ZINC CONTENT AND YIELD OF CORN AS INFLUENCED BY METHODS AND RATES OF APPLICATION OF ZINC AND PHOSPHORUS

by

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INTRODUCTION

Zinc deficiency as a problem in crop production in Kansas has become more important in recent years. As cultural practices are improved, more importance may be attached to this problem. Increased use of high analysis fertilizers and the method of placement in relation to plants may be a contributing factor in zinc deficiencies. As use of improved management practices increases yield potentials, the present level of zinc availability in soils may become limiting.

Leveling of land for irrigation may expose zinc deficient subsoils. In some areas of Kansas, zones of lime accumulation may be exposed which could decrease the availability of zinc in soils. In these and other zinc deficient soils, phosphorus may induce zinc deficiencies. Micronutrients other than zinc may become deficient in some soils of Kansas.

The objectives of this investigation were to study the effects of: (1) zinc fertilization on corn grown on soils known or suspected to be zinc deficient, (2) rates and methods of application of zinc and phosphate fertilizers on uptake of zinc by corn, (3) zinc and phosphate fertilization on corn grown on calcareous soils, and (4) to study the use of zinc fertilizers where high yields are the goal.

REVIEW OF LITERATURE

Zinc has been recognized as an essential element for several years. In an extensive literature review, Thorne (18) gives 1914 as the year when zinc was fully confirmed as an essential element. Recognition of zinc deficiencies under field conditions has developed extensively since.

Zinc deficiencies of plants result in combinations of chlorosis, rosetting, dieback, and abnormal or depressed vegetative growth (18). Barnette and Warner (2) described a physiological disease of corn called "white bud," a form of chlorosis, and found a zinc deficiency as the cause. Viets, Boawn, and Crawford (22) reported deficiency symptoms for 26 crops grown on zinc deficient soils of central Washington. Deficiency symptoms listed for corn included interveinal chlorosis and necrosis of lower leaves plus shortened internodes. Plants were tentatively classified as being very sensitive, mildly sensitive, or insensitive to zinc deficient soils. Corn, beans, and soybeans were among the common field crops listed as being very sensitive. Grain sorghum was classified as mildly sensitive.

Much of the early research concerning zinc deficiencies involved fruit crops. Chandler (9) has reviewed the history of verifying and treating zinc deficiency symptoms of fruit crops in Florida and California. Early workers found that zinc was the only micronutrient, when added to the soil, effective in relieving deficiency symptoms of fruit trees.

However, soil treatments were found to require large amounts of zinc sulfate. It was assumed that the zinc was fixed in the soil and was not available to plants. Deficiency symptoms could be alleviated by driving a number of zinc coated nails into the tree, but this method was considered impractical except for verification purposes. The most effective method of removing zinc deficiency symptoms was found to be aerial applications of a zinc sulfate solution. This technique has been used for a number of years.

Zinc deficiencies in field crops have been studied extensively only recently. Deficiencies in important field crops were believed to occur only in isolated areas and received very little attention. Barnette, Camp, Warner, and Gall (1) found that zinc sulfate was effective in curing white bud of corn on the lighter sandy soils of central Florida. Viets (20) reported zinc deficiencies in corn and beans grown on newly irrigated soils of central Washington. Pumphrey and coworkers (15) have recently noted zinc deficiencies of irrigated corn in western Nebraska and found that the symptoms were becoming more widespread in that area. The most effective treatment was found to be five pounds of zinc as $ZnSO_4$ per acre broadcast and plowed under.

Many attempts have been made to determine zinc deficiency levels in plants. Data are not sufficient to establish a critical level (18). The level at which responses may occur probably depends on other nutritional or environmental factors. A level of below 15 ppm zinc in leaves of plants has been used. Boawn and Legget (5) found that neither development of deficiencies nor elimination of deficiencies was well correlated with changes in concentration of zinc in stems and leaf tissues of potato plants. In studies on the effect of temperature on phosphorus induced zinc deficiencies of tomatoes, Martin, McLean, and Quick (14) found that both deficient and normal plants had about the same concentration of zinc at high temperatures. Watanabe, Lindsay, and Olsen (23) suggested that the use of critical values to diagnose nutrient disorders is not always satisfactory. The range in plant composition associated with deficient and normal plants often overlaps. Hiatt and Massey (12) also showed that zinc deficiency symptoms are not necessarily related to the concentration in the plant.

Soil zinc deficiencies often develop where the surface horizon has been removed by erosion or leveling for irrigation (11, 19, 20, 21). Viets (20) in 1951 reported zinc deficiencies on newly irrigated soils of central Washington. Corn and beans grown on these soils were chlorotic and stunted in growth. Application of zinc sulfate solution as foliar spray caused resumption of growth and cure of chlorosis. Viets et al. (21) found the zinc deficient soils of Washington where the topsoil had been removed were generally more alkaline in the plow layer (pH 7.6) and often had a zone of lime accumulation near the surface. Grunes, Boawn, Carlson, and Viets (11) studied "cut areas" in North Dakota and found a marked zinc deficiency in check plots.

Fertilization with zinc and addition of manure were both effective in relieving zinc deficiency symptoms and increasing yields of corn.

Travis (19) determined zinc availability in the profiles of several known or suspected zinc deficient Kansas soils. Soils from areas recently leveled for irrigation contained low concentrations of available zinc. The available zinc content of the soil is normally associated with the surface organic containing horizon and decreases in concentration in the lower horizons. Where the surface horizon of calcareous soils had been removed by erosion or land leveling, a zone of free carbonates was often found. This might be important in decreasing availability of zinc in calcareous soils.

