EVALUATION OF LIQUID AMMONIUM POLYPHOSPHATE AS A CARRIER OF IRON AND ZINC

by

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INTRODUCTION

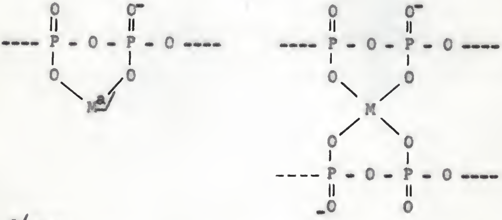
Increasing attention has been focused to the need of fertilizing with micronutrient elements to achieve maximum production and optimum quality of farm crops. The supply of these elements in the soil has become limited in some areas as a result of the introduction of high yielding varieties, better and more intensive cropping practices, and increased use of high analysis fertilizers. In some cases, the observed deficiencies of these micronutrients have been man-made due to addition of interfering elements for other purposes. For instance there is the copper induced iron chlorosis, copper being introduced as agricultural sprays and the phosphorus induced iron and zinc deficiencies, phosphorus being introduced to meet the phosphorus requirement of farm crops. How to minimize such interactions and the problems of keeping these micronutrient elements available to the plants when applied to the soil have been the subject of intensive researches.

The use of synthetic chelating agents such as ethylenediaminetetraacetic acid (EDTA), diethylenetriaminepentaacetic acid (DTPA), ethylenediaminedihydroxyphenylacetic acid (EDDHA), cyclohexanediaminetetraacetic acid (CDTA), etc. to chelate micronutrient elements has been found to alleviate the problems of interaction and availability but due to the high cost of these products, it often is not profitable when they are used in ordinary farm crops. Recently, it was thought that polyphosphates may act as sequestering agents for micronutrient elements. Since phosphorus is one of the major requirement for plant growth and development, polyphosphate fertilizer would be an invaluable product for it would serve a dual purpose.

The polyphosphate is a chain type of molecule having the simplest formula $H_4P_2O_7$ (pyrophosphoric acid) as compared to H_3PO_4 for orthophosphoric acid, the form of phosphate with which we are most familiar.

To produce the polyphosphoric acid, the proportion of water used to absorb the resulting oxide of elemental phosphorus produced in an electric furnace is restricted to give an acid containing 76 to 79 percent P_2O_5 as compared to 54 percent P_2O_5 in orthophosphoric acid. The product, pyrophosphoric acid, is the principal source of polyphosphate in the field of fertilizer manufacturing.

The suspected mechanisms by which the polyphosphates sequester metal cations are shown in figure 1.



a/ Metal

Figure 1. Chelation by polyphosphates (After R. L. Smith).

Only very limited work has so far been published on the use of polyphosphate fertilizer as a carrier of micronutrient elements. Inorder to fully evaluate its sequestering property, additional investigations are imperative. Thus, this study was conducted with the objectives of (a) determining the effectiveness of liquid ammonium polyphosphate as a carrier of iron and zinc as compared to monoammonium phosphate where the phosphorus is present as orthophosphate and (b) to observe the incidence of phosphorus-iron and phosphorus-zinc interactions.

REVIEW OF LITERATURE

Iron. Phosphorus has been shown to induce iron chlorosis. Results from various experiments have indicated that phosphorus could inactivate iron by precipitation in the growth media or within the plants, could influence iron absorption and translocation within the plants, and that phosphorus may increase the plants requirements for iron.

Sideris and Krauss (1934) found that the application of phosphate to a pineapple soil with low annual rainfall did not stimulate pineapple growth. They stated that these soils, as a result of the low rainfall, had high pH values due to their high content of unleached potassium, calcium, and magnesium. On account of these high pH values, only traces of water-soluble iron existed, the solubility of which was further lowered by the added phosphate in combination with either potassium, calcium, or magnesium which are relatively soluble under these conditions.

McDonald (1935) reported that cacao trees growing on phosphorus deficient gypseous soils failed to respond to the application of phosphatic fertilizers. His preliminary results indicated that under certain conditions, the presence of abundant phosphate may markedly depress the uptake of iron by the cacao trees. Recently, Spencer (1960) reported that the iron uptake of Ruby Red grapefruit trees growing on a previously uncropped Lakeland fine sand at Lake Alfred, Florida was markedly reduced by the heavy application of triple superphosphate.

Pot tests with peanuts by Chandler and Scarseth (1941) on Houston and Sumter clays showed that application of superphosphate to these clays produced iron chlorosis. They observed that the disorder was more severe in the highly calcareous Sumter clay. When alfalfa was used as a test plant, no iron chlorosis was evident, however, the iron content of the alfalfa was decreased with the addition of superphosphate.

Using solution cultures, Franco and Loomis (1947) observed that iron absorption by plants was reduced by phosphorus, probably by $H_2PO_4^-$ ions especially at pH values of about 6.0 or higher. By omitting the phosphorus from the solution and adding it separately 2 to 4 days later after iron has been absorbed, they were able to reduce or prevent chlorosis from occuring.

The proportion of phosphorus and iron in the growth media is an important factor controlling iron availability. Biddulph (1948) observed that in a nutrient solution containing phosphorus and iron at a molar ratio of 10:1, ferric iron was rapidly precipitated when it was introduced as the nitrate, chloride, or phosphate but when it was introduced as the citrate, tartrate, or humate, high concentrations of iron in the solution was maintained. The highest iron concentration was obtained with ferrous sulfate at pH 4.0. When Biddulph determined the uptake of iron by bean plants over a range of phosphorus concentrations for a duration of 4 days by the tracer method, he found that the greatest accumulation of iron by leaves and the least accumulation by roots occured where the phosphorus to iron ratio~~n~~ was 1:1, the phosphorus being unusually low and the iron high in these tissues. He also observed that phosphorus moved readily in the phloem whereas iron was relatively immobile. Quite similar results were reported by Rediske and Biddulph (1953) who grew Red Kidney beans in nutrient media with varying quantities of iron and phosphorus and pH values ranging from 4.0 to 7.0. They found that a high concentration of phosphorus in the nutrient solution retarded the uptake of iron. As they increased the phosphorus concentration from that equimolar with iron (at 0.2×10^{-4} M), both iron uptake into all plant parts and iron adsorption on the root decreased. When they decreased the phosphorus concentration from that equimolar with iron, iron uptake into the aerial parts also decreased, but iron adsorption on the roots was found to either decrease or increase. They also observed that the mobility of the absorbed iron was greatest when the iron and phosphorus concentrations and pH were high.

Precipitation of iron by phosphorus within the plant was believed to be the principal cause of phosphorus-induced iron chlorosis by Biddulph and Woodbridge (1952). They stated that when the amount of phosphorus present in the tissue exceeded that what was adequate for plant, a disturbance in the metabolic use of ions, particularly iron occurred. Iron was precipitated when it passed through a tissue rich in phosphorus. Doney _et al_. (1960) applied labelled iron on the leaves of bean plants. They observed that although the movement into the bean plants of the foliar-applied Fe^{59} was influenced only slightly by the high amount of phosphorus in the nutrient solution, the translocation of the absorbed Fe^{59} to the various plant parts was markedly affected. When the foliar-applied Fe^{59} reached the phosphorus-enriched tissue, it was inactivated, apparently by precipitation. Bennet (1945) and Thorne _et al_. (1950), however, expressed doubt that high phosphorus whether in the tissue or soil contributed to chlorosis. Bennet, in an attempt to produce chlorosis injected phosphate solution into French prune tree branches previous to leaf development. Although the phosphorus content of the leaves was increased many fold, no chlorotic disorder was visible. Bingham _et al_.

(1958) reported an increase in the percent phosphorus in the leaves of citrus by over six-fold as a result of phosphorus fertilizer addition but they noted no reduction in the leaf content of iron.

Sims and Gabelman (1956) found that a level of 1000 parts per million phosphorus was necessary to induce iron chlorosis in spinach grown in sand cultures. On the other hand, Brown _et_ _al_. (1955) were not able to induce iron chlorosis in rice with high phosphorus applications unless a relatively high amount of copper was also applied with the phosphorus. Brown _et_ _al_. (1959) also arrived at the conclusion that iron deficiency was accentuated by improper microelement balance. Microelement imbalance appeared to be the causative factor controlling the development of iron chlorosis in milo grown Quinlan and Tripp soils while an abundance of available phosphorus and calcium appeared to be the controlling causative factors of iron chlorosis in PI-54619-5-1 soybeans grown on the naturally calcareous Millville soil.

Watanabe _et_ _al_. (1965) reported an antagonistic effect of zinc on iron and phosphorus on iron and zinc. When they added zinc to a calcareous solution culture where there was intermediate level of iron, they observed an accentuated iron deficiency symptom and a depression in the yield of corn. With that same intermediate level of iron, but with increased concentration of phosphorus, they observed that the yield of corn was first increased; then phosphorus-induced iron deficiency symptom appeared accompanied by a depression in the yield. In both cases, they were able to counteract the depression in yield by increasing the level of iron in the culture solutions.

