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The relationships between zinc, iron, and phosphorus in sweet corn were investigated under field and greenhouse conditions. The soils used in this study (both acid and calcareous) were low in available zinc and phosphorus.

The experiments received standard, uniform rates of nitrogen, potassium, magnesium, and sulphur. Corn was used as an indicator crop in all experiments. Plant samples from the field experiments consisted of whole plants collected at six weeks and index leaves collected at silking stage, while the middle three leaves were collected at eight weeks from the greenhouse experiment.

The plants that showed visual zinc deficiency symptoms contained very high iron contents and responded to applied zinc. When either phosphorus or soil acidity was limiting growth, no response was obtained from applied zinc and the iron levels were low. Applications of phosphorus and lime both apparently induced a zinc

deficiency and a high iron uptake by the plant. Under these conditions marked growth responses to applied zinc were obtained and sharp reductions in iron contents of the plants were noted.

These results are contradictory to those reported by other workers for the effect of phosphorus and lime on the uptake of iron; normally, these two materials reduce the uptake of iron by the plant. This was actually the case when zinc was adequate but the reverse was true when a zinc deficiency existed.

To explain these results, the hypothesis was advanced that one characteristic of a zinc-deficient plant is a high iron content. Although the actual lime and phosphorus effect is probably a reduction of iron uptake, their effect on creating a zinc deficiency and the associated high iron content was most likely the over-riding factor.

THE RELATIONSHIPS BETWEEN ZINC, IRON, AND PHOSPHORUS IN SWEET CORN

by

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THE RELATIONSHIPS BETWEEN ZINC, IRON, AND PHOSPHORUS IN SWEET CORN

INTRODUCTION

Marion County is a major area of vegetable crop production. In 1963 it contributed about one-fourth of Oregon's 38 million dollar vegetable crop income. The fertility level of the soils in the county varies from that of fertile, sandy river bottom soils that are relatively uniform to infertile gravel soils that may have as many as four or five different soil series within a 30 acre field. Uniform growth and maturation in such a field is quite important to the quality of the crop where mechanical harvesting is employed. Harvesting is scheduled when the major part of a field is ready; therefore, variations in maturity can result in considerable loss in yield of a marketable crop and materially increase the grading, handling, and processing costs.

In certain areas the Sifton soil contributes substantially to the lack of uniformity within a field. This soil is found intermingled with other soils of the area and occurs in spots ranging in size from less than one acre up to 20 acres or more. It is located on slight rises and has a high organic matter content (see Table 2) that gives it a darker color than the surrounding soil. The Sifton soil appears to retain moisture longer (possibly due to poorer plant growth) and is loose and fluffy, a condition which has been attributed to a high volcanic ash content. It is not uncommon for 25% of some fields to be composed of Sifton soil. The crops grown on these areas have poor growth, low yields, and delayed maturity.

In 1963 visual symptoms of zinc deficiency on corn were identified on these soils. The crop matured later and developed small, poorly-filled ears. Experiments with sweet corn and bush beans were established the following year to study the effect of applied zinc. Analysis of plant samples revealed a very high iron content in plants exhibiting visual zinc deficiency symptoms. These experiments also revealed the ability of these soils to fix a large amount of phosphorus. This fixation could be the result of large amounts of amorphous materials which is normal for soils high in ash content.

The objectives of this research were to investigate the zinc deficient areas located on Sifton soil and the factors affecting the uptake and utilization of zinc on these soils. This study was carried out by observing the effects that applied zinc, phosphorus, and lime had upon the yield and concentration of zinc, iron, and phosphorus within the plant. Additional emphasis was placed on evaluating the high iron concentration present within zinc deficient plants and the effect that this iron had on the phosphorus utilization within the plant.

REVIEW OF LITERATURE

Factors Affecting Availability of Zinc

Factors affecting the uptake and utilization of zinc by the plant can be divided into two groups. One area includes those factors affecting the availability of zinc within the soil and the other comprises those factors influencing the uptake and utilization of zinc by the plant.

Factors Affecting the Availability of Zinc Within the Soil

Soil pH has a marked effect on the availability of soil applied zinc as well as native zinc in the soil. Most zinc deficiency occurs on soils with a pH of 6.0 or greater. It is recognized by workers in this area that the addition of enough lime to increase the soil pH will reduce the availability of zinc to the plant. The decrease in availability is caused either by the formation of a zinc-calcite complex (Jurinak and Baver, 1956 and Jurinak and Therman, 1955) or by a direct pH effect (Wear, 1956). The pH effect is involved with the conversion of zinc into forms that are insoluble in the soil solution and therefore unavailable to the plant.

Some of the zinc deficiency in California and Florida has been associated with soils high in organic matter. It is present on many of the peat soils in Florida and has been found on old barn yards and corral sites in California (Seats and Jurinak, 1957). Deremer and Smith (1964) reported that organic matter which had been added to the soil reduced the availability of zinc. This reduction in availability of zinc was apparently the result of some type of chelation with the organic fraction (Brown, 1950; Himes and Barber, 1958; and Miller and Ohlrogge, 1959).

The adsorption of zinc on colloids has been observed in many soils (Thorne, 1957). It has been determined that adsorbed zinc is not readily replaced by other cations (Elgabaly, 1950). Elgabaly (1950) reported that zinc was apparently substituting for magnesium in clay containing magnesium in the crystal lattice and was fixed in spaces not occupied by Al in the octahedral layer of crystalline clays.

Factors Influencing Uptake and Utilization of Zinc by the Plant

Ozanne (1955) reported that subterranean clover growing on Australian soils which were low in available zinc showed increased zinc deficiency symptoms when the nitrogen supply was increased. Adding nitrogen as NH_4NO_3 or $(NH_4)_2SO_4$ decreased the amount of zinc in the tops. Ozanne concluded that zinc was being held in the roots by the formation of an immobile zinc-protein complex. Rosell and Ulrich (1964) reported that the accumulation of nitrates occurred within the blade of zinc deficient sugar beet plants and they contributed it to a lack of growth, or as a result of the lack of zinc to serve as a co-enzyme or activator in the stepwise transformation of nitrate to protein-nitrogen. On the other hand, Pumphrey et al. (1961) and Langin et al. (1962) reported that an increase in zinc uptake resulted when nitrogen was applied as NH_4NO_3 to sweet corn.

Many workers have reported that zinc and copper deficiencies in corn were being induced by high rates of phosphorus fertilization. The more soluble sources of phosphorus caused a greater reduction in zinc and copper utilization. Boawn and Legget (1964) suggested that a mutual antagonism was present between phosphorus and zinc in their uptake and accumulation within the plant. Burleson, Dacus and Gerand (1961) hypothesized that calcium from the phosphorus source might be interfering with zinc adsorption; however, Bingham and Garber (1960) conducted an experiment using different sources of phosphorus, with and without calcium, and their results showed similar reductions of zinc utilization with all sources of phosphorus. Some workers have concluded that the antagonism between phosphorus and zinc is physiological in nature, rather than being the result of an external soil zinc-phosphorus complex. The following reasons are offered in argument against soil fixation; the incubation of high levels of phosphorus in soil had no effect on the acid-soluble fraction of zinc (Olson, Stukenholtz and Hooker, 1965); broadcast applications of phosphorus did not decrease plant zinc as much as banded phosphorus applications (Langin et al., 1962); and very small quantities of zinc prevented zinc deficiency (Ellis, Davis and Thurlow, 1964). Olson, Stukenholtz and Hooker (1965) decided that the interaction was occurring only at the roots and not elsewhere within the plant because the addition of phosphorus reduced the level of zinc proportionately throughout the plant. This did not agree with Biddulph (1955) who reported the formation of a zinc-phosphorus complex in the veins and leaf midribs of beans grown in a nutrient solution low in iron. At higher iron levels an iron-phosphorus complex was formed because of its greater insolubility.

A nutrient balance of heavy metals appeared essential for the proper growth of plants (Brown and Tiffin, 1962; Hewitt, 1953; Millikan, 1961). When an element is present in high or low concentration, the balance may be upset. There are many articles written on the deficiencies of iron, manganese, zinc, and copper that were the result of applied iron, manganese, zinc, or copper.

Hewitt (1948) reported that high rates of applied iron resulted in manganese deficiency and vice versa. He determined the proper iron-manganese balance with the use of an iron-manganese ratio. Lingle et al. (1963) determined that zinc was the strongest interfering ion that depressed iron uptake and translocation to the tops of bean plants. Lindsay (1963) found that increasing rates of iron caused a decrease in the zinc concentration of corn plants. Newitt (1949) and Brown (1962) also reported a decreased iron concentration in corn and millet plants but not in kidney beans and tomatoes when zinc was applied. Watanabe et al. (1965) reported that an iron-zinc ratio of less than 1.5 appeared to have a detrimental effect on the yield of corn. Rosell and Ulrich (1964) reported that iron and manganese concentrations of over 1000 ppm were present in sugar beet plants suffering from zinc deficiency. The accumulation of iron within the nodes of zinc-deficient corn plants was observed by Winters and Parks (1955).

The acutal causes of these imbalances within the plant are not thoroughly understood. Tiffin and Brown (1962) hypothesized that one of the interfering ions may be replacing the other, but Lingle (1963) disagreed with this hypothesis. He showed that the two interfering ions acted independently of one another in their translocation within the plant. Hewitt (1953) demonstrated that the antagonism was not related to the oxidation-reduction potential of the simple ions or to the ability to show valence change.

Interaction Between Phosphorus and Iron Within the Plant

The effect of phosphorus is not the same on all heavy metals. As stated previously, high levels of phosphorus reduced the uptake of copper and zinc but only in some cases was the iron uptake affected.

Bingham and Martin (1956) observed that 900 pounds of phosphorus reduced copper and zinc but had no effect on the iron concentration of citrus. Lindsay (1963) and Brown and Tiffin (1962) demonstrated that corn grown on a calcareous soil where high rates of phosphorus had been applied developed iron chlorosis. Biddulph (1955) showed that iron can also have an adverse effect on the utilization of phosphorus within the plant. Using radiotracers on beans, he determined that a phosphorus-iron complex was formed within the plant and that the complex obstructed the flow of other ions within the plant. This happened when excess phosphorus or iron was present. Some workers have reported higher concentrations of iron in iron chloratic plants than normal green plants (Olsen, 1935; Dekock and Hall, 1955; Rediske and Biddulph, 1953). This helps substantiate Biddulph's work that iron is being immobilized within the plant.

EXPERIMENTAL METHODS

Field Experiments

Sites and Soils

The field experiments were conducted on three different sites of Sifton soil. These sites were located in the southern part of Marion County and were selected because of visual zinc deficiency symptoms that were present in previous crops. Legal descriptions are given in Table 1.

Table 1 Legal description of experiment locations.