Zinc deficiencies frequently occur in soils containing abnormally high contents of soluble or total phosphates (18). Zinc deficiencies induced by phosphate fertilizer applications have been reported by several workers (5, 7, 8, 10, 11, 13, 14, 16, 23). Other workers (6, 8, 21) have found that such treatments do not induce zinc deficiencies.

Most of the early evidence of phosphorus induced zinc deficiency was observational (6). The appearance or accentuation of zinc deficiency symptoms as a result of phosphate application provided qualitative evidence that the symptoms were phosphorus induced. Rogers and Wu (16) were among the first to present quantitative data which showed a decrease in total zinc content of plant tops as a result of applying phosphate fertilizers. Working with varying treatments of lime, phosphate, and zinc on oats in Florida, it was found that zinc content of plants decreased to an almost constant value with increasing rates of phosphate, while phosphorus content increased regularly in direct ratio to that applied.

Subsequent work in Washington (6, 21) and Tennessee (17) failed to show zinc deficiencies induced by phosphorus. Viets et al. (21) found that applications of phosphate did not induce zinc deficiency symptoms or restrict zinc uptake in corn as shown by leaf analysis. However, potassium and phosphate accumulated in zinc deficient plants. The conclusion was that accumulations of soluble phosphate in the soil could not account for zinc deficiency of corn on those soils. Boawn (6) considered the effect of phosphate applications to the very sensitive field bean in the same area of Washington. Phosphate application had no effect on the uptake of either applied or native soil zinc. Seatz, Sterges, and Kramer (17) studied the response of flax and sorghum to fertilization in Tennessee. Yields were significantly affected by liming and phosphorus and zinc fertilization. Plants receiving zinc contained less phosphorus than those not receiving zinc. However, phosphorus fertilization up to 1000 pounds phosphate per 2,000,000 pounds of soil had no influence on zinc response, but did significantly increase yields.

In more recent work, there is better agreement that phosphorus can induce zinc deficiencies. Grunes and coworkers (11) noted that in corn growing in cut areas in North Dakota, concentrated superphosphate appeared to increase zinc deficiency symptoms. For two consecutive years, Burleson, Dacus, and Gerard (8) observed phosphorus induced zinc deficiencies in corn grown in the Lower Rio Grande Valley of Texas.

Most of the recent work has been conducted in greenhouses using soils that produced phosphorus induced zinc deficiencies in the field (7, 8, 10, 13, 14, 23). Burleson *et al.* (8) noted severe phosphorus induced zinc deficiency in kidney beans with phosphorus fertilization. Zinc absorption was increased by zinc fertilization and decreased by phosphorus fertilization. Phosphorus uptake was increased by phosphorus fertilization and decreased by zinc fertilization. When both zinc and phosphorus were applied, the uptake of both zinc and phosphorus were reduced. It was concluded that phosphorus fertilization may induce zinc deficiencies in some crops under certain soil and climatic conditions. Langin, Ward, Olson, and Rhoades (13) showed that phosphorus applications markedly reduced zinc concentration in corn. The more effectively phosphorus was utilized, the more severe the curtailment of zinc uptake. It was believed that the problem was greatest in calcareous soils which are initially high in available phosphorus and where zinc solubility is restricted by high pH. Ellis, Davis, and Thurlow (10) studied zinc availability in a calcareous Michigan soil. High phosphorus applications decreased zinc concentration and ten pounds of zinc added increased zinc concentration in corn tops. Yields of field beans were reduced mainly due to phosphorus induced zinc deficiency.

Boawn and Legget (5) grew Russet Burbank potatoes on field plots of the Columbia River Basin in Washington and in nutrient solutions. Levels of phosphorus and zinc nutrition were varied so that both normal and zinc deficient plants were produced. Increasing the supply of phosphorus induced a growth disorder that could be eliminated by an increased supply of zinc.

Brown and Tiffin (7) and Watanabe *et al.* (23) studied nutrient balances involving phosphorus, iron, and zinc. Brown and Tiffin (7) found that in the absence of iron and zinc, increasing additions of phosphate accentuated or caused some plants to develop zinc deficiencies when grown in Tulare clay (a zinc deficient soil). It was also reported that too much zinc caused iron chlorosis to develop in corn and millet. Watanabe (23) encountered various nutrient interactions from addition of modest levels of zinc, iron, and phosphorus to a calcareous soil showing response to these nutrients. Further investigations of nutritional effects of various levels of phosphorus, iron, and zinc in nutrient solution cultures buffered by means of solid phase $CaCO_3$ were made on corn and pinto beans. Results with corn showed that zinc concentrations were depressed at all zinc levels with addition of phosphorus. Additions of phosphorus did not interfere with the utilization of zinc in pinto beans.

The effects of temperature on phosphorus induced zinc deficiencies have been reported by several workers (8, 10, 14). Burleson (8) noted zinc deficiencies in corn grown in cold wet soils during the early part of the growing season and suggested that this was probably phosphorus induced. It was thought that phosphorus induced zinc deficiency is caused by restricting root development near the zone of fertilizer placement. Ellis and coworkers (10) found that yield, zinc concentration in the plant, and zinc uptake by corn decreased when the soil temperature of a calcareous Michigan soil was decreased from 75 to 55° F. Martin, McLean, and Quick (14) grew tomatoes as indicator plants in zinc and phosphorus deficient soils. On a soil moderately low in zinc, phosphorus induced zinc deficiency symptoms occurred at 50 and 60° F. On an acutely zinc deficient soil, phosphorus induced zinc deficiencies were noted at all temperatures.