Zinc. A high amount of soluble or total phosphates in soils has been observed to be one of the factors reducing zinc availability. Mowry and Camp (1934) in their study on the zinc deficiency of tung trees in Florida concluded that the high amount of phosphate in the soil reduced zinc availability. Thorne and Wann (1950) reported similar results. They collected soil samples from three orchards where there was observed zinc deficiency and from orchards where the trees were normal. They found that samples from the zinc deficient areas had much higher contents of soluble phosphorus than soils supporting normal trees.

Numerous results have also been published about induced zinc deficiency due to the application of readily available phosphorus fertilizers. Rogers and Wu (1948) found that phosphate applications to virgin Lakeland fine sand decreased the zinc content of Florida 167 variety of oats. The zinc content of the plants decreased to an almost constant value with increasing rates of phosphate application. The same observation was reported by Loneragan (1951) who grew flax plants in a zinc-deficient Jojonup gravelly sand to which different amounts of phosphate had been added.

Symptoms of zinc deficiency appeared in four weeks and reached maximum severity in six weeks, after which recovery commenced. The severity of the symptoms and the response to zinc treatments increased with increased phosphate applications.

Bingham and Martin (1956) added different levels of monocalcium phosphate ($Ca(H_2PO_4)_2.H_2O$) to three California soils and found that the copper and zinc contents of citrus plant tops were markedly reduced. Severe copper deficiencies were induced by as little as 360 pounds of phosphorus per acre while zinc absorption was reduced at high rates.

Burleson _et_ _al_. (1961) reported that phosphorus-induced zinc deficiency is influenced by soil and climate conditions. In a greenhouse experiment with Red Kidney beans (_Phaseolus_ _vulgaris_), they observed severe phosphorus-induced zinc deficiency with phosphorus fertilization. The absorption of zinc was decreased by phosphorus fertilization but was increased by zinc fertilization. Likewise, the absorption of phosphorus was decreased by zinc fertilization but was increased by phosphorus fertilization. When both zinc and phosphorus were applied, the uptake of both zinc and phosphorus was reduced. They concluded that the phosphorus-induced zinc deficinecies were enhanced by the cold wet soils during the early part of the growing season. Direct evidence for their conclusion was presented by Ellis _et_ _al_. (1964) who grew Michigan hybrid corn number 250 under controlled temperatures of 75° and 55°F. They found that the decrease in temperature from 75° to 55°F decreased the zinc concentration of the corn tops from 310 to 73 ug per pot.

The phosphorus-induced zinc deficiency as a result of row application of readily available phosphorus fertilizer to corn or grain sorghum was reported by Langin et al. (1962) to be more pronounced in calcareous soils which have a high level of phosphorus and where the plant zinc concentrations were already approaching a critical level. They stated that the more effectively the applied phosphorus is utilized by the crop, the more severe will be the curtailment of zinc uptake.

Reductions in yield of farm crops have also been reported to be due in some cases to phosphorus-induced zinc deficiency. Boawn and Legget (1963) found that the growth disorder of Russet Burbank potatoes previously referred to as fern leaf, is caused by a deficiency of zinc. They reported that development of this deficiency was associated with the application of phosphorus fertilizer. The plants that were treated with phosphorus but no zinc eventually died and produced no marketable tubers, whereas the plants that did not receive phosphorus fertilization or were treated with zinc in addition to phosphorus, had normal growth and produced sizeable tonnages of marketable potatoes. Thurlow et al. (1963) observed zinc deficiency of beans where much phosphate was applied. Yields were 11 bushels per acre lower where 800 pounds per acre of phosphate was applied than where no phosphate was applied. Ellis et al. (1964) also reported a severe reduction in yield of field beans due mainly to phosphorus-induced zinc deficiency.

Contrary to the phenomenon of phosphorus-induced zinc deficiency is the result of a study of Boawn et al. (1954) who failed to influence the uptake of either applied or native soil zinc by beans through the application of phosphate to soils in Central Washington. More than doubling the concentration of phosphate in the plant tissue failed to produce zinc deficiency symptoms or reduce the yield of dry matter. Thorne (1957) also was unable to increase zinc deficiency symptoms of peach trees by application of superphosphate equivalent to a ton of soluble P_2O_5 per acre in an orchard where mild zinc deficiency symptoms were general.

Lately, the incorporation of micronutrient elements with fertilizers carrying macronutrient elements had been introduced. It was again observed that zinc availability to plants is apparently affected by the source of phosphorus when zinc is incorporated or mixed with phosphorus carrying fertilizers. Recent investigation by Terman and Allen (1964) showed that dry matter production and zinc uptake by corn from zinc sulfate pressure granulated with various phosphorus sources decreased as follows: ammonium polyphosphate>monoammonium phosphate>concentrated superphosphate>dicalcium phosphate.

Field test in Michigan by Judy et al. (1964) gave some indication that ammonium polyphosphate was superior to monoammonium phosphate as a carrier of zinc when row-applied to pea beans in calcareous soils. Yields were slightly higher and zinc concentrations in plant tissues taken during the growing season were much higher with incorporation of zinc oxide in ammonium polyphosphate as compared to incorporation in monoammonium phosphate.

Giordano and Mortvedt (1965) reported that zinc oxide and zinc sulfate incorporated in ammonium nitrate, ammonium polyphosphate, and concentrated superphosphate were equally effective and markedly superior to zinc sulfide as source of zinc when mixed with the soil. Ammonium nitrate and ammonium polyphosphate containing 2 percent zinc were comparable as carriers, whereas concentrated superphosphate containing 9 percent zinc was inferior. They attributed these differences to the concentration of zinc in the macronutrient carriers. Lessman and Ellis (1965) observed that the percentage of zinc which remained water soluble decreased with increasing quantities of zinc oxide incorporated in ammonium polyphosphate. When zinc oxide was incorporated with ammonium orthophosphate, it was less water soluble than the same quantity of zinc oxide incorporated in ammonium polyphosphate. This water soluble zinc present in the fertilizer was found to be related to the zinc content of pea beans at an early stage of growth. Yield and zinc uptake data from their field experiments with pea beans grown on calcareous soils indicated that ammonium polyphosphate is a more effective carrier than ammonium orthophate in supplying zinc to the plants.

From this review it is apparent that mixed fertilizers containing phosphorus in the polyphosphate form is better than mixed fertilizers with orthophosphate form of phosphorus as a carrier of zinc. As to whether this could also be true with other microelements is still a question. And if mixed fertilizers with polyphosphate prove to be a good carrier of microelements, could we dispense from using expensive synthetic chelating agents to render microelements more available to plants? This study was conducted to answer in part some of these questions.

MATERIALS AND METHODS

Fertilizer Materials. Two forms of phosphorus containing fertilizer materials were used as carriers of iron and zinc. One was liquid ammonium polyphosphate (APP) and the other was monoammonium phosphate (MAP). The APP had an analysis of 10-34-0 in which 60 percent of the phosphorus present was in the polyphosphate form, the rest in the orthophosphate form. The MAP had an analysis of 8-24-0 in which all the phosphorus was present in the orthophosphate form. The ferrous sulfate ($FeSO_4$), monosodium hydrogen ferric diethylenetriamine pentaacetate (NaFeDTPA), zinc sulfate ($ZnSO_4$), or disodium zinc ethylenediamine tetraacetate ($Na_2ZnEDTA$) was dissolved/mixed in the two carriers prior to application. Liquid monoammonium phosphate was produced by dissolving the fertilizer material MAP in water.

Ammonium nitrate (NH_4NO_3) was also added to the solution/mixture when the nitrogen present in the carriers did not satisfy the rates that were needed, and where potassium was needed in the treatment, potassium chloride (KCl) was used.

Field Experiments. In 1964, four sites were selected in three Kansas counties (Osborne, Pottawatomie, and Shawnee). The cooperating farmers, the corresponding locations, and the soil chemical properties of their respective farms are given in Table 1.

Table 1. Cooperators, locations, and soil chemical analyses of the areas used in the experiment[a]

Cooperator	Location	pH	O.M.	Avail. P	Acid ext. Zn	Exch.K
			%	Lbs./A	Lbs./A	Lbs./A
Campbell	Shawnee Co.	5.7	0.7	40.0	4.8	251
Parr-Gentry	Shawnee Co.	5.7	1.3	80.0	5.5	361
Kaser	Osborne Co.	7.5	1.6	18.0	5.4	500+
Miller	Pottawatomie Co.	7.0	1.2	78.0	10.3	500+

[a] Analysis of the surface soil.

All sites had been previously levelled for irrigation purposes and had been cropped for some time before this experiment was conducted. The experimental areas were prepared for planting by the farmers with the same cultural procedures used on their respective farms. Planting, fertilization, and harvesting operations were performed by the investigator. All other operations including irrigation were carried out by the cooperators.