Experiment	Location (with reference to the Portland Meridian)
420	Edward Gilbert's Farm NW$\frac{1}{4}$ SE$\frac{1}{4}$ sec. 1, T. 9 S., R. 2 W.
424	William Grenz's Farm NW$\frac{1}{4}$ SW$\frac{1}{4}$ sec. 34, T. 9 S., R. 2 W.
Greenhouse	
Soil 434 from	George Fery's Farm SE$\frac{1}{4}$ NE$\frac{1}{4}$ sec. 17, T. 9 S., R. 1 W.
Soil 435 from	Edward Bartosz's Farm NE$\frac{1}{4}$ SE$\frac{1}{4}$ sec. 35, T. 8 S., R. 2 W.
Soil 436 from	Irrigation Experiment Station at Prosser, Washington.
434	George Fery's Farm SE$\frac{1}{4}$ NE$\frac{1}{4}$ sec. 17, T. 9 S., R. 1 W.

The soil test values for the experiments are given in Table 2. It is difficult to interpret these values because of the high percentage of gravel mixed throughout the horizon and because soil test calibration data is not available on these specific soils. These soils have apparently originated from river wash material and are located in small, scattered areas. The high amount of organic material in the surface horizon gives the soil a dark color and it has been suggested that the high volcanic ash content is responsible for the loose, fluffy texture of the soil. These soils have a bulk density of less than .9.

Table 2 Chemical analysis of soils from the experiment locations.

Location	Lime rate T/A	pH	P ppm	me/100 gms.				Zn ppm	OM 0/0
				K	Ca	Mg	CEC		
Experiment 420	0	4.9	18.0	.67	1.2	0.4	23.0	1.3	10.61
	3.5	5.7	19.0	.70	9.3	0.7			
	7.0	6.0	24.0	.72	12.4	0.7			
Experiment 424	0	5.9	35.0	.88	6.4	1.3	19.6	1.9	5.40
Greenhouse Experiments									
Soil 435	0	4.7	13.2	.60	2.2	1.0	21.5	1.2	7.22
	4	5.8	10.2	.55	10.7	1.0		0.8	
Soil 434	0	5.2	13.0	.45	3.4	1.2	16.4	0.8	6.67
	4	6.1	11.0	.40	8.8	1.2		1.2	
Soil 436	0*	7.3	2.0	.32	10.2	2.8	12.5	1.6	0.66
	16	7.5	2.0	.32	9.9	2.8		1.5	
Experiment 434	0	5.4	12.0	.42	3.6	0.4	21.4	1.5	6.26

*Lime was replaced by iron.

The soil tests for Ca, Mg, K, P, and CEC were run according to the methods listed by Alban and Kellogg (1959). Zinc was determined by the method described by Viets, Boawn, and Crawford (1955) with modifications. Fifty ml. of O. IN HCI were added to five grams of soil. This mixture was shaken on a mechanical shaker for 45 minutes. It was then filtered and zinc in the supernate was determined with an atomic adsorption spectrophotometer.

A survey conducted in the Willamette Valley on sweet corn using the index leaf of the plant showed that 76% of the plants sampled had 20 ppm of zinc or less when the zinc soil analysis value was below 2 ppm. Plants sampled from soils having more than 3 ppm HCl-extractable zinc had values in excess of 20 ppm. A value of 15 to 20 ppm in the index leaf has been suggested as a critical level as the result of field calibration experiments in the Willamette Valley and elsewhere.

Experimental Design

Experiment 420 was arranged in a split block design and was replicated three times. Three rates of lime served as the main plots and four fertilizer treatments in factorial arrangement served as the subplots. The fertilizer treatments included two rates of phosphorus (120, 240 lbs. of P_2O_5 per acre) and two rates of zinc (0, 4 lbs. of Zn per acre) in all possible combinations. Each plot consisted of two 25 foot rows.

Experiment 424 was arranged in a randomized block design with six replications. The treatments were 0, 1, 2, 4, and 8 lbs. of zinc per acre applied as zinc sulfate. Each plot consisted of two rows 30 feet long.

Experiment 434 was set up in a randomized block design with a factorial arrangement of treatments. Four rates of zinc (0, 2, 4, 8 lbs. of zinc per acre) and three rates of phosphorus (0, 120, 240 lbs. of P_2O_5 per acre) in all possible combinations served as the treatments. Each plot was 30 feet long and contained two rows.

Field Procedure

All treatments received a blanket application of nitrogen, potassium, sulphur, and magnesium. The potassium, sulphur, and magnesium were banded two inches below and two inches to the side of the seed at planting time as Sul-Pol-Mag at the rate of 50 lbs. S, 50 lbs. K_2O, and 25 lbs. Mg per acre. Fifty pounds of nitrogen per acre were banded at planting time as $(NH_4)_2SO_4$. The phosphorus variables were banded at planting time as T. V. A. concentrated superphosphate and zinc variables were banded at planting time as $ZnSO_4$. To insure maximum distribution of the zinc, the fine powdered $ZnSO_4$ was granulated with $(NH_4)_2SO_4$ using diesel oil as the sticking agent. Nitrogen as $(NH_4)_2SO_4$ was added to all treatments to bring the total nitrogen rate that was banded up to 50 lbs. per acre. Weed control consisted of Eptan that was broadcasted before planting time.

Plant Sampling and Analysis

The above ground portion of the corn plants was sampled when the plants reached six weeks of age. When the plants reached silking stage, ten of the first leaves below the top ear, normally the sixth leaf from the top, were also randomly sampled from each plot. When the experiment reached maturity the ears were harvested by hand, graded and weighed.

The plant samples were dried, ground, and then digested with HNO_3 and $HC10_4$. The plant digests were analyzed for Ca, Mg, Zn, Fe, and Mn with an atomic adsorption spectrophotometer. The potassium determinations were made with a flame photometer and the phosphorus determinations were made by the method described by Barton (1948).

Greenhouse Experiment

Soils

Three soils were used in the greenhouse experiment. Two were Sifton soils from areas like those previously described and one was the calcareous Shano soil from Central Washington. The soil analyses are given in Table 2. The Shano soil is a silt loam derived from recent loess. These soils had 1. 2, 0. 8, 1. 6 ppm of acid extractable zinc, respectively.

Design and Treatment

A split-plot design was used for the greenhouse experiment with soils as main plots and fertilizers as subplots. The factorial arrangement of treatments on the two Sifton soils consisted of four rates of zinc (0, 2, 4, 8 lbs. per acre), three rates of phosphorus (0, 120, 240 lbs. of P_2O_5 per acre), and two rates of lime (0, 4 tons $CaCO_3$ per acre). The Washington soil had similar rates of phosphorus and zinc but two rates of iron (0, 16 lbs. per acre) replaced the lime variable. Since the fertilizer treatments differed on the Shano soil, it was treated as a separate randomized block experiment with treatments in factorial arrangements when the statistical analyses were made.

Procedure

The corn was grown in plastic pots containing 6 lbs. of soil. The soil was screened with ½ inch mesh screen to remove the larger rocks. The lime and iron treatments were mixed with the soil in the pots two weeks before the corn was planted. Each pot received blanket applications of nitrogen, magnesium, and sulphur at the rate of 100 lbs. of N per acre, 15 lbs. of Mg per acre, and 50 lbs. of S per acre. This material, as well as the material applied for the zinc and phosphorus variables, was applied as a liquid in a band one inch below the seed. When the plants reached eight weeks of age, the above ground portions were weighed and sectioned in nodes, internodes, and leaves. Chemical analyses were then run on these fractions.

RESULTS

Experiment 424-1964

Experiment 424 was established in the spring of 1964 to study the effect of applied zinc on a zinc deficient area of Sifton soil. The following rates of zinc applied in a band at planting: 0, 1, 2, 4, 8 lbs. of zinc per acre. All plots received standard recommended rates of nitrogen, phosphorus, magnesium, sulphur, and potassium. The area had been limed within the last five years.

Within a week after emergence, the plants in the plots without zinc were very chlorotic and stunted. On all plots with zinc, the plants were green and vigorous. On the plots without zinc the corn exhibitied typical zinc deficiency symptoms throughout the season. Interveinal chlorosis extended from the base of the leaf blade toward the tip of the leaf with the midrib and leaf margin usually remaining green. As the season progressed small, white spots of dead tissue appeared within the chlorotic area. The internodes were markedly shortened. The zinc deficient plants tasseled later than the other plants and the ears were small and poorly-filled.

Plant samples were taken twice during the growing season. Whole plant samples were taken six weeks after emergence and the index leaves (the first leaf below the primary ear) were sampled at silking stage.

The yield data, presented in Table 3, shows a significant increase in yield with the addition of one pound of zinc. Although there appeared to be a slight trend toward increased yields at zinc rates above one pound, the differences were not statistically significant.

Table 3 The effect of applied zinc on the yield of sweet corn. Experiment 424. Yield(tons/acre).

	0 lb Zn/A	1 lb Zn/A	2 lb Zn/A	4 lb Zn/A	8 lb Zn/A
Yield (T/A)	2.56	6.21	5.86	6.76	7.62
L.S.D.	1%-1.98 T/A				

Table 4 shows the zinc, iron, and phosphorus concentrations and uptake in the whole plant at six weeks.

Table 4 The effect of applied zinc on the zinc, iron, and phosphorus concentrations of sweet corn. Experiment 424. Whole plant samples six weeks of age.

Treatment Zn lbs/A	Zinc		Iron		Phosphorus	
	ppm	μg/plant	ppm	μg/plant	%	mg/plant
0 lbs	16.4	53	1184	3623	.51	17.2
1 lbs	27.3	167	357	2212	.32	20.4
2 lbs	30.1	160	390	2049	.31	17.6
4 lbs	42.5	243	294	1645	.29	16.8
8 lbs	63.3	370	355	2107	.30	16.3
L.S.D. 1%	14.6	109	225	1240	.08	9.6

These data show the consistent increase in the zinc content of plants that were obtained from increased increments of added zinc. The treatment that did not receive zinc had an unusually high level of iron within the plants. The addition of 1 lb. of zinc reduced the iron significantly, both in concentration and in total amount. The increasing increments of zinc had little additional influence on the iron level. It is interesting to note the close relationship between yield response to zinc and the influence of zinc on the iron level in the plant. In both instances, maximum effect was obtained from the 1 lb. rate of zinc and additional zinc had no significant effect. The phosphorus contents in plants that did not receive zinc were nearly twice as high as those plants that did receive zinc; however, the total amount of phosphorus taken up at six weeks was not materially affected by zinc. It seems reasonable to conclude, therefore, that the reduction in phosphorus content was due primarily to dilution.

Table 5 The effect of applied zinc on the zinc and iron concentrations of sweet corn. Experiment 424. Leaves sampled at the silking stage.