The mechanisms and conditions involved in the development of phosphorus induced zinc deficiencies are not fully understood. Frequently offered as an explanation is that insoluble zinc phosphates and hydroxides are formed (3, 4, 16). Bingham and Martin (4) concluded that copper and zinc were adversely affected by large applications of $Ca(H_2PO_4)_2 \cdot H_2O$ and presumeably by other phosphate carriers. Bingham and Garber (3) later studied availability of zinc in the presence of an excess of $Ca(H_2PO_4)_2$ in 19 zinc deficient California soils. It was concluded that phosphorus fertilization may produce important interactions with zinc in soils low in available zinc.

Data of Ellis (10) support the possibility that the zinc-phosphorus interaction is either at the root surface or within the plant. Langin _et_ _al_. (13) concluded that damaging effects of phosphorus on zinc utilization is physiologically within the plant, perhaps in plant root cells, and is not a simple chemical precipitation of zinc phosphate external to the roots. Since applied zinc counteracts the harmful phosphorus effects, it would appear to be an absorption phenomona in root cells where increasing levels of phosphorus would block absorption of zinc, and vice versa. Watanabe _et_ _al_. (23) suggested that phosphorus may interfere with normal utilization of zinc in the plant.

Data collected by Boawn and Legget (5) showed that abnormal growth is not associated with decline in zinc concentration or total zinc in the plant, but suggests that abnormal growth results from an imbalance between phosphorus and zinc. Results showed that high concentrations of phosphorus in tissues resulting in a high phosphorus/zinc ratio appear to offer a better explanation for metabolic upset. Healthy potato plants had a phosphorus/zinc ratio of less than 400, while deficient plants had a ratio of greater than 400. Watanabe (23) reported that slightly depressed yields of corn appeared to be associated with an extremely high phosphorus/zinc ratio. Further evidence of the importance of proper nutrient element balance was given by Brown and Tiffin (7).

Burleson, Dacus, and Gerard (8) suggested the possibility of a phosphorus-zinc antagonism within the root. Boawn and Legget (5) stated that a mutual antagonism might exist, but that a full understanding of the mechanism will probably involve more than a simple relationship involving only phosphorus and zinc.

Further progress in understanding the phosphorus-zinc relationship depends to a large extent upon understanding the factors involving plant and soil relationships. The research that has been done demonstrates the importance of nutrient element balance in plant nutrition and soil management (7).

EXPERIMENTAL PROCEDURE

Field experiments were conducted with irrigated corn at three locations in Kansas in 1965. One location was on the farm of Mr. Joe Campbell in the Kansas River valley in Shawnee County. This experiment was conducted during the second crop season after leveling for irrigation. A second location was in the Kansas River valley in Pottawatomie County on the farm of Dr. Ernest Mader. The soil at this location had not been leveled for irrigation. A third location was in the Solomon River valley in north central Kansas.

This experiment was on a newly leveled, calcareous soil on the farm of Mr. George Gilson in Osborne County.

A randomized complete block design with four blocks and twelve treatments was used. The blocks were 50 feet in length at the Pottawatomie and Osborne County locations and 25 feet in length at the Shawnee County location. Four rows (row width was 40 inches) were used for each treatment.

All locations received a blanket application of nitrogen before the corn was planted. Applications of 150 pounds per acre of actual nitrogen were made in Shawnee and Pottawatomie Counties. Experimental fertilizer treatments were made immediately after the corn was planted. Rates of fertilizer used, on a per acre basis, were 10 pounds of zinc as zinc sulfate, starter (10-40-20) without zinc and starter (10-40-20) with 5, 10, and 20 pounds of zinc as zinc sulfate mixed with the starter. These rates were applied by two methods, broadcasting and banding. Fertilizers for the broadcast treatments were distributed by hand. The banded treatments consisted of placing the fertilizer in a localized area at the side of the row with a tillage implement. One additional treatment was made using starter (10-40-20) plus 10 pounds of zinc as zinc sulfate as a split application, i.e., half was broadcast and the other half banded. A check plot was the twelfth treatment.

Two absorption spectroscopy techniques were used for the laboratory analyses. Phosphorus was determined using a colorimetric procedure. Colorimetry concerns the absorption of visible light by a colored solution. Radiation absorption is measured as a function of wavelength and sample concentration. The wavelength of incident light chosen is the wavelength most absorbed by the test solution. The amount of light absorbed is related to the intensity of incident light I_0 and the intensity I after passing through the solution. The sample concentration c can be found by using the Beer's-law expression: $\ln(I_0/I) = \alpha cl$, where l is the length of the sample cell and α is the absorption coefficient. The amount of light transmitted through the sample, %T, can be used to determine sample concentration since $\%T = I/I_0 \times 100$.

Atomic absorption spectroscopy was used for zinc, iron, and manganese analyses. Certain atoms in their ground state will absorb radiation of a resonance wavelength. In atomic absorption spectroscopy, a solution containing the test element is vaporized by using a high temperature flame. The absorbance of the flame for light of a resonance wavelength is a measure of the concentration of absorbing atoms in the flame. Therefore it is also a measurement of the concentration of atoms in the test solution.