The treatments in the experiment were arranged in a randomized complete block design. There were 16 treatments and all were replicated 4 times. The plots used per treatment measured 60 x 13.33 feet. The distance between blocks was 30 feet. Four rows of corn were planted to each plot. Planting was accomplished by means of an International Harvester seed planter at a speed of 3½ mph. The fertilizers were applied to the side and below the level of the seed at planting time. In order to apply the correct amount of fertilizer per treatment, the applicator device was calibrated prior to its use in the field.

Each cooperator applied 150 pounds nitrogen per acre as anhydrous ammonia to their respective fields prior to the planting of the experimental plots. Ten pounds of N, 34 pounds of P_2O_5, and 17 pounds of K_2O per acre were applied to all plots except the check plots at planting time. Applications of 0.0, 0.3, 0.6, 3.0, 4.8, and 10.5 pounds per acre of zinc were dissolved/mixed in the base fertilizers to complete the treatments. The phosphorus carriers in treatments 2 to 11 were in the liquid state necessitating dissolution of the zinc as $ZnSO_4$ and $Na_2ZnEDTA$ in the fertilizer solutions. In the case of treatments 12 to 16, the zinc was mixed with the solid phosphorus carriers. The complete treatments are given in Table 2.

The corn was planted May 13-19, 1964. About two weeks after planting, the plants were thinned to a population of about 18,000 plants per acre.

Height of the plants were measured at the Campbell farm in Shawnee County 52 days after planting. Ten plants per row were randomly picked and measured in the middle two rows from each plot.

At maturity, 40 feet in the center of the inside two rows from each plot was harvested by hand-picking the ears. Ear samples were collected for moisture determinations. The yield was converted into bushels per acre after adjusting the moisture content to the 12 percent level.

In 1965, only two experimental sites were selected. The cooperating farmers, the corresponding locations, and the soil chemical properties of their respective farms are given in Table 3.

Areas selected for the 1965 experiment had also been levelled for irrigation operations and had been cropped for some time prior to the initiation of the experimental work. The cooperating farmers also took charge of all the field.

Table 2. Description of the different treatments used in 1964

Treatment[a], [b]	Zinc source[c]	Carrier
$N - P_2O_5 - K_2O - Zn$		
Lbs./A.		
1. 150 - 0 - 0 - 0.0	---	---
2. 160 - 34 - 17 - 0.0	---	MAP[d]
3. 160 - 34 - 17 - 0.3	$Na_2ZnEDTA$	MAP
4. 160 - 34 - 17 - 0.6	$Na_2ZnEDTA$	MAP
5. 160 - 34 - 17 - 3.0	$Na_2ZnEDTA$	MAP
6. 160 - 34 - 17 - 0.3	$ZnSO_4$	MAP
7. 160 - 34 - 17 - 0.6	$ZnSO_4$	MAP
8. 160 - 34 - 17 - 3.0	$ZnSO_4$	MAP
9. 160 - 34 - 17 - 0.3	$ZnSO_4$	APP[e]
10. 160 - 34 - 17 - 0.6	$ZnSO_4$	APP
11. 160 - 34 - 17 - 3.0	$ZnSO_4$	APP
12. 160 - 34 - 17 - 0.0	---	MAP
13. 160 - 34 - 17 - 0.3	$Na_2ZnEDTA$	MAP
14. 160 - 34 - 17 - 0.6	$Na_2ZnEDTA$	MAP
15. 160 - 34 - 17 - 4.8	$ZnSO_4$	MAP
16. 160 - 34 - 17 - 10.5	$ZnSO_4$	MAP

[a] 150 lbs. per acre N as anhydrous ammonia was applied before planting.

[b] Treatments 1 to 11 are in liquid state, and treatments 12 to 16 are in dry state.

[c] Dissolved/mixed in the carrier prior to application.

[d] Monoammonium phosphate in which the P is present as orthophosphate.

[e] Ammonium polyphosphate in which the P is present as polyphosphate.

Table 3. Cooperators, locations, and soil chemical analyses of the areas used in the experiment

Cooperator	Location	pH	O.M.	Avail. P	Acid ext. Zn	Avail. Fe	Exch. K
			%	Lbs./A.	Lbs./A.	Lbs./A.	Lbs./A
Campbell	Shawnee Co.[a]	5.7	2.2	15.0	4.4	---	169
Nonamaker	Osborne Co.						
	0 - 6"	8.3	1.0	9.0	---	16.8	292
	6 - 12"	8.2	1.0	7.0	---	17.2	302

[a] Surface soil.

operations on the experimental areas except planting, fertilizing, and harvesting. The methods of planting, fertilizing, and treatment lay-out were exactly the same as in 1964. The treatments, however, were modified.

The Joe Campbell farm located in Shawnee County was the site of the 1965 zinc experiment. The complete treatments included in this experiment are presented in Table 4. The zinc sulfate applied in treatment 2 was mixed with the potassium chloride. In treatments 3 to 13, the zinc sulfate and zinc chelate ($Na_2ZnEDTA$) were dissolved in the liquid carriers, ammonium polyphosphate and monoammonium phosphate, prior to their application.

The MFA K6 hybrid corn was planted on May 9, 1965. About three weeks after planting, the plants were thinned to a population of about 18,000 plants per acre. The plots were harvested as in 1964.

The Dale Nonamaker farm located in Osborne County was the site of the 1965 iron experiment. The treatments

Table 4. Description of the different treatments used in 1965

Treatment[a/] $N - P_2O_5 - K_2O - Zn$	Zinc source[b/]	Carrier
Lbs./A.		
1. 150 - 0 - 30 - 0.0	---	---
2. 150 - 0 - 30 - 2.0	$ZnSO_4$	---
3. 160 - 34 - 30 - 0.0	---	APP[c/]
4. 160 - 34 - 30 - 0.5	$ZnSO_4$	APP
5. 160 - 34 - 30 - 1.0	$ZnSO_4$	APP
6. 160 - 34 - 30 - 2.0	$ZnSO_4$	APP
7. 160 - 34 - 30 - 0.5	$Na_2ZnEDTA$	APP
8. 160 - 34 - 30 - 1.0	$Na_2ZnEDTA$	APP
9. 160 - 34 - 30 - 2.0	$Na_2ZnEDTA$	APP
10. 160 - 34 - 30 - 0.5	$ZnSO_4$	MAP[d/]
11. 160 - 34 - 30 - 1.0	$ZnSO_4$	MAP
12. 160 - 34 - 30 - 0.5	$Na_2ZnEDTA$	MAP
13. 160 - 34 - 30 - 1.0	$Na_2ZnEDTA$	MAP

[a/] 150 lbs. per acre of N as anhydrous ammonia was applied before planting. The 30 lbs. per acre K_2O as KCl was applied to the side and below the seed at planting time.

[b/] Dissolved in the liquid carrier except in treatment 2 wherein it was mixed with the dry KCl.

[c/] Liquid 10-34-0 ammonium polyphosphate in which the P is present as polyphosphate.

[d/] Dissolved 8-24-0 monoammonium phosphate in which the P is present as orthophosphate.

included in this experiment are presented in Table 5. In treatment 2, the ferrous sulfate was applied by mixing it with the mixture of ammonium nitrate and zinc sulfate. In the other treatments where iron was added, the ferrous sulfate or iron chelate was dissolved in the liquid carriers, ammonium polyphosphate and monoammonium phosphate, prior to their application.

One hundred thirty-five pounds per acre of nitrogen as anhydrous ammonia were applied by the cooperators to the experimental area prior to planting time. Fifteen pounds per acre of nitrogen as ammonium nitrate and 5 pounds per acre of zinc as zinc sulfate were also applied to all plots at the time of planting.

The grain sorghum, variety Pioneer 820, was planted on May 20, 1965. The rows were spaced 30 inches apart. Harvesting was accomplished by handcutting the grain sorghum heads. Plot yields were taken from 10 feet of the center two rows. The harvested heads were dried and threshed, and the grain weighed. The yield was converted to bushels per acre. A sample of the grain was taken from each treatment and oven-dried at 60°C then ground for protein analysis.

<u>Soil Sampling</u>. Soil samples were taken at random from the experimental areas prior to planting. The samples were air-dried in the laboratory, pulverized with a wooden mallet, and passed through a two millimeter sieve. The soil Testing Laboratory of the University analyzed the soil samples for

Table 5. Description of the different treatments used in 1965

Treatment[a], [b] N - P_2O_5 - K_2O - Fe Lbs./A.	Iron source[c]	Carrier
1. 150 - 0 - 0 - 0.0	---	---
2. 150 - 0 - 0 - 2.0	$FeSO_4$	---
3. 160 - 34 - 0 - 0.0	---	APP[d]
4. 160 - 34 - 0 - 0.5	$FeSO_4$	APP
5. 160 - 34 - 0 - 1.0	$FeSO_4$	APP
6. 160 - 34 - 0 - 2.0	$FeSO_4$	APP
7. 160 - 34 - 0 - 0.5	NaFeDTPA	APP
8. 160 - 34 - 0 - 1.0	NaFeDTPA	APP
9. 160 - 34 - 0 - 2.0	NaFeDTPA	APP
10. 160 - 34 - 0 - 0.5	$FeSO_4$	MAP[e]
11. 160 - 34 - 0 - 1.0	$FeSO_4$	MAP
12. 160 - 34 - 0 - 0.5	NaFeDTPA	MAP
13. 160 - 34 - 0 - 1.0	NaFeDTPA	MAP

[a] 135 lbs. per acre of N as anhydrous ammonia was applied to all plots before planting.