Treatments	0 lbs Zn/A	1 lb Zn/A	2 lbs Zn/A	4 lbs Zn/A	8 lbs Zn/A
Zinc(ppm)	12.2	15.0	16.7	29.4	57.6
Iron (ppm)	990.0	317.0	276.0	264.0	267.0
L.S.D. for iron	1%-119 ppm				
L.S.D. for zinc	1%- 7.6 ppm				

The leaf concentration data are given in Table 5. The zinc and iron concentrations of leaves at silking are fairly comparable to those of the whole plant sampled at six weeks. The zinc content of the leaves was increased over the entire range of zinc rates but the iron content was affected significantly only by the first increment of zinc. It was evident that iron must have accumulated in the leaves as well as in the nodes since the leaves also exhibited the high iron concentration.

The correlation coefficients between iron concentrations of the leaf samples and yields, and zinc concentrations of the leaf samples and yields were calculated. There was a correlation coefficient of -.86 between yield and iron and a correlation coefficient of +.54 between yield and zinc.

The lower three nodes of the plants were taken at harvest time to obtain a measure of the effect of zinc on iron and phosphorus at the nodes as shown in Table 6. An inch of material was taken at each node; later samples showed that the internodes had much lower iron and zinc concentrations than the nodes and thus the internode material diluted the concentration of iron and zinc in the nodes.

An application of more than 2 lbs. of zinc per acre was necessary to bring about a significant increase in the zinc content of the nodes, although iron and phosphorus were both reduced significantly with the 1 lb. rate. A correlation coefficient of +.80 between the iron and phosphorus concentrations within the nodes suggests the presence of a close relationship between iron and phosphorus in this tissue, while a correlation coefficient of -.37 between the zinc and iron levels and -.26 between the zinc and phosphorus levels within the nodes indicates a somewhat antagonistic relationship present between zinc and iron, and zinc and phosphorus.

Table 6 The effect of applied zinc on the zinc, iron, and phosphorus concentrations of nodal material. Experiment 424. Sampled at harvest time.*

Treatment	ppm Zinc	ppm Iron	% Phosphorus
0 lbs Zn/A	6.8	303	.16
1 lb Zn/A	6.9	165	.11
2 lbs Zn/A	6.7	98	.10
4 lbs Zn/A	10.0	78	.08
8 lbs Zn/A	27.6	81	.09
L.S.D. -1%	5.3	106	.04

*1 inch of material was taken at each node.

Experiment 420-1964

Experiment 420 was established to evaluate the response of sweet corn grown on Sifton soil to applied lime, zinc, and phosphorus. In contrast to Experiment 424, this site was quite acid. The area had been planted to corn for the past several years with very low yields.

The following treatment variables were applied: lime rates of 0, 3.5, and 7.0 tons per acre; phosphorus rates of 120 and 240 lbs. of P_2O_5 per acre; zinc rates of 0 and 4 lbs. per acre. All plots received standard rates of sulphur, potassium, magnesium, and nitrogen.

The nonlimed treatments showed little response to any of the fertilizer treatments and made very little growth throughout the season. On those treatments that received lime, a significant response was obtained from applied zinc. The limed treatments that did not receive zinc exhibited visual zinc deficiency symptoms throughout the growing season.

Table 7 presents the yield data while Table 8 gives the total uptake and concentration of iron, zinc, and phosphorus within the plant at six weeks of age. The potassium, magnesium, manganese, and calcium levels for this experiment are given in the appendix.

Table 7 The effect of applied zinc, phosphorus, and lime on the yield of sweet corn. Experiment 420. Yield data (tons/acre).

	L_0	L_1	L_2
P_1Zn_0	0.44	1.28	1.79
P_1Zn_1	1.58	4.83	4.54
P_2Zn_0	0.17	1.54	2.30
P_2Zn_1	0.31	4.28	4.34

L.S.D. 1% -		
	Fertilizers	1.11
	Lime	1.57

It is evident from the yield data that a marked zinc-lime interaction was present with applications of both lime and zinc being required for the greatest yield increases.

The following yield data from Table 7 illustrates this point.

		Zn_0	Zn_1			Zn_0	Zn_1
at P_1	L_0	0.44	1.58	at P_2	L_0	0.17	0.31
	L_1	1.28	4.83		L_1	1.54	4.28

The above data also indicates a slight detrimental effect by increasing the phosphorus level from 120 to 240 pounds. It appears that 120 pounds of P_2O_5 was approaching the optimum level under these conditions. Increasing the lime rate from 3.5 to 7.0 tons per acre had little effect on yield.

Table 8 gives the concentration and total uptake of zinc, phosphorus, and iron within the plant at six weeks of age. The iron concentrations within the plants were generally higher than what normally would be expected. The iron concentration data below were taken from Table 8. Since phosphorus did not have a significant effect on iron in this experiment, the data were averaged over the P_1 and P_2 rates.

		L_0	L_1	L_2
Zn_0	ppm Fe	836	1006	1270
	μg/plant	1987	3285	4844
Zn_1	ppm Fe	836	570	575
	μg/plant	2303	2556	3326

Table 8 The effect of applied zinc, phosphorus, and lime on the zinc, iron, and phosphorus concentrations of sweet corn. Experiment 420 Whole plant samples six weeks of age.

	IRON						ZINC						PHOSPHORUS					
	L_0		L_1		L_2		L_0		L_1		L_2		L_0		L_1		L_2	
	ppm	µg	ppm	µg	ppm	µg	ppm	µg	ppm	µg	ppm	µg	%	mg	%	mg	%	mg
P_1Zn_0	913	1994	1093	3365	1345	4445	20.5	44	22.5	70	20.0	66	.52	14.8	.35	10.6	.42	13.6
P_1Zn_1	916	2846	566	2721	600	3340	79.5	230	66.0	305	81.6	450	.68	18.6	.28	13.4	.31	17.0
P_2Zn_0	760	1980	920	3206	1195	5244	20.5	53	21.3	75	23.5	102	.67	17.6	.55	19.2	.49	21.4
P_2Zn_1	756	1761	575	2391	550	3313	107.6	222	34.6	144	39.6	238	.68	15.2	.33	13.6	.34	20.5
L. S. D. 1% - Lime					- ppm 241							28.4					%	.12
					µg 944							55					mg	3.2
- fertilizers					ppm 341							40.0					%	.19
					µg 1366							77					mg	4.5

These data indicate that zinc decreased the concentration and uptake of iron only in the presence of lime. It was also under these same conditions that the major yield response from zinc was noted. The fact that lime increased the uptake and concentration of iron in the absence of applied zinc is quite significant since lime normally reduces the iron availability in the soil. These increases in iron levels in the plant cannot be due to dilution since there was a significant increase in growth associated with liming in the absence of applied zinc. The growth was quite poor on the nonlimed treatments, and if dilution were a factor, these treatments should have been the highest in iron.

The addition of zinc increased the zinc concentration and uptake in all cases and the only noticeable effect of lime on the zinc concentration occurred on the P_2Zn_1 treatments where lime decreased the zinc concentration within the plants. The following data from Table 8 illustrates the effect that higher rates of phosphorus had upon reducing the zinc concentration and uptake.

			L_1	L_2
at Zn_1	P_1	ppm Zn	66.0	81.6
		µg/plant	305.0	450.0
	P_2	ppm Zn	34.6	39.6
		µg/plant	144.0	238.0

This reduction corresponded to a small decrease noted in yields on the same treatments, but the reduced zinc levels of 34-39 ppm should be adequate under normal conditions. Therefore, the reduction in growth may have been caused by some other factors.

The level of phosphorus within the plants was generally increased by the additional increment of phosphorus. The lower level of phosphorus in plots that received lime could be entirely due to a dilution effect since there was a marked increase in yield from the application of lime. However, the reduction of phosphorus uptake by applied zinc at the P_2 level and the increase in phosphorus uptake with the addition of zinc at the P_1 level are not dilution effects.

The two field experiments carried out during 1964 revealed some unexpected treatment effects, specifically the high levels of iron in zinc deficient plants and the marked effect of zinc in reducing their iron concentrations. Additional experiments were considered necessary to help study and explain these relationships; therefore, a greenhouse experiment was established in the spring of 1965.

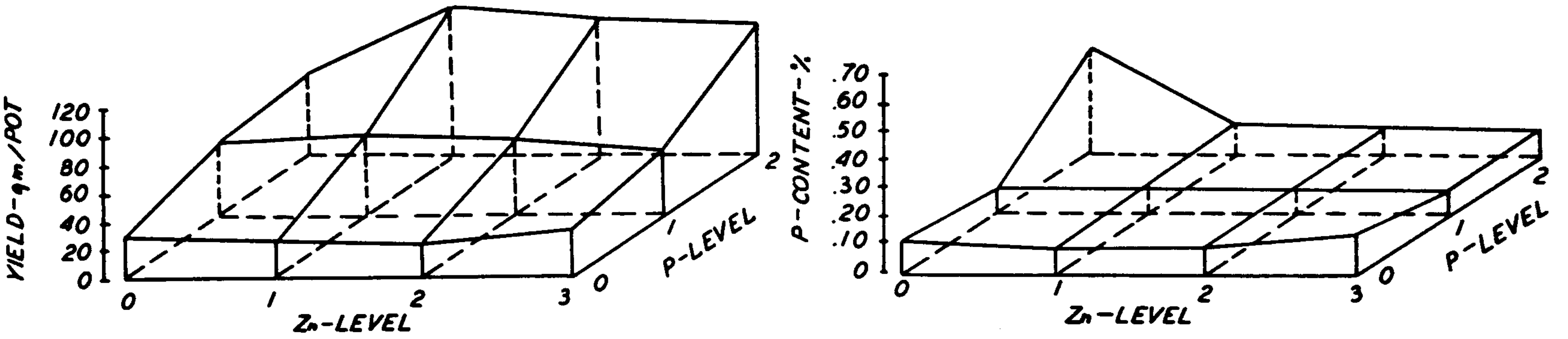
Greenhouse Experiment - 1965

The Greenhouse experiment conducted during the spring of 1965 was established to obtain additional information on the effects of lime, zinc, and phosphorus on the growth of sweet corn. The concentrations of zinc, iron, and phosphorus within the nodes, internodes, and leaves were studied and compared. A zinc deficient, calcareous soil was included in the experiment to compare the effects obtained from an acid soil with relatively high iron availability with those obtained from a calcareous soil in which the iron availability would be low.

The two Sifton soils used in this experiment received lime, zinc, and phosphorus variables. The calcareous Shano soil received the same zinc and phosphorus variables with iron replacing the lime treatments. The treatments were as follows: phosphorus rates were 0, 120, and 240 lbs. of P_2O_5 per acre; zinc rates were 0, 2, 4, 8 lbs. of zinc per acre; lime rates were 0, 4 tons of lime per acre; and iron rates were 0, 16 lbs. of iron per acre.