Soil samples from each location were analyzed for available zinc. The extracting agent used was 0.2N HCl. The samples were processed using a wooden roller and a 40 mesh stainless steel sieve to avoid contamination. Five grams of soil were placed in 100 ml polyethylene centrifuge tubes and 50 ml of 0.2N HCl were added. After stirring, the tubes were stoppered with polyethylene stoppers and placed on a wrist action shaker for one hour. After shaking, the pH of a small portion of the suspension was measured. The pH must be less than 5 in order to insure complete extraction of available zinc. The samples were then centrifuged until the supernatant liquid was clear. A 40 ml aliquot of the supernatant liquid was taken to dryness. The residue was brought into solution, filtered, and made to a final volume of 25 ml with 0.1N HCl. A Perkin Elmer Model 303 atomic absorption spectrophotometer was used to determine zinc concentrations. The wavelength used was 2138A. A standard curve was made using zinc concentrations of 1, 2, and 3 ppm.

The third leaf from the top of the corn plant was used for tissue analyses of phosphorus and zinc. Ten leaves were taken from the two center rows, excluding ten feet at each end (2½ feet at each end in Shawnee County) for each treatment. The samples were dried at 65° C for three days and then ground. The ground samples were stored in cardboard boxes.

Phosphorus concentration in leaf tissues were determined in duplicate using 0.4 gm samples. Samples were placed in 50 ml pyrex beakers and 5 ml of alcohol solution containing $Mg(C_2H_3O_2)_2 \cdot 4H_2O$ were added to each sample. The beakers were placed on a hot plate and the samples were ignited by applying a flame to the beakers. After the burning had stopped, the samples were placed in a muffle furnace and ashed at 550° C for two hours. After cooling, 10 ml of 2N HCl were added to the residue. The residue was filtered and the filtrate taken to the desired volume with distilled water. The pH of the filtrate was adjusted to a phenolphthalein end point with 0.2N NaOH. A blue color was developed in the filtrate by adding 2 ml of ammonium molybdate solution and 2 ml of organic reducing agent (aminonaphthol-sulfonic acid) and mixing. The concentration of phosphorus in solution is related to the amount of light that can be transmitted through the colored solution. After 15 minutes, the transmittancy was measured with a Coleman Junior spectrophotometer at a wavelength setting of 660 mμ. A standard curve was made using known phosphorus concentrations.

For the determination of zinc concentration in plant tissues, 2.0 gm samples were used. Duplicate samples were placed in 50 ml pyrex beakers and dry ashed at 550° C in a muffle furnace for two hours. About 10 ml of 0.1N HCl were added to the residue and stirred. The residue was filtered and the filtrate was made to a final volume of 25 ml with 0.1N HCl. Zinc concentration was determined using the atomic absorption spectrophotometer.

Iron and manganese concentrations were determined for the plant tissue samples from Osborne County after poor growth was observed at that location. The atomic absorption spectrophotometer was used for these analyses using the extract prepared for the zinc determination. Wavelengths used were 2480A for iron analysis and 2800A for manganese analysis.

Yields were determined for each treatment by hand harvesting the middle 30 feet of the two center rows (the middle 20 feet of the two center rows in Shawnee County) and weighing. The moisture content was determined by weighing a three ear sample immediately after harvesting, then drying at 65° C to a constant weight. The weights of the harvested corn were then corrected to 15.5% moisture. The weight of corn per plot was converted to bushels per acre (one bushel ear corn = 70 pounds).

RESULTS AND DISCUSSION

The effects of phosphate and zinc fertilization on the concentration of zinc and phosphorus in corn leaves, and yields of corn were studied at three locations. Various fertilizer rates and methods of fertilizer application were used. Data obtained at each location are discussed separately with no attempt being made to correlate the results obtained at different locations. The significance of differences are based on the 5% level.

Available zinc levels in the soil at each location are given in Table 1. Available zinc levels at a soil depth of three feet are given for the Shawnee and Osborne County locations.

Table 1. Levels of available zinc in the soil profiles at three experimental locations.

Location of experiment	Concentration of available zinc (ppm)	
	Sampling depth	
	0-6 inches	3 feet
Shawnee County	1.6	0.9
Pottawatomie County	2.7	
Osborne County	2.3	2.8

Shawnee County

The soil at the Shawnee County location contained 1.6 ppm of extractable zinc in the surface horizon and 0.9 ppm at a depth of three feet. This level of extractable zinc was considered to be too low for normal growth of corn. Visible zinc deficiency symptoms were noted in corn plants that had not received zinc. Deficiency symptoms were pronounced during the early stages of growth, but tended to disappear during the latter part of the growing season. Soil conditions were colder and wetter than normal during the early stages of growth, which may partially account for the pronounced deficiency symptoms. More extensive root growth after the soil had warmed may have decreased the severity of zinc deficiencies. A more extensive root system may increase zinc uptake by the plant because of increased root contact with the soil, or possibly by roots growing into a soil layer with a higher concentration of available zinc. However, in this soil, the level of available zinc appeared to decrease with soil depth.

The concentrations of zinc and phosphorus in corn leaves and yields of corn are given in Table 2. Zinc concentrations in corn leaves were higher, when compared to the check plot, for all fertilizer treatments containing zinc, except where ten pounds of zinc per acre was banded. Banding zinc increased zinc concentration in the plant, but the difference was not significant. Zinc concentration was not significantly affected by applying 10-40-20 fertilizer without zinc.

