; but this observation was not true for all materials studied in the field.

Susceptible inbred lines and single crosses showed reduction in dry weight of leaves under high phosphorus treatment. Resistant lines showed no significant dry weight reduction under high phosphorus treatment, indicating that the resistant lines were able to grow well in either the normal nutrient solution or in high phosphorus nutrient solution.

It was noted that zinc content of the seed sources varied among

inbred lines and hybrids, while phosphorus level showed no marked variations. H28, an early resistant line, had the highest zinc content; and K55, a late resistant line, had the lowest zinc content. It was postulated that H28 was able to make use of its zinc from the seeds during germination and in the early growth, but unable to take up zinc from the soil later, resulting in the susceptible reaction. Zinc level of seeds in K55 probably was not adequate to meet the requirements of early growth of the plant, thereby resulting in apparent susceptibility; however, in the later part of its growth, with the formation of an adequate root system, K55 was able to take up zinc, even under high phosphorus level. Single cross H28 x K55, a resistant line, also had a high seed zinc content, 28.0 ppm. It appeared that this line was able to make use of the zinc from the seeds in the early growth and obtained zinc from the soil towards the later part of growth, even though the line was under high phosphorus treatment.

The nature of resistance to phosphorus-induced zinc deficiency is still obscure, but appears to be under genetic control. Both recessive genes and complementary gene effects appeared to control zinc deficiency. Further investigations need to be conducted to determine the nature of genetic control of resistant to zinc deficiency.

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APPENDIX

Information on procedure used for cleaning culture containers and glassware for micronutrient deficiency experiment.

The utmost care in cleaning all utensils and handling them is essential for success in this type of experiment. Contamination in all stages of the experiment must be prevented. The following procedure was used for cleaning all culture containers and every item of glassware used in the experiment.

1. All utensils were washed thoroughly with water after soaking them in detergent.

2. They were rinsed at least three times with distilled water.

3. The containers and glassware (beakers, volumetric flasks etc.) were soaked in 0.1 M EDTA (ethylene-diaminetetraacetate) for fifteen minutes to remove all traces of contamination.

4. The utensils were then washed in distilled water, by three rinses.

5. They were then transferred in 10% HNO_3 bath for fifteen minutes and more. They were periodically rotated in the bath so that all surfaces came in contact with the acid.

6. After the acid bath, utensils were rinsed with small quantities of double distilled water, at least six times, to remove all traces of HNO_3.

7. Drying was carried out by carefully placing them on clean paper towels.

8. When dried, they were kept in clean polyethylene bags, when not immediately used.

Preparation of nutrient solution culture and procedure used in the growth chamber studies.

The composition of the nutrients and concentrations of the major elements were adopted as described by Hoagland, D. R., and W. C. Snyder, 1933. (Proc. Amer. Soc. Hort. Sci. 30:288). The micronutrients were provided according to the recommendation of Johnson, C. M., et al., 1957. (Plant and Soil 8:337).

Macronutrient solution

Chemicals	Ml. molar stock soln. in one liter of final solution
KNO_3	5.0
$Ca(NO_3)_2 \cdot 4H_2O$	5.0
$MgSO_4 \cdot 7H_2O$	2.0
KH_2PO_4	1.0

Concentrations of elements in final solution:

	ppm		ppm
N	210	S	64
K	234	Mg	48
Ca	200	P	31

Micronutrient solution

Chemicals	Mg. per liter of stock solution	Chemicals	Mg. per liter of stock solution
KCl	3728	$ZnSO_4 \cdot 7H_2O$	575
H_3BO_3	1546	$FeSO_4 \cdot 7H_2O$	556
$MnSO_4 \cdot 7H_2O$	845	$CuSO_4 \cdot 5H_2O$	125
		$(NH_4)_6 Mo_7O_{24} \cdot 4H_2O$	184

Concentrations of elements in final solution:

	ppm		ppm
Cl	1.77	Zn	0.13
B	0.27	Cu	0.03
Mn	0.27	Mo	0.01
Fe	0.22		

In the above table iron is considered a micronutrient. It was provided from 0.002 M $FeSO_4 \cdot 7H_2O$ solution adjusted to pH 3.5 with H_2SO_4. It was added to each culture when supplied to plants, every fourth day. The micronutrient stock solutions (except iron) were prepared at 1000 times the concentration shown for the final solution. One ml. of each stock solution was then added to each liter of final medium. The pH of nutrient cultures were maintained at 5.5, by adjusting the pH using 0.1 N KOH.