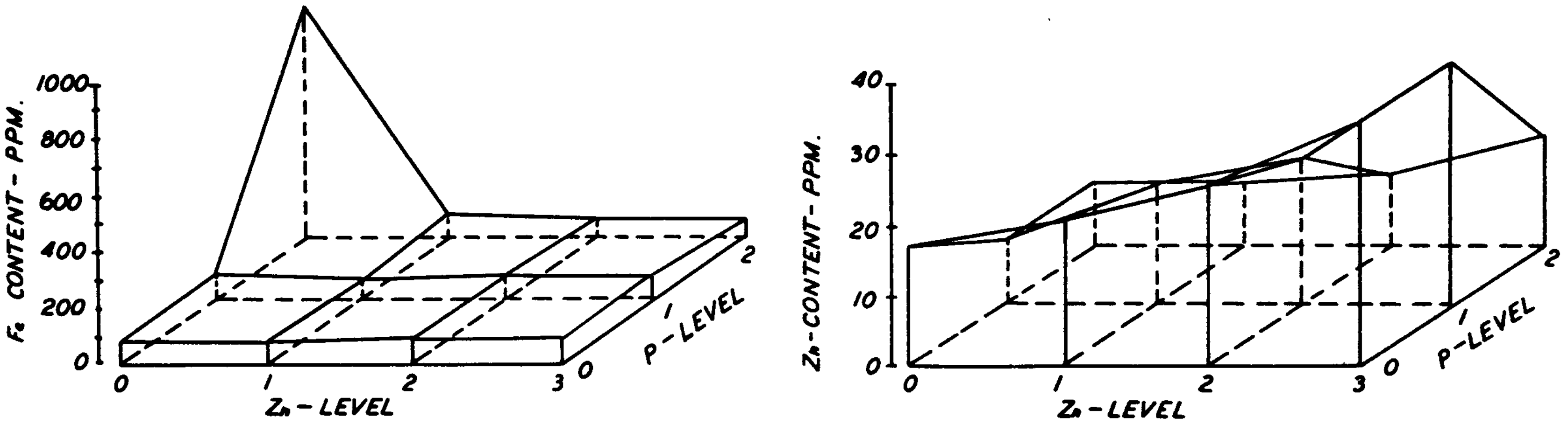
At eight weeks of age, the plants were weighed and sectioned into nodes, internodes, and leaves. The material was dried; but after drying, not enough nodal and internodal material was available for chemical analyses, thus the analyses were limited to leaf tissue. The magnesium, manganese, potassium, and calcium results for the leaf tissue are presented in the appendix.

Figures 1, 2, and 3 present the yield data for soils 434 and 435. A lack of phosphorus appeared to have been the most limiting factor on soils 434 and 435; consequently, the treatments that did not receive phosphorus showed no response to applied zinc. The addition of lime to the P_0 treatments caused a small increase in growth on soil 435; this could have been the result of increased phosphorus availability.



(a) Yield

(c) Phosphorus



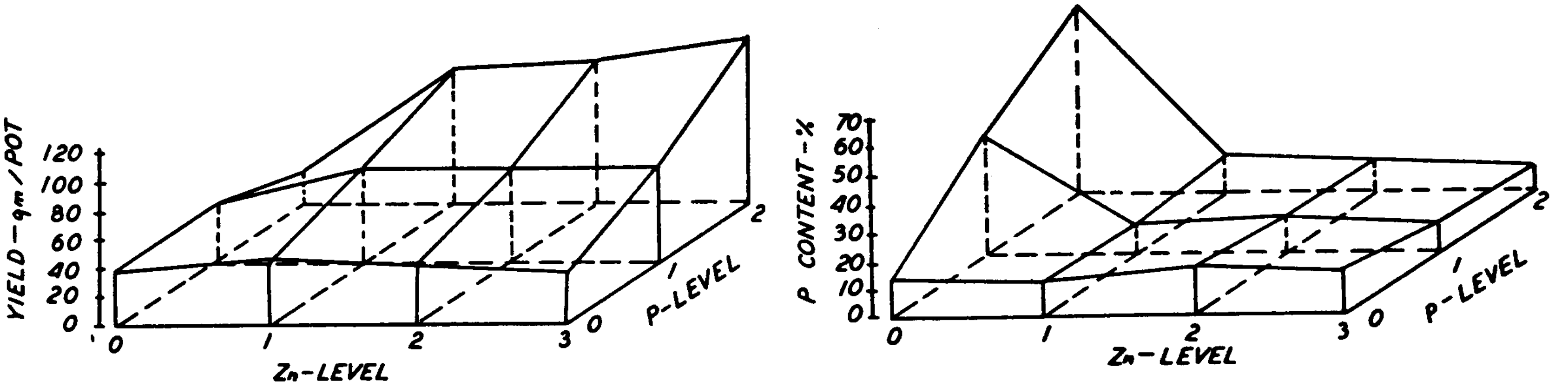
(b) Iron

(d) Zinc

Figure 1. The Effect of Zinc and Phosphorus in the Absence of Lime on the Iron, Phosphorus, and Zinc Contents of Corn Leaves and on the Weight of Whole Corn Plants Harvested at 8 Weeks. Greenhouse Soil 435.

(a) Yield

(c) Phosphorus



(b) Iron

(d) Zinc

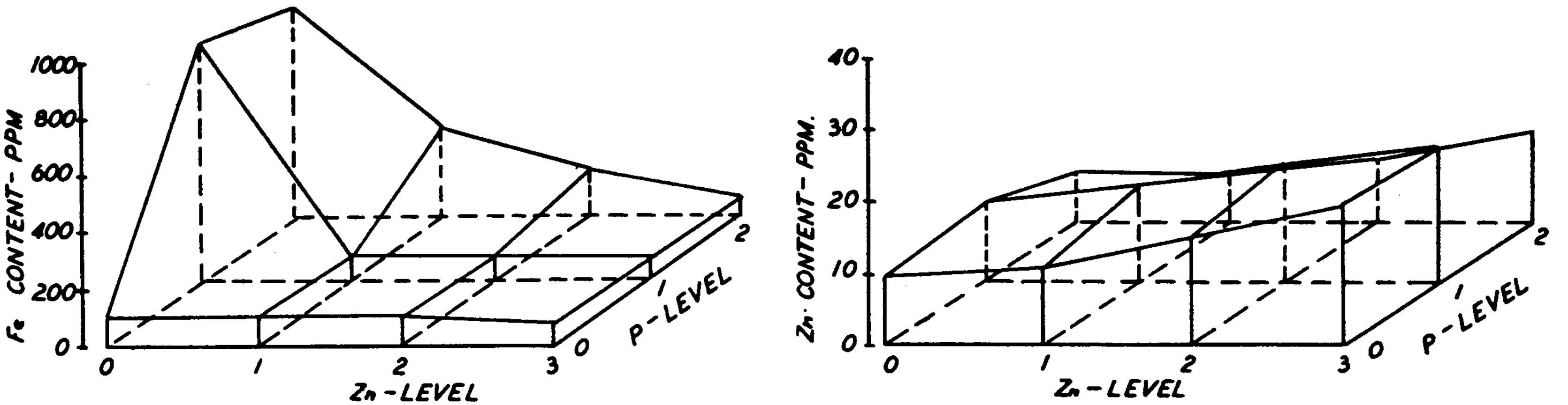


Figure 2. The Effect of Zinc and Phosphorus in the Presence of Lime on the Iron, Phosphorus, and Zinc Contents of Corn Leaves and on the Weight of Whole Corn Plants Harvested at 8 Weeks. Greenhouse Soil 435.

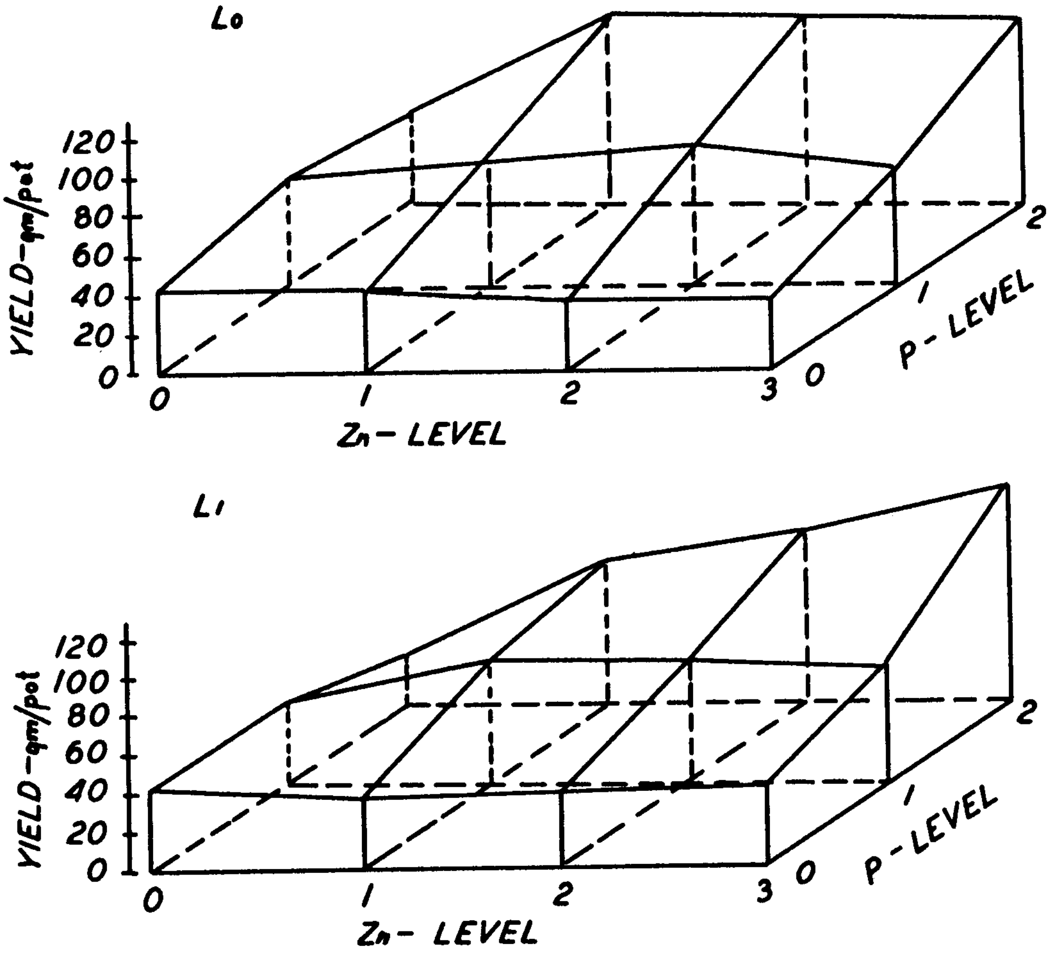


Figure 3. The Effect of Zinc, Phosphorus, and Lime on the Yield of Sweet Corn. Greenhouse Soil 434. Whole Plants Harvested at 8 Weeks.