The method of fertilizer application appeared to be a factor in leaf zinc concentration when 10-40-20 fertilizer was used. For the broadcast applications of 10-40-20 fertilizer there was little difference in leaf zinc concentration, except the treatment of 10-40-20+20Zn did have a higher concentration than the 10-40-20 without zinc treatment. However, differences were observed when 10-40-20 fertilizers with various rates of zinc were banded. Treatments of 10-40-20+10Zn and 10-40-20+20Zn had higher leaf zinc concentrations than the other banded treatments.

For the 10-40-20+0Zn treatments, leaf zinc content was lower when the fertilizer was banded. Leaf zinc concentration was not affected by the method of application for the 10-40-20+5Zn treatment. Banded treatments of 10-40-20+10Zn and 10-40-20+20Zn had higher leaf zinc concentration than

Table 2. Effect of rate and method of application of zinc on the zinc and phosphorus concentrations in leaf tissues and on the yield of corn grown on irrigated soil in Shawnee County.

Treatment[a] N-P_2O_5-K_2O+Zn (as $ZnSO_4$)	Zinc concentration (ppm Zn in leaf)		Phosphorus concentration (% P in leaf)		Yield (bu/acre)	
	Broadcast	Banded	Broadcast	Banded	Broadcast	Banded
0--0--0 +10	8.7	7.1	0.16	0.15	122	115
10-40-20+0	6.9	3.9	0.22	0.39	121	93
10-40-20+5	9.1	9.3	0.19	0.29	142	131
10-40-20+10	9.0	13.6	0.21	0.22	139	140
10-40-20+20	10.3	13.4	0.18	0.23	150	144
10-40-20+10[b]	9.0		0.18		134	
Check	5.1		0.15		108	
Least significant difference (.05)	2.7		0.06		19	

[a] A uniform application of 150 pounds of nitrogen per acre was applied in addition to the nitrogen in the starter.

[b] One half of the fertilizer was broadcast and the other half was banded.

did the corresponding broadcast treatments. The split application of 10-40-20+10Zn gave the same effects as the broadcast treatment.

Both the method of application and the rate of zinc in the 10-40-20 fertilizers affected phosphorus concentration in corn leaves. The treatments where 10-40-20 was banded, regardless of the zinc rate, had higher leaf phosphorus concentrations than the check plots. Broadcast treatments of 10-40-20 fertilizers also increased leaf phosphorus concentration, but not to the degree that the banded treatments increased phosphorus concentration. However, increases for the broadcast treatments of 10-40-20 with 5 and 20 pounds of zinc were not significant at the 5% level. Zinc alone did not influence phosphorus concentration in leaves.

The rate of zinc did not affect phosphorus concentration in the corn plants when the 10-40-20 fertilizers were broadcast. However, leaf phosphorus was affected by banding the 10-40-20 fertilizers with different rates of zinc. Leaf phosphorus concentration was very high for the 10-40-20 without zinc treatment and decreased with increasing rates of zinc.

Banding the 10-40-20 fertilizer without zinc and with 5 pounds of zinc resulted in much higher leaf phosphorus levels than when these rates were broadcast. The method of application did not significantly affect leaf phosphorus concentration at the higher rates of zinc in the 10-40-20 fertilizers.

Yields of corn were higher with all treatments of 10-40-20+Zn, regardless of the method of application and rate of zinc, when compared to the check plots. Treatments of zinc alone and broadcast application of 10-40-20 without zinc increased yields, but the increases were not significant at the 5% level. Banding 10-40-20 fertilizer without zinc decreased the yield 15 bushels per acre, but the difference was not significant at the accepted level of significance.

For broadcast applications, there were no significant differences in yield for the various 10-40-20+Zn treatments. However, yields were lower when zinc alone and 10-40-20 without zinc were applied. When the fertilizers were banded, yields did not differ for the various 10-40-20+Zn treatments. Where 10-40-20 without zinc was banded, the yield was much lower than for all other banded treatments. Applications of 10-40-20 with the higher rates of zinc were more effective in increasing yields than banding zinc alone.

In general, the method of application did not significantly affect yields for the various fertilizer treatments. However, the 10-40-20 without zinc treatment was an important exception. Banding 10-40-20+0Zn resulted in a decreased yield of 28 bushels per acre.

The yields were relatively high throughout the experiment with only two treatments giving yields of less than 115 bushels per acre. However, yields were affected by the phosphorus-zinc relationship, especially when the treatments were banded. For the banded 10-40-20+0Zn treatment, zinc concentration in the leaf was very low (3.9 ppm), phosphorus concentration in the leaf was very high (0.39%), and yields were much lower than the other treatments (93 bushels per acre). It appeared that a phosphorus induced zinc deficiency was produced by this treatment. Increasing rates of zinc up to ten pounds with the banded 10-40-20 treatments increased zinc concentration in the leaf, decreased phosphorus concentration in the leaf, increased yield of corn and apparently was effective in relieving deficiency symptoms of the plants.

It appeared that a level of 9 ppm zinc in the corn leaf, at the time of sampling, was sufficient for yields of about 140 bushels per acre except where less than ten pounds of zinc was banded with the 10-40-20 fertilizer. Application of five pounds zinc with the banded 10-40-20 fertilizer gave a yield of 131 bushels per acre while the leaf zinc concentration was 9.3 ppm. The phosphorus level in the leaf for this treatment was 0.29%, which was greater than when higher rates of zinc were banded with the 10-40-20 fertilizer. The increased content of phosphorus might have caused the slight decrease in yield.

Results obtained in this experiment indicate that the phosphorus-zinc relationship was important under the existing experimental conditions. Results showed that application of zinc with 10-40-20 starter fertilizer was effective in alleviating zinc deficiency symptoms and increasing yields of corn.