For the high phosphorus nutrient solution, similar macronutrients and micronutrients as in the tables were used, except the phosphorus source, KH_2PO_4, was increased to contain 10mm per liter of the solution.

Steps for the determination of phosphorus by Molybdate-Elon method: Fisker-Subbarow method.

The determination of phosphorus is based on the reduction of hexavalent molybdenum of phosphomolybdic acid by phosphomolybdate and elon to a blue colored reduction products. The color thus formed is a measure of the amount of phosphomolybdic acid formed and hence of the concentration of phosphate ion originally present in the samples.

Reagents:

i) Acid Molybdate: Dissolve 10.0 g. of sodium molybdate ($Na_2MO_2 \cdot 2H_2O$) in 400 ml. of 2.5 N H_2SO_4. (27.56 ml. Conc. H_2SO_4/400 ml). Store in an amber glass bottle at 0°C.

ii) Elon: Dissolve 4.0 g. of elon in 400 ml. of 3% $NaHSO_4$. Store in an amber glass bottle at 0°C.

iii) Phosphorus standard: Dissolve 136.09 mg/2.149 g. KH_2PO_4 in 1000 ml. of 0.1 N HCl to obtain a solution containing 1.0 mole/500 g. phosphorus per ml.

Procedure:

One ml of samples were pipetted into 50 ml. volumetric flasks containing two ml. of acid molybdate. Standards were prepared by pipetting 0.0, 0.1, 0.2, 0.3, 0.4, and 0.5 ml. of phosphorus standard (containing 500 g. phosphorus per ml.) into 50 ml. volumetric flasks containing two ml. of acid molybdate.

After thirty minutes, two ml. of Elon solution were added to all volumetric flasks (of samples and standard) and each flask was diluted to 50 ml. with distilled water. The samples were then allowed to stand for thirty minutes at room temperature, after which the color complex

from each flask was measured for optical density versus the optical density of the blank at 660 mμ.

Absorbance values obtained from the samples were converted to sample values from curve drawn with phosphorus standard sample values. Percentages of the phosphorus were then calculated on dry weight basis.

Zinc determination in plant material by Atomic Absorption Spectrophotometer.

The sensitivity of the determination is about 0.04 ppm per 1% absorption. The sensitivity for zinc can be increased about two times by using a low-temperature flame.

Reagents:

Nitric acid

Zinc of high purity

Double distilled water

Standard solutions:

Stock zinc solution: Dissolve 0.50 grams of high purity zinc in 100 ml. nitric acid (1 - 1). Cool and dilute to one liter. This provides a stock zinc solution containing 500 mg Zn/ml.

Zinc standards: Prepare four 25-ml. standard solutions containing 1.0, 2.0, 3.0, and 5.0 ppm of zinc by diluting the stock solution as required.

Operating condition:

Wavelength 215 mμ

Range UV

Slit 5 (3mm, 20A)

Source 10 ma, hollow cathode

Burner Perkin-Elmer premix

Air-pressure 20-30 psi; flow 2-6 on flow meter

Auxiliary Air: Increase air flow to 9.0 on flow meter by setting the air needle valve

Fuel Acetylene pressure 8 psi; flow 5.0 on flow meter

Flame Clear and non-luminescent

Sample uptake rate 2-5 ml./minute

Procedure:

Follow routine procedure using SCALE control at setting that includes analytical absorption range.

Plot absorption vs. concentration for working curve.

Determine the sample concentration.

Note:

Allow the lamp to warm up for twenty minutes at a current of 10 ma, then optimize the lamp current by adjusting the SOURCE.

Control to obtain a noise level of one to two divisions on the NULL meter.

Blank solution is required for setting zero percent absorption.