The response from phosphorus was evident on the nonlimed treatments and occurred across all zinc levels, although the response was greatest in the presence of added zinc. On the limed treatments a response was obtained from the applied phosphorus, but only in the presence of added zinc. On both soils those treatments receiving the first rate of phosphorus responded to zinc in the presence of lime, while in the absence of lime only those treatments on soil 434 which received the first rate of phosphorus responded to zinc. There was also a depression in growth from the application of lime at the P_1Zn_0 level, which was overcome by the addition of zinc. The possible cause of these effects will be discussed later.

On the treatments receiving the second rate of phosphorus, both the limed and nonlimed treatments responded to the applied zinc. The limed P_2Zn_0 treatment showed a marked decrease from that of the nonlimed P_2Zn_0 treatment. This appears to be the same effect that was noted on the P_1 treatment, only more severe, because four pounds of zinc were required to increase growth to comparable levels with the nonlimed treatment.

Figures 4 and 5 illustrate some of the treatment effects on the limed plots. Figure 4 shows that no response was obtained without both phosphorus and zinc. The decrease in yield at the high phosphorus rate in the absence of zinc is also quite evident. Figure 5 shows the marked response observed from applied phosphorus on the treatments that received zinc.

Figures 1 and 2 present the concentrations of zinc, iron, and phosphorus within the leaves at eight weeks of age for soil 435. Table 9 gives the same information for soil 434. Since the data

Figure 4. The Effect of Zinc and Phosphorus on Plant Growth in the Presence of Lime. Greenhouse Experiment Soil 435.

Figure 5. The Effect of Phosphorus on Plant Growth in the Presence of Zinc and Lime. Greenhouse Experiment Soil 434.

Table 9 The effect of applied zinc, phosphorus, and lime on the zinc, iron, and phosphorus concentrations of sweet corn. Greenhouse experiment - Soil 434.

	Zinc ppm		Iron ppm		Phosphorus %	
Treatments	L_0	L_1	L_0	L_1	L_0	L_1
P_0Zn_0	14.3	11.2	80	92	.12	.15
P_1Zn_0	14.2	12.5	123	411	.14	.40
P_2Zn_0	8.4	16.1	888	1004	.59	.74
P_0Zn_1	16.5	12.5	85	88	.14	.14
P_1Zn_1	11.3	9.7	112	80	.13	.11
P_2Zn_1	7.5	8.5	103	378	.12	.13
P_0Zn_2	18.2	18.3	80	82	.14	.15
P_1Zn_2	14.0	12.5	68	77	.10	.11
P_1Zn_2	9.0	7.5	63	100	.10	.11
P_0Zn_3	18.5	18.7	79	75	.14	.13
P_1Zn_3	20.8	16.1	73	72	.12	.10
P_2Zn_3	12.2	10.3	58	63	.10	.10

L.S.D. 1% -	Zinc	2.6	66	.08
	Phosphorus	2.2	57	.04
	Lime	1.8	47	.04

were quite similar for these two acid soils, only the results from soil 435 will be discussed.

Figures 1 and 2 show the marked effects that resulted from adding phosphorus to the Zn_0 treatments on soil 435. Both iron and phosphorus contents were greatly increased while the zinc content was slightly decreased. Increasing the zinc level resulted in a marked reduction of these high iron and phosphorus contents and a general increase in zinc content.

The limed and nonlimed treatments can also be compared in these figures. The following data are the same as those used in Figures 1 and 2 but they are grouped to allow direct comparison of the effect of lime and phosphorus on the iron content.

		L_0	L_1			L_0	L_1
		ppm Fe	ppm Fe			ppm Fe	ppm Fe
at P_1	Zn_0	97	844	at P_2	Zn_0	816	743
	Zn_1	72	80		Zn_1	80	302
	Zn_2	80	73		Zn_2	68	157
	Zn_3	83	73		Zn_3	68	70

With the addition of lime to the P_1Zn_0 treatment, the iron content was greatly increased. At the P_2 level the addition of lime did not result in a further increase in the iron content at the Zn_0 level but it did result in an increase at the Zn_1 and Zn_2 levels. The increased iron content from the additional phosphorus rate (P_2Zn_0) on the nonlimed treatment is also evident in the above data.

Lime also influenced the phosphorus content of these plants as shown by the following data.

		L_0	L_1			L_0	L_1
		%P	%P			%P	%P
at P_1	Zn_0	.09	.42	at P_2	Zn_0	.37	.67
	Zn_1	.10	.11		Zn_1	.11	.13
	Zn_2	.10	.13		Zn_2	.10	.12
	Zn_3	.10	.11		Zn_3	.10	.10

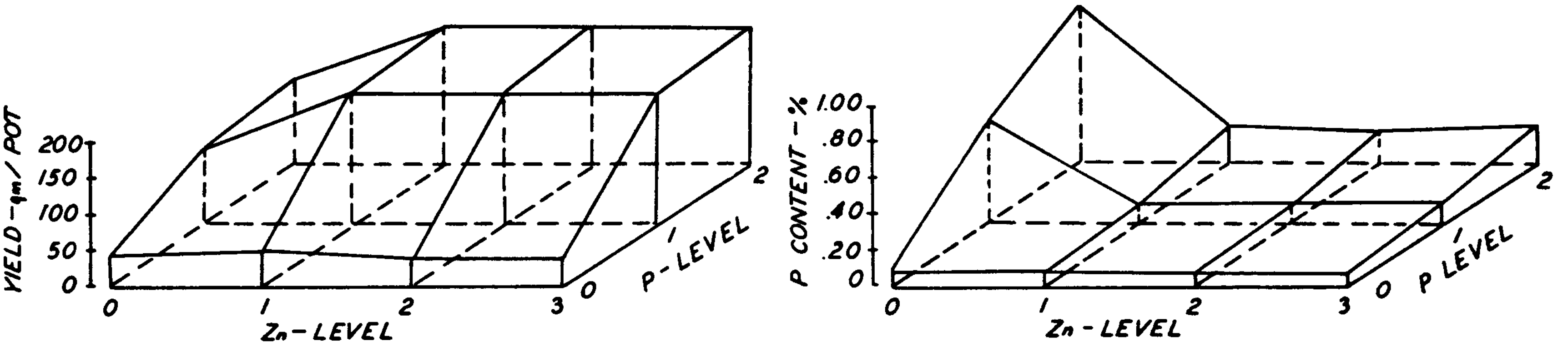
At the Zn_0 level the addition of lime resulted in a considerable increase in the phosphorus content at both the P_1 and P_2 levels. In the presence of added zinc, lime had only a slight effect on the phosphorus content.

The zinc concentrations were generally increased as a result of applied zinc and decreased as a result of applied phosphorus and lime. Even though there were significant growth responses to phosphorus and lime, the decreased zinc content of the plants was greater than could be accounted for by dilution.

The yield data and concentrations of zinc, iron, and phosphorus within the leaves of plants grown on the calcareous soil are presented in Figures 6 and 7. The first rate of added phosphorus resulted in maximum yield on this soil, while the second rate of phosphorus was required for optimum yield on the two acid soils. Again, phosphorus was the most limiting element; therefore, a response from zinc

(a) Yield

(c) Phosphorus



(b) Iron

(d) Zinc

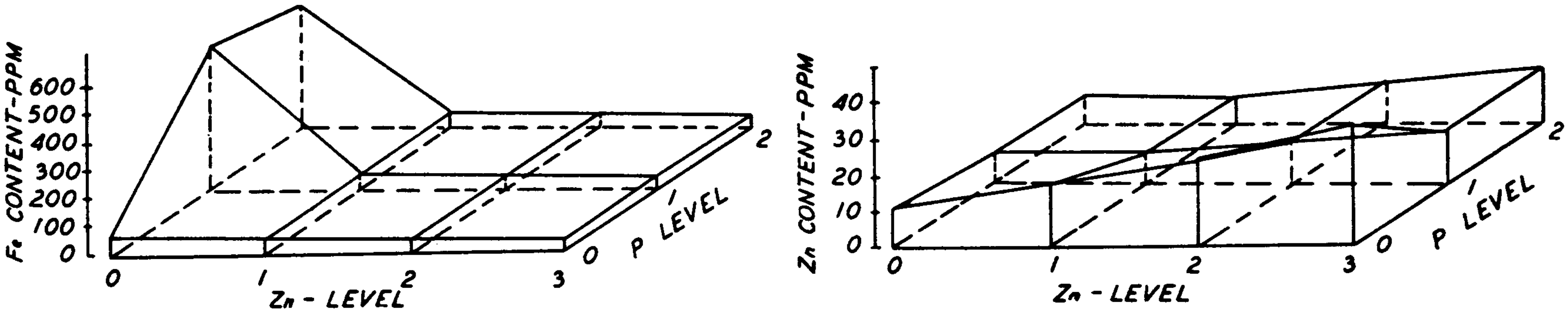
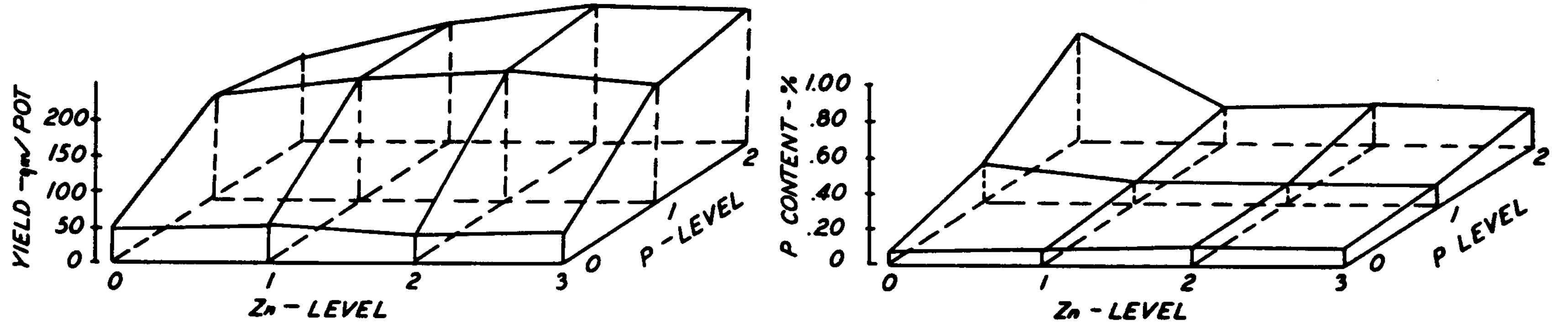


Figure 6. The Effect of Zinc and Phosphorus in the Absence of Iron on the Iron, Phosphorus, and Zinc Contents of Corn Leaves and on the Weight of Whole Corn Plants Harvested at 8 Weeks. Greenhouse Soil 436.