Pottawatomie County

The experiment in Pottawatomie County was on a soil that had not been leveled for irrigation. The concentration of available zinc in the surface horizon was 2.7 ppm. Available zinc was not determined in the lower horizons. This level of available zinc was not very high, but there was no reason to expect the soil to be zinc deficient before the experiment was started. All other soil factors were considered to be sufficient for the production of high yields. This was supported by a check plot yield of 126 bushels per acre (Table 3). The main objective of this experiment was to determine if the addition of zinc fertilizer would increase crop yields where other conditions were not limiting.

Growth was uniformly good for all fertilizer treatments throughout the growing season. There were no visible signs of zinc deficiencies noted at any time.

Concentrations of zinc and phosphorus in leaf tissues and yields for the various fertilizer treatments are shown in Table 3. Statistical analysis of variance showed that differences in yield and leaf phosphorus concentrations were not significant at the 5% level.

There were significant differences in levels of zinc concentration in corn leaves with various fertilizer

Table 3. Effect of rate and method of application of zinc on the zinc and phosphorus concentrations in leaf tissues and on the yield of corn grown on irrigated soil in Pottawatomie County.

Treatment[a] $N-P_2O_5-K_2O+Zn$ (as $ZnSO_4$)	Zinc concentration (ppm Zn in leaf)		Phosphorus concentration (% P in leaf)		Yield (bu/acre)	
	Broadcast	Banded	Broadcast	Banded	Broadcast	Banded
0--0--0 +10	13.2	11.7	0.36	0.35	128	136
10-40-20+0	10.8	10.1	0.34	0.37	124	123
10-40-20+5	9.2	12.4	0.33	0.34	124	124
10-40-20+10	11.7	13.0	0.34	0.36	120	131
10-40-20+20	11.5	15.1	0.35	0.33	126	134
10-40-20+10[b]	12.2		0.35		126	
Check	14.3		0.36		126	
Least significant difference (.05)	2.5		differences not significant		differences not significant	

[a] A uniform application of 150 pounds of nitrogen per acre was applied in addition to the nitrogen in the starter.

[b] One half of the fertilizer was broadcast and the other half was banded.

treatments, but a general relationship could not be established. It appeared that additional fertilizer applications might have depressed leaf zinc concentration except where fairly high rates of zinc were placed close to the plants. All of the broadcast treatments of 10-40-20+Zn had lower leaf zinc concentrations than the check plots. Banding treatments of ten pounds of zinc and 10-40-20 without zinc also gave lower leaf zinc contents than the check plots.

There was some difference noted among the broadcast treatments, but no definite trend could be established. Broadcasting the 10-40-20+Zn treatments gave lower leaf zinc concentrations than the ten pounds of zinc per acre treatment, but only the 10-40-20+5Zn treatment was significantly lower. For the banded treatments, a higher zinc concentration occurred for the 10-40-20+20Zn treatment than for zinc alone. When 10-40-20 treatments were banded, increasing the rate of zinc appeared to increase leaf zinc concentration.

Higher leaf zinc concentrations occurred when the 10-40-20+5Zn and 10-40-20+20Zn treatments were banded rather than broadcast. Using a split application of fertilizer did not influence the level of zinc concentration in leaves.

Although differences in phosphorus concentrations in leaves were not found, the concentrations for all treatments were high, ranging from 0.33 to 0.37% phosphorus. Banding fertilizers containing zinc increased yields from 5 to 10 bushels per acre, but these increases were not significant at the 5% level.

Data obtained in this experiment were not sufficient to establish a critical level of plant zinc concentration. The suggested value of 15 ppm was not valid for the conditions at this location since good yields were obtained for all treatments. Levels of zinc concentration, at the time of sampling, were less than 15 ppm except for one treatment. The high phosphorus concentrations may have depressed the zinc concentrations to a degree, although yields obtained were not affected. The slight increase in yields obtained for the treatments where 10 and 20 pounds of zinc per acre were banded suggests that slightly higher rates of zinc might be more effective. However, increasing zinc rates might develop complications with regards to other essential nutrient elements.

Osborne County

The experiment in Osborne County was conducted on a recently leveled calcareous soil. The surface horizon of the soil contained 2.3 ppm extractable zinc. The soil had a slightly higher level of extractable zinc, 2.8 ppm, at a depth of three feet. Before the experiment was started, it was suspected that this soil was zinc deficient. The main objective of this experiment was to study the effects of zinc and phosphorus fertilization on irrigated corn grown on a calcareous soil.

Growth of corn was stunted throughout the experimental area for the duration of the growing season. Severe deficiency symptoms similar to those for zinc deficiencies were noted for all treatments. The broadcast treatments of 10-40-20 fertilizer were not as severely deficient as the other treatments. Applications of zinc were not effective in relieving the deficiency symptoms. The failure of zinc treatments to alleviate deficiency symptoms suggested that some other minor element might be deficient or adversely affected by the calcareous nature of the soil. For this reason, leaf tissues were analyzed for iron and manganese as well as for zinc and phosphorus. The concentrations of zinc and phosphorus in leaf tissue samples and yields of corn are shown in Table 4. Iron and manganese concentrations in leaf tissues are given in Table 5.

The banded application of ten pounds of zinc per acre was the only treatment that had significantly higher leaf zinc concentration than the check plots. Some differences were noted for the other treatments when compared to the check plots, but none were significant at the 5% level.