[b] All plots received 15 lbs. per acre of N as NH_4NO_3 and 5 lbs. per acre of Zn as $ZnSO_4$, applied to the side and below the seed at planting time.

[c] Dissolved in the liquid carrier except in treatment 2 wherein it was mixed with the NH_4NO_3 and $ZnSO_4$.

[d] Liquid 10-34-0 ammonium polyphosphate.

[e] Dissolved 8-24-0 monoammonium phosphate.

pH, organic matter content, available phosphorus, and exchangeable potassium. The soil samples were also analyzed for weak hydrochloric acid-extractable zinc and available iron.

Leaf Sampling. Leaf samples were collected approximately two months after planting. The third youngest leaf was selected for tissue analyses. Twenty leaves were collected at random from the middle two rows of each plot.

The leaf samples were washed with deionized distilled water (distilled water passed through an exchange resin column), dried at 60°C in a forced air oven, and then ground in a Wiley mill. Phosphorus, zinc, and iron content of the samples were determined.

Chemical Analysis. (a) Zinc. The zinc content of the soils and plant materials was determined using the method given by Johnson and Ulrich (1959) as modified by Ellis (1964).

Soil Zinc. A five gram portion of soil was placed in a 100 ml. polyethylene centrifuge tube and 50 ml. of the 0.2 N HCl extracting reagent was added. The tube was stoppered with polyethylene stoppers and was shaken on a wrist-action shaker for one hour. To insure complete extraction of available zinc, the equilibrium pH of the supernatant liquid (after shaking for one hour) was maintained below pH 5.0. Higher concentration of the extracting solution were used if the desired pH was not attained.

The suspension was then centrifuged until the supernatant liquid was clear. A 25 ml. aliqout was withdrawn, placed in pyrex beaker and taken to dryness at low temperature. The residue was brought into solution by adding 5 ml. of 2.0 N HCl. The solution was passed through an anion exchange resin (Dowex 1-x8) column which was saturated with chloride ions by passing 5 ml. of 2.0 N HCl through the column just prior to the introduction of the sample. In the presence of excess chloride, zinc ions form a complex anion believed to be $ZnCl_4^{=}$, is quantitatively adsorbed by the resin. Before the extraction of zinc from the column, interferring ions were removed by passing 20 ml. of 1.0 N KCl through the column. The zinc was then extracted from the column by passing two 20 ml. portions of 0.1 N $NaNO_3$ through the column. The zinc content of the extract, collected in a 50 ml. volumetric flask, was determined by adding 5 ml. of zincon-buffer solution. The volumetric flask was filled to the mark with deionized distilled water and the percent transmittancy was determined in a Coleman Junior Spectrophotometer at a wavelength of 620 mu.

Zinc in Plant Materials. (1) "Zincon" Method. One gram of the finely ground, well mixed, and oven-dried plant material was dry ashed at 500° to 550°C in a muffle furnace for 4 hours or until the ash was uniformly gray or white. The ash was cooled and moistened slightly with deionized distilled water. A 5 ml. volume of 2.0 N HCl was added to dissolve the precipitate. Dissolution was facilitated by the application of a small amount of heat. The solution was then filtered directly into the resin column by means of a Whatman No. 42 filter paper. From this point on, the treatments of standard solutions, soil extracts, and filtrates from plant materials were the same.

(2) Atomic Absorption Spectrophotometric Determination of Zinc. A 2.5 gram sample of the finely ground, well mixed, and oven-dried plant material was dry ashed and taken into solution in the same manner as described in the "Zincon" method. The solution was filtered with Whatman No. 42 filter paper into a 50 ml. volumatric flask receiver. The residue was washed several times with 2.0 N HCl and the washings were added to the 50 ml. volumetric flask containing the filtrate. The filtrate and washings were diluted to volume with 2.0 N HCl. Zinc was determined directly on an aliquot of this solution by means of the atomic absorption spectrophotometer.

(b) Iron. The available iron content of the soils was determined using the procedure given by Olson (1965).

A 12.5 gram sample of air-dried soil was placed in a flask and 50 ml. of 1.0 N NH_4OAc extracting reagent, adjusted to pH 4.8, was added. The flask was stoppered and then agitated for 30 minutes on a wrist-action shaker. The soil suspension was filtered through a piece of number 2 Whatman filter paper using a Buchner funnel. A 25 ml.

portion of the extract was pipetted into each of two 50 ml. volumetric flasks. To the first flask, 4 ml. of 10% hydroxylamine hydrochloride reagent was added. The solution was mixed and 4 ml. of orthophenanthroline reagent was again added. To the second flask, only 4 ml. of 10% hydroxylamine hydrochloride reagent was added. The volume of each flask was adjusted to the 50 ml. mark with distilled water. The transmittancy of the two solutions was then read on a Coleman Junior Spectrophotometer using a wavelength setting of 510 mu. The solution without orthophenanthroline was used in adjusting the galvanometer reading to 100 percent light transmission prior to reading the sample with orthophenanthroline for iron determination.

Iron in Plant Materials. The iron content of the plant material was determined by means of the atomic absorption spectrophotometer from the same solution prepared for the determination of zinc.

(c) Phosphorus. Available phosphorus was determined in the soil samples using the phosphomolybdate method of Bray and Kurtz as adapted by Jackson (1964).

A sample of soil was shaken with the extracting reagent, 0.1 N HCl and 0.03 N NH_4F, for 40 seconds and then quickly filtered through a moist Whatman No. 42 filter paper. An aliquot of the clear filtrate was transferred to a volumetric flask. Ammonium molybdate and freshly prepared stannous chloride reagents were then added. The flask was adjusted to volume, mixed well, and the percent transmittancy of the phosphorus containing solution determined in a Coleman Junior Spectrophotometer using a wavelength setting of 660 m u.

Phosphorus in Plant Materials. The content of phosphorus in the plant material was determined following the wanadomolybdate procedure described by Jackson (1964).

A 1.0 gram sample of finely ground, well mixed, oven-dried plant material was placed in a 50 ml. capacity pyrex beaker. Five ml. of 0.5 N $Mg(NO_3)_2$ and 10 ml. of distilled water were added. This mixture was evaporated to dryness on a steam bath and then the beaker was allowed to dry. The beaker and contents were placed in a muffle furnace and ignited at 500° to 550°C for 4 hours or until the ash was uniformly gray or white in color. The beaker was cooled and then 10 ml. of approximately 2.0 N H_2SO_4 was added. Then 15 ml. of distilled water were added and the beaker was placed on the steam bath to evaporate the suspension to a volume of less than 5 ml. The dish was removed from the steam bath and 20 ml. of distilled water added. The contents were filtered into a 100 ml. volumetric flask using a piece of number 42 Whatman filter paper. The residue was washed, the washes being added to the flask, then the solution was made to volume. A 25 ml. of vanadomolybdate reagent was then added. The solution was brought to volume, mixed and then read for percent transmittancy in a Coleman Junior Spectrophotometer at a wavelength setting of 470 m u.

(d) Potassium. Following the procedure described by Jackson (1964), echangeable potassium was extracted from the soil with 1.0 N NH_4OAc (pH 7.0) by shaking the soil and the extracting reagent for 30 minutes with a mechanical shaker. The suspension was immediately filtered under suction by means of a Buchner funnel. The potassium content of the filtrate was determined with a flame emission spectrophotometer.

(e) Organic Matter. Soil organic matter was determined by means of the wet oxidation method as given by Jackson (1964). A sample of soil was allowed to react with 10 ml. of 1.0 N $K_2Cr_2O_7$ and 20 ml. of concentrated sulfuric acid added to hasten the reaction. After 30 minutes, the suspension was diluted with distilled water and then filtered. From the filtrate, the quantity of chromic acid reduced by the organic matter was then measured colorimetrically at a light maximum of 645 m u.

(f) pH. A soil:water ratio of 1:1 was prepared and stirred at regular intervals for about an hour. The pH of the suspension was then determined by means of a Zeromatic pH meter.

(g) Protein. The total nitrogen of the plant material was determined by the Kjeldahl method as described by Jackson (1964). The total nitrogen content was converted to protein on the assumption that 16 percent of protein is nitrogen.