(a) Yield

(c) Phosphorus



(b) Iron

(d) Zinc

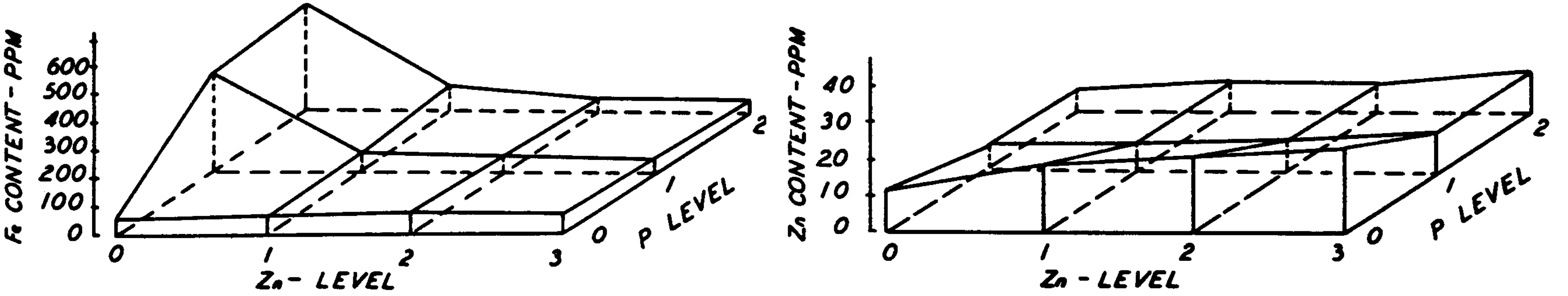


Figure 7. The Effect of Zinc and Phosphorus in the Presence of Iron on the Iron, Phosphorus, and Zinc Contents of Corn Leaves and on the Weight of Whole Corn Plants Harvested at 8 Weeks. Greenhouse Soil 436.

was not evident without added phosphorus. The total growth was also greater on soil 436. Whether this was caused by a nutritional or physical characteristic of the soil is not certain.

At the first and second rate of phosphorus, a negative response from applied iron was noted on the treatments that received the first level of zinc. The iron was apparently interfering with zinc utilization because the addition of two pounds of zinc increased yield to a comparable level of the noniron treatments. Figures 6 and 7 indicate that the addition of phosphorus to the Zn_0 treatments greatly increased the iron and phosphorus contents and slightly decreased the zinc content. Increasing the zinc level under these conditions generally increased the zinc content and greatly decreased the iron and phosphate contents. These changes were associated with significant increases in yield from the applied zinc. Adding iron to the Zn_0 treatments at the P_1 and P_2 levels caused a significant reduction of the iron and phosphorus contents and a slight reduction in zinc. At least a portion of these changes could be due to dilution effects since there was an increase in yield from applied iron at P_1Zn_0. As the zinc level was increased, the added iron increased the iron content slightly, decreased the zinc content, but did not affect the phosphorus content.

Correlation coefficients were calculated for all treatments that showed zinc deficiency as determined by a response to applied zinc.

The comparisons made between zinc concentrations and yields had coefficients of -.67, +.15, and -.34 for soils 434, 435, and 436, respectively. There were 24 points compared on each soil. This points out quite clearly that zinc content was not closely correlated with yield on plants suffering from zinc deficiency and responding to applied zinc. It also demonstrates that the relationship varies between soils.

On the other hand, significant negative correlations between yields and iron concentrations on the same treatments mentioned above were present with coefficients of -.79, -.78, and -.82 on soils 434, 435, and 436, respectively. This indicates that iron concentrations and yields were quite closely related. The coefficients of the iron-zinc ratios and yields on those treatments suffering from zinc deficiency and responding to zinc were -.54, -.75, and -.75 for soils 434, 435, and 436, respectively. This indicates that the ratios do not follow yields as closely as iron concentrations alone.

Calcium, magnesium, potassium, and manganese concentrations in the plants were also determined and the data are given in the appendix. Each of these elements exhibited concentrations below that expected under field conditions. On zinc-deficient plants a higher concentration of all elements appeared. The concentrations of potassium, magnesium, and calcium, when compared to growth, were increased on the zinc deficient plants, usually in about the same proportion that yields were decreased; therefore, dilution is undoubtedly responsible for much of the effect. However, dilution cannot entirely account for these effects since a number of low yielding treatments which were not zinc-deficient did not exhibit these changes. The manganese contents were much higher and changes cannot be attributed to dilution. The manganese contents, as affected by the zinc and phosphorus treatments, behaved quite similarly to iron, only on a smaller scale. The effect of lime in reducing the manganese levels was also quite evident.

Experiment 434 - 1965

Experiment 434 was established in the spring of 1965 to study the levels of zinc, iron, and phosphorus within the various parts of the plant. This was attempted in the greenhouse experiment but growth on most treatments was not adequate to make the plant separations. This experiment was also used to compare results obtained in the greenhouse with those obtained in the field.

The yield data, given as tons per acre of no. 1 ears, is presented in Figure 10. These data correspond quite closely to the growth responses obtained on similar treatments in the greenhouse experiment. Phosphorus was the major limiting element; therefore, yields were quite low at the P_0 level and no response was obtained from applied zinc. Increasing phosphorus to the P_1 level resulted in a yield response across all zinc rates with the larger responses being obtained on the treatments that received zinc. At the P_2 level yields were decreased at the Zn_0 rate but were increased with each successive rate of zinc. The maximum yields in this experiment resulted from the application of 240 pounds of phosphorus and 8 lbs. of zinc.

Figures 8 and 9 show some of the growth responses observed in the field from applied zinc and phosphorus. It can be seen that growth was increased with the addition of both zinc and phosphorus.

Figure 10 presents the iron, zinc, and phosphorus concentrations of the leaf. The treatment effects observed on this experiment were similar to those noted in the greenhouse. High contents of phosphorus and iron in the plant resulted from the increased phosphorus levels and the addition of zinc reduced them. It should be noted, as in all previous experiments, that the high iron content occurred only in the plants where an actual zinc deficiency was evident. Increasing the zinc level in the absence of applied phosphorus resulted in a high zinc content in the plant, but it was reduced by the application of phosphorus.

When the plants were ten weeks old, they were sectioned into three parts (nodes, internodes, and leaves). The results are presented in Table 10. It appears that the effects noted in the leaves

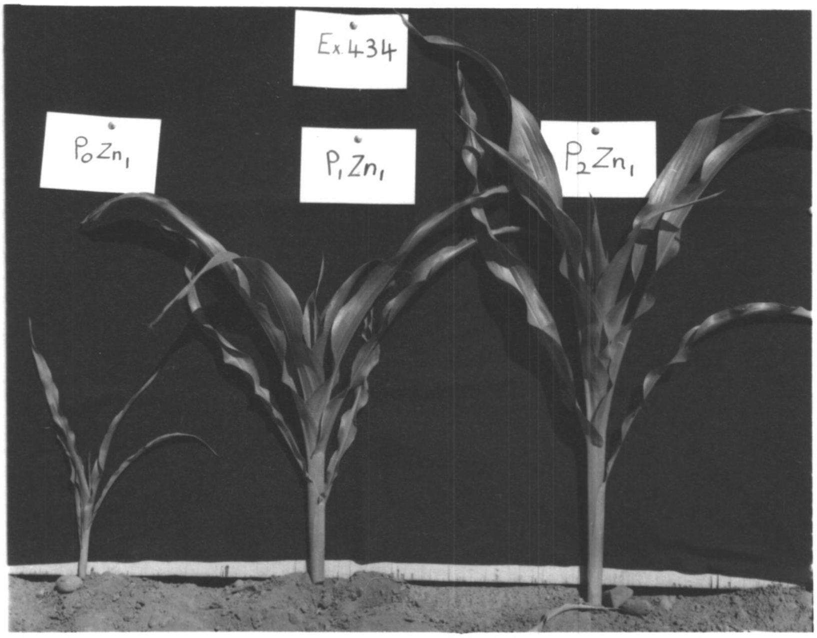


Figure 8. The Effect of Phosphorus on Plant Growth in the Presence of Zinc. Experiment 434.

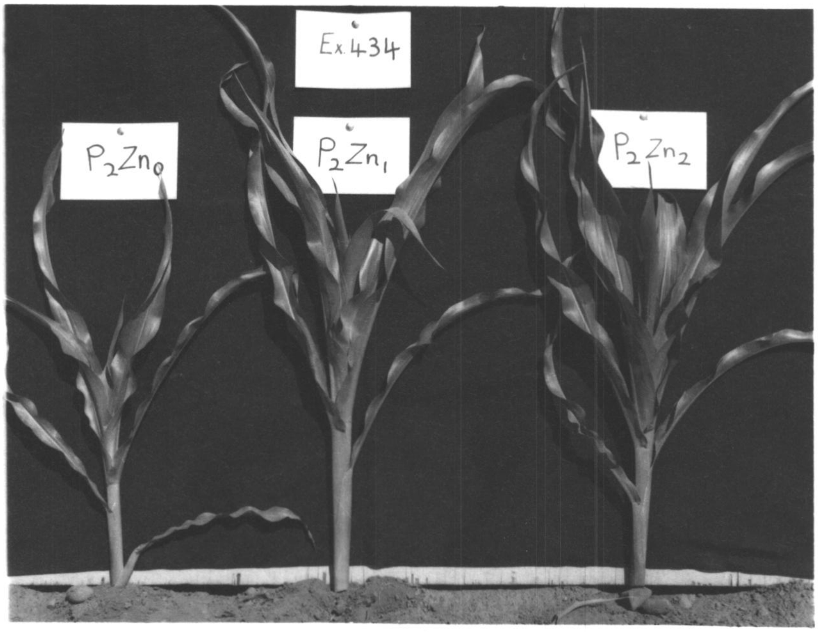
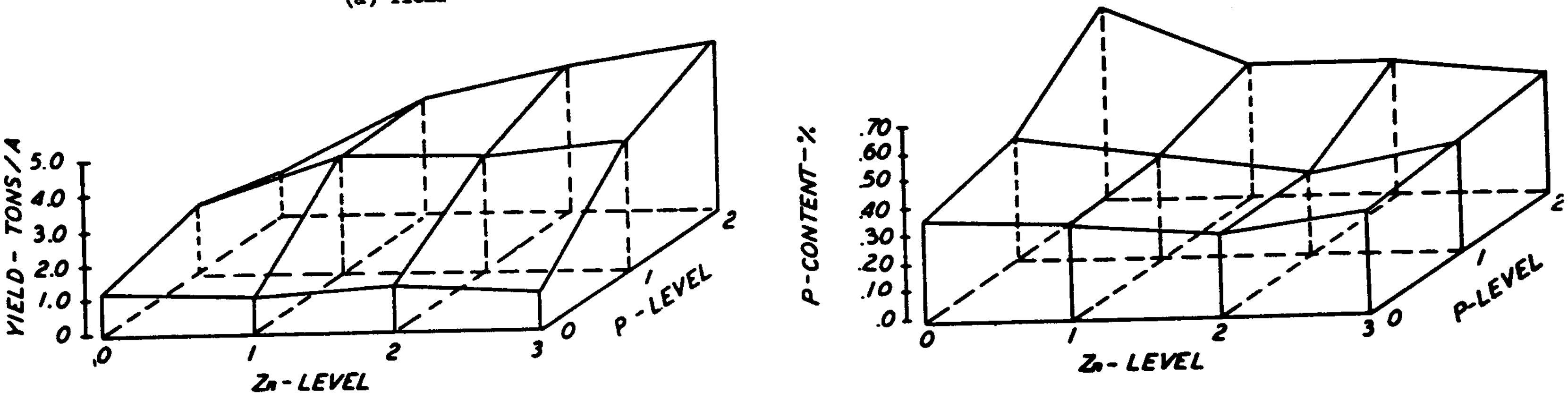
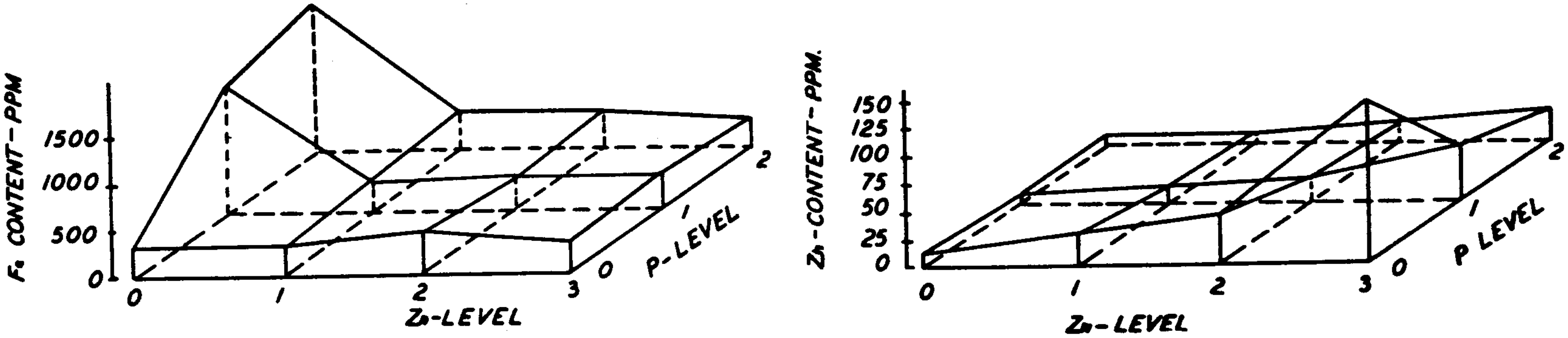