It is necessary to determine the working curve with at least three standards. The working curve must be prepared for every group of samples.

Data calculated by converting percent absorption to absorbance and reading sample values from the working curve drown with standard values. Parts per million were calculated based on dry weight of the samples.

RESPONSE OF SEVERAL STRAINS OF CORN (*Zea mays* L.) TO ZINC DEFICIENCY

by

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B. Sc., University of Malaya, 1963

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Investigations were carried out in the fields and growth chambers. Twenty-four single-cross and ten inbred lines were supplied with high phosphorus nutrient solution (10 x normal level) in the growth chambers to evaluate their responses to phosphorus-induced zinc deficiency. Zinc deficiency symptoms were noted, dry weights of leaves sampled at 28 days after emergence were recorded, and zinc and phosphorus levels were determined. Roots of various lines were examined and abnormalities recorded at time of harvest. Field studies were conducted in two locations. At one location accumulations of zinc and phosphorus were determined. At the other location, zinc and phosphorus levels were determined under two treatments, applied phosphorus and applied zinc. Determination of zinc and phosphorus content was made from leaves sampled at tasseling time. Some of the sources of seed used in these experiments were also sampled to determine zinc and phosphorus contents of seed.

The degree of zinc deficiency varied with plant genotype. H28 produced purple coloration under severe zinc deficiency symptoms, and single cross combinations of H28 also developed purple coloration under severe zinc stress. It was noted that some inbred lines, such as H28, showed early resistance to zinc deficiency, but were susceptible at later stages of growth. Other lines showed the reverse effect, susceptible in early stages of growth and resistant later, for example K55. A single cross of these lines, H28 x K55, resulted in high resistance to zinc deficiency. Similar patterns of resistance were observed in the field, which indicates that growth chamber studies generally gave a good indication of the potential performances of these lines under field conditions. The appearance of root systems also was used to detect zinc

deficiency symptoms. Resistant lines, K41, H28 x K55, had about the same root volume and appearance under control and high phosphorus treatment. Susceptible lines, K786, K729 x K166, developed reduced root volume and decayed root-tips under the high phosphorus treatment.

Differential accumulations of zinc and phosphorus were found in the field and in the growth chamber studies. No relationship was found to indicate that high phosphorus limited zinc uptake from soil for corn in general. Inbred K148 and hybrid K55 x K741 had an increase in zinc uptake under high phosphorus treatment, but still showed severe zinc deficiency symptoms. It is suggested that zinc was tied up or inactivated in the plant tissues.

Susceptible inbreds and single crosses showed reduction in their dry weight yields of leaves under the stress treatment. Resistant lines showed no significant decrease even under high phosphorus treatment. Generally, high phosphorus appeared to reduce the dry weights of the plants. These observations were based on the growth chamber studies.

When zinc was applied to the soil, in general there appeared to be an increase of zinc uptake and reduction of the severity of zinc deficiency symptoms. Similarly, applications of phosphorus tended to increase the occurrence and severity of zinc deficiency symptoms.

Zinc content of seed sources varied among lines, but phosphorus level showed no marked variations. Early resistant line, H28, had the highest seed zinc content, and it was suggested that zinc from the seeds was translocated to the growing organs, but that the line was unable to take up zinc from the soil, especially under high phosphorus treatment. Late resistant line, K55, had the lowest seed zinc content, a level

probably not adequate for early plant growth and development. The line apparently obtained zinc from the soil, during later stages of growth, even under high phosphorus treatment and, therefore, was classified as a late resistant line.

The nature of resistance to phosphorus-induced zinc deficiency is still obscure, but in this study appeared to be under genetic control. Both recessive genes and complementary genes effects appear to influence zinc deficiency. Single cross K724 x K731 was found to be a susceptible hybrid, but inbred K731 was observed to be a resistant line. This indicated that a recessive gene probably was responsible for resistance. The single cross of a late resistant line and an early resistant line, H28 x K55, showed high resistance. This is an example of an apparent complementary effect for the response to zinc deficiency. Further investigations need to be conducted to determine the nature of the genetic control of resistance to zinc deficiency.