One gram of the finely ground grain was digested with concentrated sulfuric acid until the digest was clear. The digest was allowed to cool then diluted with distilled water. Ammonia from the solution was then distilled into a boric acid receiver after the solution had been rendered stongly alkaline by the addition of 40 percent sodium hydroxide. The amount of NH_4^+-N in the boric acid receiver was determined by titration with standard sulfuric acid.

RESULTS AND DISCUSSIONS

Results of the 1964 experiments on zinc fertilization of irrigated corn as influenced by the form and state of the phosphorus fertilizers are given in Table 6. Of the 4 field experiments conducted, only the experiment at the Campbell farm in Shawnee County gave significant yield differences among the treatments. The experiments conducted at the Parr-Gentry farm in Shawnee County, Kaser farm in Osborne County, and Miller farm in Pottawatomie County did not produce significant yield responses (Table 6). Aside from the insignificant yield differences among the treatments at these three locations, there was no definite trend observed as the rate of zinc application was increased from 0 to 10.5 pounds per acre. Similarly, the forms of phosphorus produced no significant yield differences. The raw data from the three unresponsive locations indicated that a great deal of variability existed among replications of the same

Table 6. Yield of irrigated corn as influenced by zinc fertilization, and form and physical state of phosphorus, 1964

Treatment [a], [b]	Zinc[c] source	Carrier	Yield			
$N-P_2O_5-K_2O-Zn$			Campbell	Parr-Gentry	Kaser	Miller
Lbs./A.				Bu./A.		
1. 150-0-0-0.0	---	---	115.3	139.8	144.8	128.8
2. 160-34-17-0.0	---	MAP[d]	68.1	134.9	146.1	136.3
3. 160-34-17-0.3	$Na_2ZnEDTA$	MAP	84.3	137.5	150.8	147.4
4. 160-34-17-0.6	$Na_2ZnEDTA$	MAP	94.6	131.6	130.9	133.8
5. 160-34-17-3.0	$Na_2ZnEDTA$	MAP	121.2	130.5	144.8	147.0
6. 160-34-17-0.3	$ZnSO_4$	MAP	48.2	131.7	142.2	140.7
7. 160-34-17-0.6	$ZnSO_4$	MAP	65.0	138.4	158.7	143.9
8. 160-34-17-3.0	$ZnSO_4$	MAP	119.7	130.2	142.2	141.7
9. 160-34-17-0.3	$ZnSO_4$	APP[e]	80.2	137.5	132.9	130.0
10. 160-34-17-0.6	$ZnSO_4$	APP	88.4	124.9	129.6	137.9
11. 160-34-17-3.0	$ZnSO_4$	APP	120.2	136.1	131.9	139.8
12. 160-34-17-0.0	---	MAP	59.6	137.1	139.5	145.2
13. 160-34-17-0.3	$Na_2ZnEDTA$	MAP	83.6	127.3	153.0	146.1
14. 160-34-17-0.6	$Na_2ZnEDTA$	MAP	90.9	126.7	160.4	131.9
15. 160-34-17-4.8	$ZnSO_4$	MAP	113.8	128.5	144.5	140.7
16. 160-34-17-10.5	$ZnSO_4$	MAP	119.8	134.3	150.8	143.6
L.S.D. .05			18.0	N.S.	N.S.	N.S.

[a] 150 lbs. per acre N as anhydrous ammonia was applied before planting.

[b] Treatments 1 to 11 are in liquid state, and treatments 12 to 16 are in dry state.

[c] Dissolved/mixed in the carrier prior to application.

[d] Monoammonium phosphate in which the P is present as orthophosphate.

[e] Ammonium polyphosphate in which the P is present as polyphosphate.

treatment. It must be pointed out that these areas had previously been levelled for irrigation purposes and that such varied response to the treatments may have been due in part to the variability of the soil of the experimental areas.

The application of phosphorus fertilizer without the addition of zinc at the Campbell farm resulted in a significant reduction in corn yield. The yield on a per acre basis when liquid monoammonium phosphate was applied without zinc was 47 bushels lower than when only nitrogen was applied and was 56 bushels lower when this form of phosphorus was applied in the solid state. Likewise, when low rates (0.3 to 0.6 pound per acre) of zinc were applied with the phosphorus fertilizers, the yields were also significantly lower than in the case of just nitrogen application alone. The decrease in yield, however, varied in significance depending upon the source of zinc and the form of phosphorus in the fertilizer. When 0.3 pound per acre of zinc as zinc sulfate was applied with liquid monoammonium phosphate in which phosphorus was present as orthophosphate, the yield was 67 bushels lower than treatment 1. However, when liquid ammonium polyphosphate was used with the same rate and source of zinc, the yield was decreased by only 35 bushels. The significant difference in the magnitude by which the yield was decreased as a result of two forms of phosphorus in the fertilizers could be due to the fact that polyphosphate can sequester metal cations so that the zinc applied with it may have been held in solution in the soil for a longer time and therefore been more available than when applied with the orthophosphate form of phosphorus. The use of zinc chelate in the form of $Na_2ZnEDTA$ was not able to alleviate the depressing effect of phosphorus on the yield provided the rate of zinc remained the same. When the zinc treatment was increased to 0.6 pound per acre, the depressing effect of phosphorus was less noticeable. When 3.0 pounds per acre of zinc was applied, the yields were significantly higher than treatment 1. This was true regardless of the source of zinc and form of phosphorus in the fertilizer. A further increase in the rate of zinc application did not have any significant effect on the yield. Figure 2 shows the effect of zinc fertilization on the yield of corn as influenced by the source of zinc and the form of phosphorus in the carriers. It is noted that when zinc sulfate was applied with ammonium polyphosphate the yield was comparatively of the same magnitude as when zinc chelate was applied with monoammonium phosphate.

The data relative to the phosphorus and zinc content of the leaves and height of the corn plants at the Campbell farm are presented in Table 7. From these data, it can be seen that the percent phosphorus in the corn leaves was highest when little or no zinc was applied with the phosphorus. It is also evident that when small amounts of zinc as zinc sulfate were applied with monoammonium phosphate,

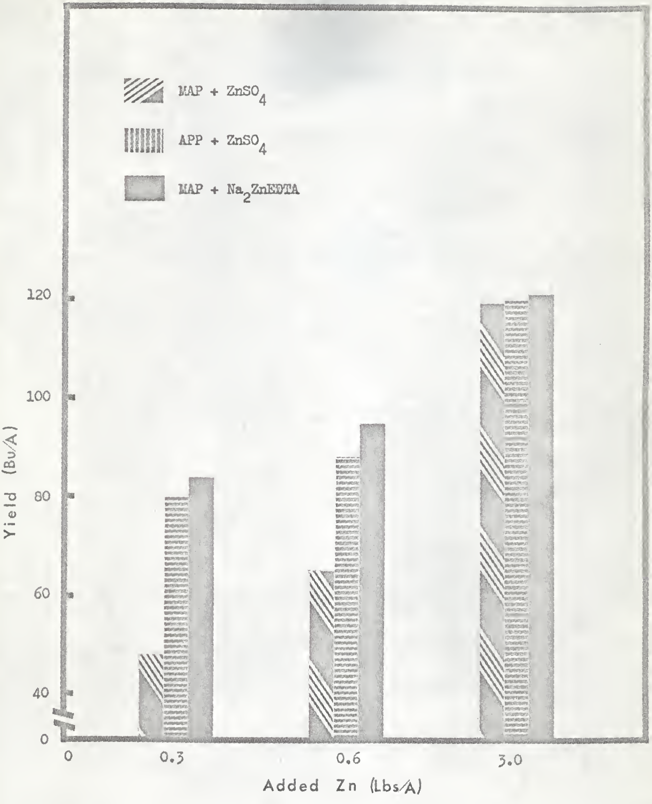


Figure 2. Effect of zinc fertilization on the yield of corn as influenced by the form of phosphorus - Campbell farm, 1964.

Table 7. Effect of zinc fertilization on yield, P and Zn content of leaves, and height of irrigated corn as influenced by the phosphate carrier - Campbell farm, 1964

Treatment[a]						
Zinc	Zinc source	Carrier	Yield	Leaf content of P	Leaf content of Zn	Height[b]
Lbs./A.			Bu./A.	%	ppm	Ft.
1. 0.0	---	---	115.3	0.16	21.0	4.0
2. 0.0	---	MAP	68.1	0.27	13.5	4.8
3. 0.3	$Na_2ZnEDTA$	MAP	84.3	0.22	17.8	5.4
4. 0.6	$Na_2ZnEDTA$	MAP	94.6	0.20	14.9	5.8
5. 3.0	$Na_2ZnEDTA$	MAP	121.2	0.12	20.0	6.7
6. 0.3	$ZnSO_4$	MAP	48.2	0.32	20.2	4.4
7. 0.6	$ZnSO_4$	MAP	65.0	0.28	13.6	5.0
8. 3.0	$ZnSO_4$	MAP	119.7	0.14	17.5	6.4
9. 0.3	$ZnSO_4$	APP	80.2	0.24	22.5	4.7
10. 0.6	$ZnSO_4$	APP	88.4	0.23	13.6	4.9
11. 3.0	$ZnSO_4$	APP	120.2	0.16	18.8	6.1
12. 0.0	---	MAP	59.6	0.26	17.4	4.0
13. 0.3	$Na_2ZnEDTA$	MAP	83.6	0.22	20.5	5.1
14. 0.6	$Na_2ZnEDTA$	MAP	90.9	0.18	17.2	5.6
15. 4.8	$ZnSO_4$	MAP	113.8	0.14	16.2	6.2
16. 10.5	$ZnSO_4$	MAP	119.8	0.15	24.0	6.6
L.S.D.$_{.05}$			18.0	0.05	5.8	0.50

[a] All plots except treatment 1 received 160-34-17 lbs. per acre of $N-P_2O_5-K_2O$, respectively, to the side and below the seed at planting time. Treatment 1 received just 150 lbs. per acre of N.