Figure 9. The Effect of Zinc on Plant Growth in the Presence of Phosphorus. Experiment 434.



(a) Yield

(c) Phosphorus



(b) Iron

(d) Zinc

Figure 10. The Effect of Zinc and Phosphorus on the Iron, Phosphorus, and Zinc Contents of Corn Leaves and on the Yield of Corn. Experiment 434.

Table 10 The effect of applied zinc and phosphorus on the zinc, iron, and phosphorus concentrations of the nodes, leaves, and internodes of sweet corn. Experiment 434. Sampled at nine weeks.

	Zinc			Iron			Phosphorus		
	L	N	IN	L	N	IN	L	N	IN
P_0Zn_0	14	32	8	317	422	46	.36	.15	.10
P_1Zn_0	10	9	6	1400	1953	62	.44	.13	.07
P_2Zn_0	10	12	6	1578	2253	100	.69	.22	.11
P_0Zn_1	30	554	21	287	332	31	.34	.13	.08
P_1Zn_1	18	15	5	317	434	32	.37	.11	.06
P_2Zn_1	11	20	6	372	822	33	.49	.13	.07
P_0Zn_2	50	652	25	447	349	46	.30	.13	.08
P_1Zn_2	26	44	5	342	436	31	.30	.08	.04
P_2Zn_2	20	35	6	417	551	45	.46	.15	.09
P_0Zn_3	147	831	49	283	350	51	.36	.14	.09
P_1Zn_3	56	304	12	398	391	33	.40	.11	.06
P_2Zn_3	28	96	6	337	524	35	.43	.13	.07
L.S.D. 1% - Zinc			44			147			.21
Phosphorus			38			128			.18
Parts			38			128			.18

were also present within the nodes. Therefore, if an iron-phosphorus complex were present, it existed in the leaves as well as in the node. The differences that did exist between the two should be pointed out. At the nodes, increasing the phosphorus level in the absence of applied zinc resulted in a marked increase in the iron content, but only a slight increase in the phosphorus content. The increased iron in the leaves that was associated with the addition of phosphorus generally occurred only at the two lower zinc levels, but within the nodes the increase occurred at all zinc levels. The zinc accumulation in plants at the P_0 level was much greater in the nodes than in the leaves.

Across the P_1 and P_2 levels a correlation coefficient of -.90 exists between the node-iron concentration and yield, while a correlation coefficient of -.77 exists between leaf-iron concentration and yield. The zinc contents of the plants were more closely related to yield in this experiment than in the greenhouse experiment. Correlation coefficients of +.42 and +.74 existed at the P_1 and P_2 level, respectively, between the zinc content and yield in the field experiment.

The data obtained from the leaves that were collected at silking time are in the appendix. Since the results are very similar to those observed in the sectioning experiment, they will not be discussed. The difference in the uptake of manganese and potassium in the greenhouse and field, however, should be noted. In the field experiment manganese levels were increased by the addition of phosphorus, while they were reduced in the greenhouse experiment. The uptake of manganese was reduced by the addition of zinc in both the greenhouse and field experiments.

The potassium values were not markedly influenced by the treatments in the field experiment but they were reduced by phosphorus in the greenhouse experiment. Since there was quite a large growth response from phosphorus in the greenhouse (more than in the field), this reduction may have been the result of a dilution effect.

DISCUSSION AND CONCLUSION

The preceding section has presented the results with a limited discussion for each experiment in this study. This section will discuss the overall implications of these results.

An abnormally high level of iron occurred only on those plants which were deficient in zinc (as shown by a growth response to applied zinc). There were no exceptions to this on the six soils used in this study. Always associated with the growth response from the applied zinc was a marked reduction of the high iron level in the plant.

When some other factor such as phosphorus or soil acidity was limiting growth, there was no response to applied zinc even though the soil was low in zinc; therefore, these plants were apparently not deficient in zinc. Under these conditions there were no high iron levels and no effect of zinc on the iron content.

Phosphorus applications appeared to induce a zinc deficiency which coincided with a high iron content within the plant. In other words, when phosphorus needs were met, zinc deficiency then occurred with the associated high level of iron. Zinc responses were then obtained and the high iron levels were reduced. However, there was no tendency for phosphorus to increase the iron content except where a zinc deficiency was created. In fact, phosphorus tended to decrease the iron content where zinc was adequate. The effect of phosphorus in reducing zinc availability and inducing zinc deficiency in sweet corn has been reported by a large number of workers. Some of these include Boawn and Legget (1964); Burleson, Dacus, and Gerard (1961); Ellis, Davis, and Thurlow (1964); Langin et al. (1962); Olsen, Stukenholtz, and Hooker (1965); Ward et al. (1963). The effect of phosphorus on reducing the iron content is also substantiated in the literature (Brown and Tiffin, 1962; Lindsay, 1963; Rediske and Biddulph, 1953). Therefore, the effect of phosphorus on increasing the iron content was an unexpected result and is associated only with zinc deficiency.

Lime also apparently induced zinc deficiency in the plants used in this study. When the soil acidity was overcome by lime, a growth response was obtained from applied zinc. When a zinc-deficient plant was obtained by liming, iron was abnormally high in the plant. This high iron content was sharply decreased when the zinc deficiency was corrected. There was no tendency for lime to increase the iron content except when zinc deficiency occurred. In fact, in the presence of adequate zinc, lime tended to reduce or have no effect on the iron content of the plant. Lime is known to reduce both zinc and iron availability (Barrows, Neff, and Gammon, 1960; Brown, 1961; Hodgson, 1963; Jurinak and Baver, 1956; Rediske and Biddulph, 1953; Thorne, 1957; Wear, 1956). Therefore, when lime resulted in an increase in the iron content, it was contrary to all expectations. However, it is important to note that this occurred only in the zinc-deficient plants.

The high iron content was also present in the zinc-deficient plants grown on the calcareous soil. In this case the zinc deficiency was due to the applied phosphorus. The important point, however, is that on a calcareous soil the iron availability should be low; yet, the same effect was noticed.

In order to account for the zinc-phosphorus-iron-lime interrelations obtained in this study, the hypothesis is advanced that one characteristic of a zinc-deficient plant is an abnormally high iron content. This hypothesis is supported by the work of Rosell and Ulrich (1964) who obtained excessive levels of iron in zinc-deficient sugar beet plants. Winters and Parks (1955) and others have reported the appearance of a dark coloration at the lower nodes of zinc-deficient corn plants. The Zinc Institute of America (1963) reported that this coloration is the result of iron accumulations.

Although the usual effect of lime and phosphorus is a reduction in the iron content of the plant, these two materials are also known to induce a zinc deficiency under certain circumstances. Therefore, it is concluded that the primary effect of the lime and phosphorus treatments was to create a zinc deficiency which resulted in abnormally high iron contents in these plants.

Dilution cannot explain the iron results. The decreased iron content when zinc deficiency was corrected were much larger than the growth changes. Furthermore, the high iron levels in zinc-deficient plants were much higher than in plants which were deficient in phosphorus and those restricted by soil acidity, even though the growth was about the same. In other words not all small plants showed the high iron levels, only the zinc-deficient ones.

Even though the zinc-deficient plants were unusually high in phosphorus, phosphorus is probably not the direct cause of the high iron levels. This is based on the following reasoning: First, in some cases, there was a high phosphorus content not associated with the high iron content; secondly, on one instance zinc increased the phosphorus uptake while it decreased the iron uptake; most significantly, phosphorus increased the iron only when phosphorus induced zinc deficiency. When zinc was adequate, no such effect was observed. Therefore, the key to these results is zinc deficiency. If phosphorus was responsible for the high iron content, it occurred only with the zinc-deficient plants. The effect, therefore is still a characteristic of zinc deficiency.

Zinc-deficient plants also tended to be high in phosphorus and manganese. This was not as clear as the iron data because of a dilution effect; however, by taking dilution into account, there was still a trend toward high phosphorus and manganese levels. Rosell and

Ulrich (1964) noted the same effect in zinc-deficient sugar beet plants. Also in some experiments, this trend was present for calcium, magnesium, and potassium, but this was probably due mostly to dilution.

These results suggest that a zinc-deficient plant is physiologically more active in iron and probably phosphorus and manganese absorption. This is probably not the result of a straightforward ion competition since the decrease in iron from the addition of zinc was much larger than the zinc uptake. Competitive effects are usually characterized by an atom for atom substitution at the absorption site.