For the broadcast treatments, application of zinc increased leaf zinc concentration. Broadcasting 10-40-20+20Zn and zinc alone were the most effective treatments. When the fertilizers were banded, the 10-40-20 without zinc and the ten pounds of zinc per acre treatments had the highest leaf zinc concentrations.

Table 4. Effect of rate and method of application of zinc on the zinc and phosphorus concentrations in leaf tissues and on the yield of corn grown on irrigated soil in Osborne County.

Treatment[a] N-P_2O_5-K_2O+Zn (as $ZnSO_4$)	Zinc concentration (ppm Zn in leaf)		Phosphorus concentration (% P in leaf)		Yield (bu/acre)	
	Broadcast	Banded	Broadcast	Banded	Broadcast	Banded
0--0--0 +10	11.4	13.0	0.14	0.14	6	7
10-40-20+0	8.0	12.4	0.16	0.15	26	11
10-40-20+5	9.9	9.1	0.16	0.15	30	15
10-40-20+10	9.7	9.0	0.17	0.15	36	19
10-40-20+20	10.8	11.2	0.16	0.15	36	15
10-40-20+10[b]	10.4		0.15		22	
Check	10.1		0.15		12	
Least significant difference (.05)	2.4		0.01		7	

[a] A uniform application of nitrogen in addition to the nitrogen in the starter was applied.

[b] One half of the fertilizer was broadcast and the other half was banded.

Table 5. Concentrations of iron and manganese in leaf tissues of corn grown on irrigated soil in Osborne County.

Treatment[a] $N-P_2O_5-K_2O+Zn$ (as $ZnSO_4$)	Iron concentration (ppm in leaf)		Manganese concentration (ppm in leaf)	
	Broadcast	Banded	Broadcast	Banded
0--0--0 +10	23.3	21.9	81	105
10-40-20+0	15.3	22.6	71	102
10-40-20+5	20.4	13.2	75	101
10-40-20+10	16.9	10.8	74	91
10-40-20+20	13.8	13.4	74	97
10-40-20+10[b]	19.1		104	
Check	23.1		101	
Least significant difference (.05)	4.2		15	

[a] A uniform application of nitrogen in addition to the nitrogen in the starter was applied.

[b] One half of the fertilizer was broadcast and the other half was banded.

The method of application did not affect leaf zinc concentration when zinc was included in the fertilizer treatment. However, higher leaf zinc concentration did occur when 10-40-20 without zinc was banded rather than broadcast. Under the existing experimental conditions, banding phosphorus fertilizer without zinc did not decrease leaf zinc concentration as might be expected. Instead, banding 10-40-20+0Zn increased zinc concentration by 4.2 ppm.

Phosphorus concentrations in leaf tissues were low for all treatments, but significant differences were noted. Application of zinc alone had slightly lower leaf phosphorus concentrations than the other treatments. Higher phosphorus concentrations occurred when 10-40-20 fertilizers, both with and without zinc, were broadcast.

Yields for all treatments were much lower than normally expected for irrigated corn. Yields should have approached, or even exceeded, 100 bushels per acre with a proper nutrient balance under the existing environmental conditions. Yields for all treatments ranged from 6 to only 36 bushels per acre. An extremely low yield of 12 bushels per acre for the check plots suggested a severe soil deficiency of some nutrient or nutrients. The highest yield of 36 bushels per acre indicates that the fertilizer treatments used were partially effective, but that other elements might be lacking.

Application of zinc alone decreased yields when compared to the check plots, but decreases were not significant at the 5% level. All broadcast treatments of 10-40-20 fertilizers had higher yields than the check plots. Banded and split application of 10-40-20+10Zn also resulted in slightly higher yields.

For broadcast applications of 10-40-20 fertilizers, increasing rates of zinc up to ten pounds increased yields. The broadcast treatment of zinc alone resulted in a much lower yield. Ten pounds of zinc applied with 10-40-20 fertilizer was the most effective treatment when the fertilizers were banded. Broadcasting 10-40-20 fertilizers, at all zinc rates, was more effective than banded treatments of corresponding rates.

A general relationship between yields and zinc concentration in the leaves could not be established. Treatments where the higher yields were obtained did not necessarily have higher concentrations of zinc in leaves at the time of sampling. A possible explanation may be that dilution of the leaf zinc concentration occurred where plant growth was increased.

Yields did appear to be related to phosphorus concentration in the leaves. Although leaf phosphorus concentrations were thought to be too low for good yields, the higher yields were obtained for treatments where phosphorus concentrations were also higher. It was expected that corn plants would have higher leaf phosphorus concentrations when 10-40-20 fertilizers were banded, but this was not the case under the existing conditions. Data obtained were not sufficient to explain this unexpected result.

Since the application of both zinc and 10-40-20 fertilizer failed to relieve deficiency symptoms and increase yields to the expected levels, it was concluded that some other nutrient was limiting. Levels of iron and manganese in the leaf tissues were determined to see if these elements might have affected yields and plant growth.

Leaf concentrations of manganese were relatively high for all treatments, ranging from 71 to 105 ppm. Generally, where yields were highest, leaf manganese concentrations were lowest, and vice versa. Where manganese concentrations were lowest, it was noted that plant growth was generally the best. The lower concentrations may have been due to a dilution effect caused by increased growth. The possibility that manganese might have been a factor in plant growth and yields of corn was discarded.

Iron concentrations in the leaf tissues ranged from 10.8 to 23.3 ppm. There appeared to be no general relationship between leaf iron concentrations and yields of corn, but the levels of iron present were probably too low for good plant growth. There are no data available that would indicate the critical level of iron needed for the existing experimental conditions.