[b] Measurement taken 52 days after planting. Average of 80 plants.

the levels of phosphorus in the leaves were consistently higher than where the same zinc rates and source were applied with ammonium polyphosphate (Figure 3). Interestingly enough, the plants that had the highest content of phosphorus in the leaves (ranging from 0.26 to 0.32 percent) were the ones that produced the lowest yields. When the rate of zinc application was increased to 10.5 pounds per acre with the level of phosphorus held constant, the phosphorus content of the leaves was decreased significantly. This observation conforms with the findings of Seatz _et al_. (1959).

An application of phosphorus without the addition of zinc resulted in a significant decrease in the zinc content of corn leaves. When 0.3 pound per acre of zinc was applied with the phosphorus fertilizer, the zinc content of the leaves was of the same magnitude as the plants that received neither phosphorus nor zinc. Increased rates of zinc fertilization caused an increase in the level of zinc in the leaves but did not exceed the level in the plants that received neither phosphorus nor zinc except when 10.5 pounds of zinc per acre was applied. In all cases, the plants that received 0.6 pound of zinc per acre had a lower leaf content of zinc than those plants that received 0.3 and 3.0 pounds per acre zinc. It appears that the source of zinc and the form of phosphorus in the fertilizers had an effect on the concentration of zinc in the leaves (Figure 3). When the

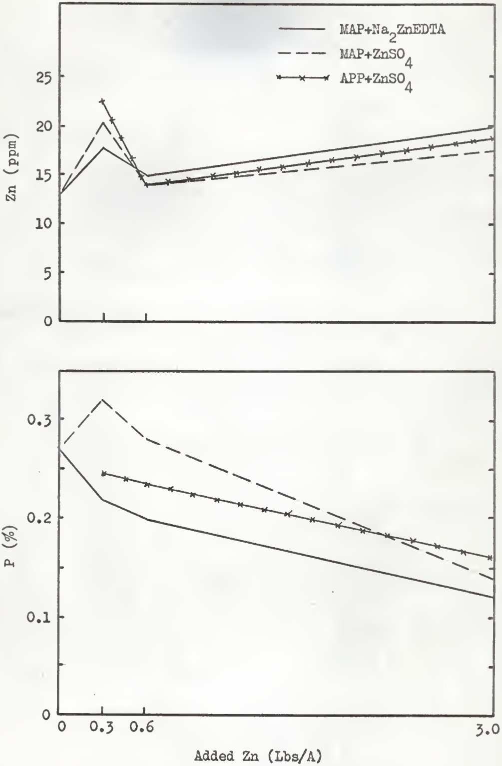


Figure 3. Phosphorus and zinc content of corn leaf at various levels of added zinc. All plots received 34 pounds per acre of phosphorus (1964).

rates of zinc applied were beyond 0.6 pound per acre, the plants that received monoammonium phosphate with the chelate form of zinc had consistently higher concentrations of zinc in their leaves than the plants that received ammonium polyphosphate with zinc sulfate. The plants that received monoammonium phosphate with zinc sulfate were consistently lowest in their leaf content of zinc.

The height of the corn plants was found to be affected by zinc fertilization. The plants that received no or low levels of zinc (0 and 0.3 pound per acre) were significantly shorter than those that received 3.0 pounds per acre. Beyond 3.0 pounds, the height was no longer significantly increased. Height and yield were found to have a weak positive correlation. The linear correlation coefficient value was: $r = 0.2203$. Visual observations on the field revealed that very mild or in some cases no zinc deficiency symptoms were exhibited by the plants which received no zinc or phosphorus (treatment 1). The leaves were almost uniformly green, gracefully arched, and soft textured. In comparison to the plants which received phosphorus and no zinc (treatment 2) whose average height was significantly greater than those in treatment 1 but with significantly lower yield, the leaves of the plants were chlorotic, deformed, crumpled and brittle. The plants in treatments 6 and 12 also exhibited this same appearance. The source of zinc and the form of phosphorus in the carrier had some effect on the stand and the incidence of zinc deficiency on the plants. Where zinc was applied as a chelate ($Na_2ZnEDTA$) with monoammonium phosphate or where zinc as zinc sulfate was applied with ammonium polyphosphate even at low zinc rate, the zinc deficiency symptoms were not as severe as when a low rate of zinc as zinc sulfate was applied with monoammonium phosphate.

The data in Table 8 demonstrates the effect of phosphorus fertilization on corn yield as influenced by the original level of available phosphorus and weak acid extractable zinc in the soil. It is noted from the tabel that where the levels of available phosphorus and weak acid extractable zinc were 18.0 and 5.4 pounds per acre, respectively, phosphorus fertilization did not reduce the corn yield. On the other hand, when 40.0 and 4.8 pounds per acre of available phosphorus and weak acid extractable zinc, respectively, were present the addition of phosphorus fertilizer to the soil caused a significant decrease in corn yield. There was also a slight reduction in corn yield when the same amount of phosphorus fertilizer was applied to a field containing 80.0 and 5.5 pounds per acre of available phosphorus and weak acid extractable zinc, respectively. Strikingly enough, when an equal amount of phosphorus fertilizer was applied to a soil with 78.0 pounds per acre of available phosphorus but with 10.3 pounds per acre of weak acid extractable zinc, the corn yield was increased slightly. The data in this table illustrates an important point. When the amount of weak acid extractabel zinc in the soil is within the critical range, 5.5 pounds per acre and below, application of zinc should accompany the use of phosphatic fertilizers particularly when the phosphorus is banded near the seed. This is also especially true when the amount of available phosphorus present in the soil is more than adequate for the plants. With the method used in this experiment for the determination of available phosphorus in the soil, Jackson gave a general guide to crop response; below 3 ppm P is very low, 3 to 7 ppm is low, 7 to 20 ppm is medium, and above 20 ppm is adequate to high.

Table 8. Effect of P fertilization on corn yield as influenced by the original level of available P and weak acid extractable Zn in the soil[a]

Farm	Soil content of		Yield	
	Avail. P	Acid ext. Zn	34 lbs. P_2O_5/A.	0 lbs. P_2O_5/A.
	Lbs./A.		Bu./A.	
Campbell (Shawnee County)	40.0	4.8	68.1	115.3
Parr-Gentry (Shawnee County)	80.0	4.4	134.9	139.8
Kaser (Osborne County)	18.0	5.4	146.1	144.8
Miller (Pottawatomie County)	78.0	10.3	136.3	128.8

[a] The phosphorus in the fertilizer was present as orthophosphate.

Results of the 1965 experiments on the use of ammonium polyphosphate and monoammonium phosphate as carriers of zinc and iron are presented in Tables 9 and 10 and in Figures 4 to 7. Data included in Table 9 indicate that the application

Table 9. Effect of zinc fertilization on yield and leaf content of P and Zn of irrigated corn as influenced by the phosphate carrier - Campbell farm, 1965

Treatment[a]	Zinc[b] source	Carrier	Yield	Leaf content of	
N-P_2O_5-K_2O-Zn				P	Zn
Lbs./A.			Bu./A.	%	ppm
1. 150-0-30-0.0	---	---	109.0	0.20	9.4
2. 150-0-30-2.0	$ZnSO_4$	---	110.3	0.16	11.6
3. 160-34-30-0.0	---	APP[c]	93.4	0.34	8.4
4. 160-34-30-0.5	$ZnSO_4$	APP	116.0	0.24	9.8
5. 160-34-30-1.0	$ZnSO_4$	APP	124.4	0.26	8.9
6. 160-34-30-2.0	$ZnSO_4$	APP	122.6	0.20	9.5
7. 160-34-30-0.5	Na_2ZnEDTA	APP	123.0	0.22	8.8
8. 160-34-30-1.0	Na_2ZnEDTA	APP	120.4	0.22	0.5
9. 160-34-30-2.0	Na_2ZnEDTA	APP	130.1	0.20	12.8
10. 160-34-30-0.5	$ZnSO_4$	MAP[d]	114.8	0.24	8.5
11. 160-34-30-1.0	$ZnSO_4$	MAP	118.1	0.21	8.6
12. 160-34-30-0.5	Na_2ZnEDTA	MAP	123.4	0.22	9.1
13. 160-34-30-1.0	Na_2ZnEDTA	MAP	120.5	0.18	9.4
L. S. D. $_{.10}$			17.0	0.04	2.2

[a] 150 lbs. per acre of N as anhydrous ammonia was applied before planting. The 30 lbs. per acre K_2O as KCl was applied to the side and below the seed at planting time.