SUMMARY

The relationships between zinc, iron, and phosphorus in sweet corn were investigated under field and greenhouse conditions. The soils used in this study (both acid and calcareous) were low in available zinc and phosphorus.

The experiment received standard, uniform rates of nitrogen, potassium, magnesium, and sulphur. Corn was used as an indicator crop in all experiments. Plant samples from the field experiments consisted of whole plants collected at six weeks and index leaves collected at eight weeks from the greenhouse experiment.

The plants that showed visual zinc deficiency symptoms contained very high iron contents and responded to applied zinc. When either phosphorus or soil acidity was limiting growth, no response was obtained from applied zinc and the iron levels were low. Applications of phosphorus and lime both apparently induced a zinc deficiency and a high iron uptake by the plant. Under these conditions marked growth responses to applied zinc were obtained and sharp reductions in iron contents of the plants were noted.

These results are contradictory to those reported by other workers for the effect of phosphorus and lime on the uptake of iron; normally, these two materials reduce the uptake of iron by the plant. This was actually the case when zinc was adequate but the reverse was true when a zinc deficiency existed.

To explain these results, the hypothesis was advanced that one characteristic of a zinc-deficient plant is a high iron content. Although the actual lime and phosphorus effect is probably a reduction of iron uptake, their effect on creating a zinc deficiency and the associated high iron content was most likely the over-riding factor.

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APPENDIX

Appendix Table 1 Chemical composition and yield of whole corn plants six weeks of age. Experiment 420. 1964. Means of three replications.

Treatments		Zn ppm	Fe ppm	Mn ppm	P %	Mg %	Ca %	K %	Yield Tons/Acre
P_1Zn_0	L_0	20	913	195	.52	.53	.33	4.07	.44
	L_1	22	1093	173	.35	.57	.45	4.23	1.28
	L_2	20	1345	205	.42	.55	.55	4.78	1.79
P_1Zn_1	L_0	79	916	240	.68	.49	.31	4.16	1.58
	L_1	66	566	160	.28	.44	.38	4.13	4.83
	L_2	87	600	190	.31	.39	.43	3.83	4.54
P_2Zn_0	L_0	20	760	208	.67	.58	.35	3.70	.17
	L_1	21	920	200	.55	.65	.52	3.87	1.54
	L_2	23	1195	187	.49	.57	.51	4.52	2.30
P_2Zn_1	L_0	107	756	250	.68	.51	.26	3.59	.31
	L_1	35	575	158	.33	.47	.48	3.07	4.28
	L_2	40	550	157	.34	.41	.41	3.28	4.34

Appendix Table 2 Chemical composition and yield of corn leaves. Experiment 424. 1964. Means of six replications.

Treatments	Zn ppm	Fe ppm	Mn ppm	P %	Yield Tons/Acre
0 lbs Zn	16	1184	160	.51	2.56
1 lbs Zn	27	357	90	.32	6.21
2 lbs Zn	30	390	87	.31	5.86
4 lbs Zn	42	294	75	.29	6.76
8 lbs Zn	63	355	84	.30	7.62

Appendix Table 3 Yield data of sweet corn. (Expressed as grams of fresh weight). Greenhouse Experiment 1965. Means of three replications.

Treatments	Soil 434		Soil 435		Soil 436	
	L_0	L_1	L_0	L_1	Fe_0	Fe_1
P_0Zn_0	44	45	28	40	46	50
P_0Zn_1	41	39	28	48	50	53
P_0Zn_2	39	40	25	42	43	40
P_0Zn_3	39	41	32	39	38	45
P_1Zn_0	57	43	53	42	101	142
P_1Zn_1	63	66	59	68	190	175
P_1Zn_2	72	67	55	69	184	188
P_1Zn_3	61	64	47	69	187	178
P_2Zn_0	48	25	57	27	118	120
P_2Zn_1	100	74	106	95	199	166
P_2Zn_2	99	90	99	101	194	192
P_2Zn_3	99	112	96	116	197	187

Appendix Table 4 Chemical composition of corn leaves. Greenhouse soil 434. 1965. Means of three replications.

	Zn ppm		Fe ppm		P %		Mn ppm		K %		Ca %		Mg %	
	L_0	L_1	L_0	L_1	L_0	L_1	L_0	L_1	L_0	L_1	L_0	L_1	L_0	L_1
P_0Zn_0	14.3	11.2	80	92	.12	.15	63	39	2.57	2.57	.31	.46	.32	.33
P_0Zn_1	16.5	12.5	85	88	.14	.14	65	28	2.75	2.97	.31	.51	.32	.33
P_0Zn_2	18.2	18.3	80	82	.14	.15	76	28	3.08	2.87	.34	.50	.32	.33
P_0Zn_3	18.5	18.7	79	75	.14	.13	63	30	3.00	2.97	.33	.38	.30	.29
P_1Zn_0	14.2	12.5	123	411	.14	.40	63	56	2.40	3.52	.32	.49	.33	.39
P_1Zn_1	11.3	9.7	112	80	.13	.11	57	22	2.12	1.82	.32	.45	.33	.31
P_1Zn_2	14.0	12.5	68	77	.10	.11	48	23	1.68	1.73	.30	.45	.27	.31
P_1Zn_3	20.8	16.1	73	72	.12	.10	52	22	1.93	1.77	.32	.37	.30	.26
P_2Zn_0	8.4	16.1	888	1004	.59	.74	181	143	3.43	3.37	.55	1.23	.63	.71
P_2Zn_1	7.5	8.5	103	378	.12	.13	44	37	1.25	1.23	.23	.60	.22	.36
P_2Zn_2	9.0	7.5	63	100	.10	.11	37	20	1.10	1.10	.19	.37	.20	.25
P_2Zn_3	12.2	10.3	58	63	.10	.10	38	14	1.05	.97	.22	.26	.21	.19

Appendix Table 5 Chemical composition of corn leaves. Greenhouse soil 435. 1965. Means of three replications.

	Zn ppm		Fe ppm		P %		Mn ppm		K %		Ca %		Mg %	
Treatments	L_0	L_1	L_0	L_1	L_0	L_1	L_0	L_1	L_0	L_1	L_0	L_1	L_0	L_1
P_0Zn_0	17.0	10.2	92	110	.12	.14	140	57	3.03	2.80	.39	.59	.27	.25
P_0Zn_1	20.4	11.8	86	110	.11	.14	146	50	3.07	2.60	.34	.53	.25	.26
P_0Zn_2	25.8	15.3	93	100	.12	.18	159	57	3.02	3.13	.37	.53	.27	.23
P_0Zn_3	34.1	18.7	79	78	.14	.16	159	53	3.11	3.08	.35	.50	.24	.21
P_1Zn_0	9.8	11.5	97	844	.09	.42	117	135	2.47	3.26	.29	.86	.25	.42
P_1Zn_1	16.5	13.8	72	80	.10	.11	123	43	2.53	2.08	.31	.50	.24	.25
P_1Zn_2	20.3	16.7	80	73	.10	.13	115	42	2.53	2.18	.30	.52	.22	.25
P_1Zn_3	34.3	19.3	83	73	.10	.11	107	48	2.57	1.93	.32	.54	.24	.23
P_2Zn_0	9.2	7.3	816	743	.37	.67	238	192	2.88	3.37	.54	1.11	.45	.56
P_2Zn_1	9.0	7.5	80	302	.11	.13	67	65	1.33	1.25	.21	.60	.16	.26
P_2Zn_2	10.5	9.5	68	157	.10	.12	77	52	1.38	1.10	.23	.49	.17	.22
P_2Zn_3	16.0	13.0	68	70	.10	.10	77	28	1.28	1.08	.23	.35	.17	.17

Appendix Table 6 Chemical composition of corn leaves. Greenhouse soil 436. 1965. Means of three replications.

	Zn ppm		Fe ppm		P %		Mn ppm		K %		Ca %		Mg %	
Treatments	Fe_0	Fe_1	Fe_0	Fe_1	Fe_0	Fe_1	Fe_0	Fe_1	Fe_0	Fe_1	Fe_0	Fe_1	Fe_0	Fe_1
P_0Zn_0	11.2	12.6	68	73	.07	.07	56	26	2.65	2.63	.53	.43	.43	.44
P_0Zn_1	18.8	19.0	68	75	.08	.07	52	24	2.40	2.28	.60	.48	.45	.44
P_0Zn_2	24.5	22.1	62	78	.08	.09	46	29	2.63	3.05	.49	.45	.41	.44
P_0Zn_3	34.6	24.7	61	77	.08	.08	51	28	2.58	2.83	.57	.52	.43	.47
P_1Zn_0	8.8	7.5	515	356	.57	.20	191	108	3.27	1.50	.73	.58	.71	.66
P_1Zn_1	7.8	8.0	55	70	.12	.11	27	27	.77	1.05	.34	.29	.34	.36
P_1Zn_2	11.8	10.0	48	58	.12	.11	26	25	.60	.85	.32	.31	.36	.36
P_1Zn_3	15.8	12.0	48	53	.11	.11	20	16	.67	.95	.28	.29	.32	.33
P_2Zn_0	8.3	6.8	437	380	.89	.60	180	112	2.69	1.74	.70	.57	.75	.67
P_2Zn_1	7.2	8.2	58	80	.23	.23	29	31	.76	1.07	.32	.33	.37	.36
P_2Zn_2	11.3	8.7	50	50	.20	.23	27	22	.76	.97	.29	.31	.37	.33
P_2Zn_3	15.5	12.0	50	53	.22	.22	29	22	.76	1.08	.26	.33	.34	.35

Appendix Table 7 Chemical composition and yield of corn leaves. Experiment 434. 1965. Means of four replications.

Treatments	Zn ppm	Fe ppm	Mn ppm	P %	K %	Mg %	Ca %	Yield Tons/Acre
P_0Zn_0	12	265	102	.22	2.50	.36	.55	1.20
P_0Zn_1	30	242	95	.21	2.25	.32	.51	1.20
P_0Zn_2	65	247	87	.18	2.10	.32	.53	1.43
P_0Zn_3	107	261	95	.21	2.25	.31	.53	1.20
P_1Zn_0	9	1287	187	.23	2.09	.55	.70	1.96
P_1Zn_1	13	197	109	.20	1.96	.41	.57	3.39
P_1Zn_2	25	244	92	.18	2.06	.35	.63	3.39
P_1Zn_3	45	246	114	.20	2.06	.37	.55	3.78
P_2Zn_0	8	1538	245	.32	2.00	.60	.73	1.20
P_2Zn_1	13	307	139	.20	1.94	.46	.65	3.39
P_2Zn_2	17	252	121	.24	1.87	.40	.61	4.16
P_2Zn_3	28	216	104	.20	1.95	.39	.63	4.45