The availability of iron to the corn plant may have been decreased due to the calcareousness of the soil. A decrease in availability was probably more likely than an actual deficiency of iron in the soil. Organic matter may increase availability of iron, but the organic containing soil horizon had been removed prior to the experiment. The lack of organic matter and the excess of calcium carbonates in the soil probably were both effective in reducing iron availability to the plant.

The results obtained indicate that both zinc and iron were deficient in the soil used for this experiment. Broadcase applications of 10-40-20 fertilizers with zinc increased yields to a degree. Levels of iron in leaf tissues indicate that this element might be lacking. Increasing the organic matter content of the soil, either by natural accumulation or application of manure, might increase the availability of both zinc and iron. Further work needs to be done at this experimental site to determine the zinc and iron relationships to plant growth. It may be found that zinc-iron interactions are important and that phosphorus may be involved at higher concentrations of all elements concerned.

SUMMARY

Data obtained show that zinc-plant relationships were important when corn was grown on zinc deficient soils. Some evidence was found that zinc may be limiting when other factors are sufficient for high yields of irrigated corn.

Visible zinc deficiency symptoms were noted in corn grown on the zinc deficient soil in Shawnee County. Application of zinc was effective in relieving deficiency symptoms.

Both zinc and phosphorus concentrations in leaves were affected by rates and methods of application of 10-40-20 fertilizers containing zinc. Treatments containing zinc increased yields, but the increases where zinc alone was applied were not significant at the 5% level. The zinc-phosphorus relationship was important at this location. There were indications that some of the severe deficiencies were phosphorus induced.

Banding rates of zinc up to 20 pounds per acre increased yields of corn in Pottawatomie County, but the increases were not significant. Phosphorus concentrations in leaves were extremely high for all treatments. Zinc concentrations in the leaves were affected by the various fertilizer treatments, but the levels appeared not to be related to yields.

In Osborne County, growth of corn was stunted and deficiency symptoms were apparent for all treatments. Yields were low in all cases indicating that some nutrient besides zinc was deficient. Zinc concentrations in leaves were affected by various fertilizer treatments, but levels could not be related to yields. Leaf phosphorus concentrations were very low, regardless of the fertilizer treatment. Manganese concentrations in leaves apparently were sufficient for good growth. Low concentrations of iron were found in the leaves. Iron deficiency may have been the most important factor limiting production of high yields of corn at this location.

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ZINC CONTENT AND YIELD OF CORN AS INFLUENCED BY METHODS AND RATES OF APPLICATION OF ZINC AND PHOSPHORUS

by

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ABSTRACT

An investigation was conducted to study the effects of zinc and phosphorus fertilization on irrigated corn under various field conditions. Three locations were used for the experiment. Locations were in Shawnee and Pottawatomie Counties in the Kansas River valley and in Osborne County in the Solomon River valley. Fertilizer treatments were ten pounds of zinc per acre and 10-40-20 starter with 0, 5, 10, and 20 pounds of zinc per acre. The methods of application were broadcast and banded.

The experiment in Shawnee County was conducted on a recently leveled, zinc deficient soil. Visible zinc deficiency symptoms were observed in corn plants that had not received zinc. Deficiency symptoms tended to disappear during the latter part of the growing season indicating that temperature may play a role in the uptake of zinc by corn.

The rates and methods of fertilizer application affected both zinc and phosphorus concentrations in corn leaves. Yields of corn were increased with treatments of 10-40-20 fertilizer containing zinc. Application of zinc alone increased yields, but the increases were not significant at the 5% level.

The zinc-phosphorus relationship in corn plants was important at the Shawnee County location. Banded application of 10-40-20 fertilizer without zinc decreased yields

and zinc concentration in the leaves, but increased phosphorus concentration in the leaves. Increasing rates of zinc in the banded 10-40-20 fertilizer treatments increased yields, increased leaf zinc concentrations, and decreased leaf phosphorus concentration to a normal level. There were indications that some of the severe zinc deficiencies were phosphorus induced.

The experiment in Pottawatomie County was conducted on a soil that was not considered to be zinc deficient. High yields of corn were expected at this location. A yield of 126 bushels per acre was obtained for the check plots indicating that conditions for growth were good. Zinc concentrations in the leaves were affected by the various fertilizer treatments containing zinc. Levels of phosphorus concentrations in the leaves were high for all treatments, but differences between treatments were not significant. Yields were increased 5 to 10 bushels per acre by increasing banded rates of zinc up to 20 pounds per acre, but these increases were not significant at the 5% level.

The experiment in Osborne County was conducted on a recently leveled, calcareous soil. The soil was expected to be zinc deficient due to the removal of the organic containing soil horizon and the calcareous nature of the soil. Growth of corn was stunted and deficiency symptoms similar to those for zinc deficiencies were noted for all treatments. Zinc concentrations in the leaves were affected by the various fertilizer treatments, but no general relationships could be established. Phosphorus concentrations in the leaves were higher where 10-40-20 fertilizers were broadcast, but the levels were low in all cases. Yields were increased by the broadcast treatments of 10-40-20 fertilizers, but were still not as high as expected. The levels of manganese concentrations in the leaves indicated that manganese was not a limiting factor. Iron concentrations in corn leaves were low and could have been the most important limiting factor. A relationship involving phosphorus, zinc, and iron might have been responsible for the poor growth and low yields of corn at this location.