[b] Dissolved in the liquid carrier except in treatment 2 wherein it was mixed with the dry KCl.

[c] Liquid 10-34-0 ammonium polyphosphate in which the P is present as polyphosphate.

[d] Dissolved 8-24-0 monoammonium phosphate in which the P is present as orthophosphate.

Table 10. Effect of iron fertilization on yield, protein in grain, and P, Fe and Zn content of leaves of irrigated grain sorghum as influenced by the phosphate carrier
Nonamaker farm, 1965

Treatment[a/], [b/] N-P_2O_5-K_2O-Fe	Iron[c/] source	Carrier	Yield	Protien in grain	Leaf content of P	Leaf content of Fe	Leaf content of Zn
Lbs./A.			Bu./A.	%	ppm	ppm	ppm
1. 150-0-0-0.0	---	---	48.0	9.6	1250	52.8	13.0
2. 150-0-0-2.0	$FeSO_4$	---	55.6	9.8	1250	58.1	14.6
3. 160-34-0-0.0	---	APP[d/]	82.8	9.4	1450	52.6	14.1
4. 160-34-0-0.5	$FeSO_4$	APP	57.2	9.4	1275	59.3	14.6
5. 160-34-0-1.0	$FeSO_4$	APP	65.6	9.9	1300	51.2	12.9
6. 160-34-0-2.0	$FeSO_4$	APP	61.6	9.8	1400	52.1	13.4
7. 160-34-0-0.5	NaFeDTPA	APP	63.1	9.8	1425	57.0	13.2
8. 160-34-0-1.0	NaFeDTPA	APP	76.8	9.4	1450	49.1	12.6
9. 160-34-0-2.0	NaFeDTPA	APP	77.6	9.4	1425	54.8	15.3
10. 160-34-0-0.5	$FeSO_4$	MAP[e/]	54.0	9.5	1275	53.2	15.4
11. 160-34-0-1.0	$FeSO_4$	MAP	59.1	9.4	1350	48.8	13.9
12. 160-34-0-0.5	NaFeDTPA	MAP	62.6	9.7	1300	54.2	14.6
13. 160-34-0-1.0	NaFeDTPA	MAP	64.8	9.5	1400	54.0	14.1
L.S.D.$_{.10}$			17.5	N.S.	N.S.	N.S.	N.S.

[a/] 135 lbs. per acre of N as anhydrous ammonia was applied to all plots before planting.

[b/] All plots received 15 lbs. per acre N as NH_4NO_3 and 5 lbs. per acre Zn as $ZnSO_4$, applied to the side and below the seed at planting time.

[c/] Dissolved in liquid carrier except in treatment 2 wherein it was mixed with the NH_4NO_3 and $ZnSO_4$.

[d/] Liquid 10-34-0 ammonium polyphosphate.

[e/] Dissolved 8-24-0 monoammonium phosphate.

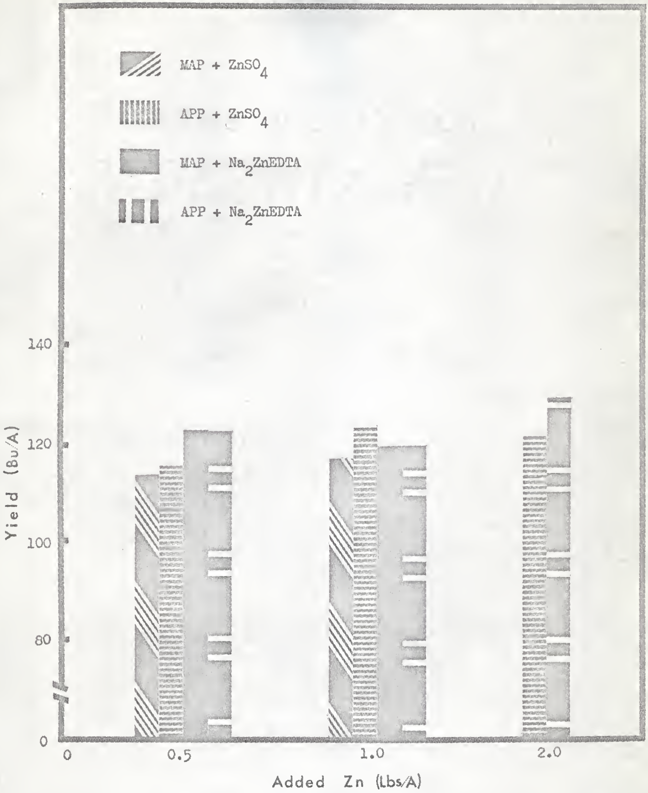


Figure 4. Effect of zinc fertilization on the yield of corn as influenced by the form of phosphorus - Campbell farm, 1965.

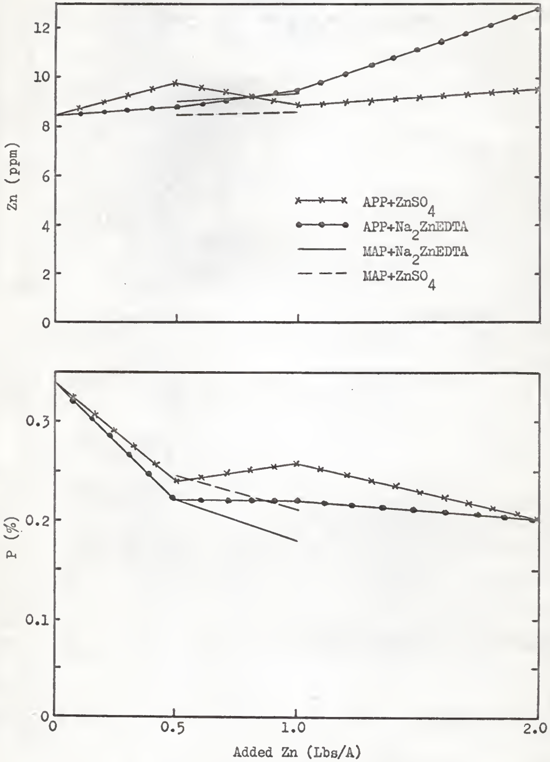


Figure 5. Phosphorus and zinc content of corn leaf at various levels of added zinc. All plots received 34 pounds per acre of phosphorus (1965).

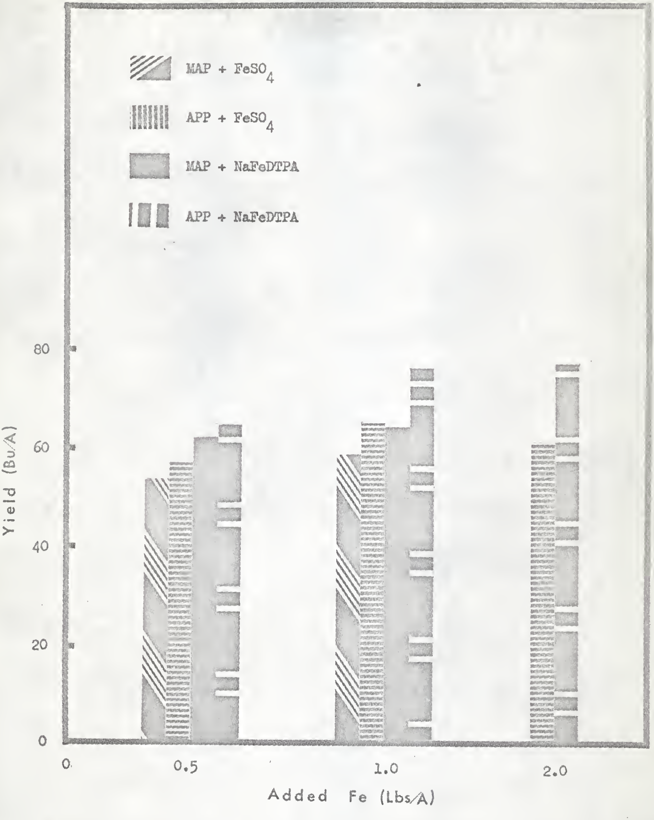


Figure 6. Effect of iron fertilization on the yield of grain sorghum as influenced by the form of phosphorus - Nonamaker farm, 1965.

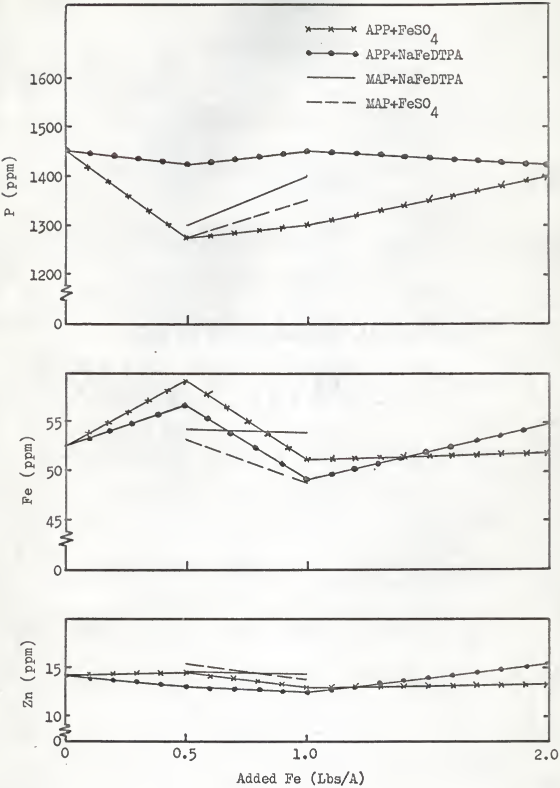


Figure 7. Zinc, iron, and phosphorus content of grain sorghum leaf at various levels of added iron. All plots received 5 and 34 pounds per acre of zinc and phosphorus, respectively.

of zinc to corn at the Campbell farm in Shawnee County resulted in higher yields in 1965 as it did in 1964. The differences among the various treatments, however, were only significant at the 10 percent level. When phosphorus in the form of polyphosphate fertilizer was applied without zinc, it resulted in a reduction in yield of 15.6 bushels as compared to the check, treatment 1. This depressing effect of banded polyphosphate was less severe than that noted when orthophosphate was applied in a similar manner in 1964. Polyphosphates, aside from sequestering the microelements applied with them, are also suspected of causing a dissolution of the microelements present in an unavailable form in the soil and making them available.

As indicated in Table 9 and Figure 4, an increase in the rate of zinc application as either zinc sulfate or zinc chelate brought about a corresponding increase in corn yield. At all levels of zinc fertilization, ammonium polyphosphate seemed to be a better carrier of zinc as zinc sulfate than monoammonium phosphate as measured by the corn yield (Figure 4). The 1964 observation that zinc sulfate applied with ammonium polyphosphate produced almost the same performance as zinc chelate applied with monoammonium phosphate particularly at higher levels (1.0 and 3.0 pounds zinc per acre) was confirmed.

Zinc application caused a significant reduction in the corn leaf content of phosphorus and decreased progressively as the rate of zinc application was increased (Figure 5). On the other hand, the application of phosphorus also caused a depression in the corn leaf content of zinc. Increased rate of zinc application was able to counteract this depressing effect of phosphorus. Similar results were observed in the 1964 experiment.

Some of the treatments included in a similar study on grain sorghum produced significant yield differences (Table 10). In the plots where iron as ferrous sulfate was applied, ammonium polyphosphate being used as a carrier, the yields were consistently higher than where monoammonium phosphate was used as the ferrous sulfate carrier. When ammonium polyphosphate was applied without the addition of iron, highest yield was obtained. The addition of iron without the addition of phosphorus was also able to increase the yield slightly but not as markedly as when phosphorus was added. When iron and phosphorus were applied there was an increase in yield, the relative increase becoming more significant as the level of iron was increased. However, the yield produced by the highest level of iron (2.0 pounds per acre) was still lower than when phosphorus was applied alone. Only 8 pounds per acre of available phosphorus was present in the plow layer of the field where this experiment was conducted (Table 3). This represents a low level for general crops response according to the method used in extracting the available phosphorus, therefore, crop response to the addition of phosphorus was anticipated. The iron content of the soil of the experimental area was determined to be 17 pounds per acre which is considered to be adequate for general crop needs. Olson, whose method of extracting available iron was used in extracting the available iron of the soil in the experimental area, stated that when the soil content of available iron was 0.01 to 0.3 ppm, iron chlorosis was moderate to severe; at 0.3 to 2.2 ppm, it was slight to moderate; and when the soil content was 2.0 to 32 ppm, no chlorosis was observed.

Iron supplied in the chelated form (NaFeDTPA) was generally more effective in increasing the yield of grain sorghum than was iron supplied as ferrous sulfate although the differences were not great (Table 10). Figure 6 shows that the 1.0 pound per acre of iron as ferrous sulfate applied with ammonium polyphosphate was as effective as the chelated form of iron applied with monoammonium phosphate. It is also noted from the figure that the application of iron chelate with ammonium polyphosphate resulted to a significantly higher yields than when iron chelate was applied with monoammonium phosphate.

The protein contents of the grain did not show any response to the different treatments. However, the concentrations of phosphorus, iron, and zinc in the leaves of the plants showed some degree of response to the various treatments (Table 10 and Figure 7). All the plants that received phosphorus fertilizer had higher leaf contents of phosphorus than those that did not receive phosphorus fertilizer, although the differences were not significant. Generally, the plants that had a higher leaf content of phosphorus gave higher yields. The leaf content of iron was increased when ferrous sulfate was added without the added phosphorus fertilizer. When either the sulfate or chelate form of iron was applied with the phosphatic fertilizer carriers, the levels of iron in the grain sorghum leaves were high when 0.5 and 2.0 pounds iron per acre were added but it was low when the rate of iron applied was 1.0 pound per acre. The same pattern was exhibited by the levels of zinc in the grain sorghum leaves.

SUMMARY AND CONCLUSIONS

Field experiments were conducted using ammonium polyphosphate fertilizer having an analysis of 10-34-0 and monoammonium phosphate with an analysis of 8-24-0 as carriers of zinc and iron. Zinc as zinc sulfate and as zinc chelate ($Na_2ZnEDTA$) were dissolved/mixed in the carriers and were applied to corn. Iron as ferrous sulfate and as iron chelate (NaFeDTPA) were dissolved in the carriers and were applied to grain sorghum. Grain yields, protein contents, height, and phosphorus, zinc and iron contents of the leaves of the test plants were examined.

At the locations where responses to zinc and iron fertilizations were observed, liquid ammonium polyphosphate proved to be a better carrier of either the sulfate or chelate forms of these elements than monoammonium phosphate. The yields resulting from the addition of the sulfate forms of either zinc or iron with ammonium polyphosphate were comparatively equal in magnitude to the yields where their chelate counterparts ($Na_2ZnEDTA$ and NaFeDTPA) were applied with monoammonium phosphate. This indicates that the polyphosphate might have sequestered the zinc or iron out of their sulfate forms and, therefore, were rendered as available as their commercially chelated forms applied with monoammonium phosphate.

The severe reduction in corn yield as a result of banded phosphorus applications was observed only in the zinc fertilization studies. The data showed that the addition of phosphorus fertilizer without added zinc was detrimental when the available phosphorus content of the soil was adequately high but the level of weak acid extractable zinc was critically low. Phosphorus induced zinc deficiency was apparently the cause of the severe reductions in the yield of corn. This was accompanied by a very significant increase in the phosphorus content of the corn leaves and a concomitant decrease in the zinc content when the phosphorus fertilizer was applied without zinc. The application of zinc counteracted the depressing effect of the phosphorus fertilizer on the corn yield and on the leaf content of zinc.

When low rates (0.3 to 0.6 pound per acre) of zinc as zinc sulfate were applied with monoammonium phosphate to corn, the phosphorus contents of the leaves were consistently higher than when the same rate of zinc sulfate was applied with ammonium polyphosphate. Interestingly enough, these corn plants that had higher concentrations of phosphorus in their leaves were the ones that gave low yields. In the case of the grain sorghum, however, it was the reverse. The sorghum plants with high content of phosphorus in their leaves had high yields.

The application of either the sulfate or chelate form of iron with the phosphatic fertilizer carriers to grain sorghum increased the plants leaf content of iron when the amounts of iron applied were 0.5 and 2.0 pounds per acre but it was decreased when 1.0 pound of iron was added.

The protein content of grain sorghum appeared not to have responded to the application of iron.

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EVALUATION OF LIQUID AMMONIUM POLYPHOSPHATE AS A CARRIER OF IRON AND ZINC

by

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Field experiments were conducted using corn and grain sorghum as test plants to determine the availability of zinc and iron when their sulfate forms ($ZnSO_4$ and $FeSO_4$) were applied with liquid ammonium polyphosphate compared to their availability when their chelate counterparts (Na_2ZnEDTA and NaFeDTPA) were applied with monoammonium phosphate. Grain yields, protein contents, height, and phosphorus, zinc and iron contents of the test plants were examined.

The application of zinc sulfate and ferrous sulfate with liquid ammonium polyphosphate produced similar yield responses in corn and grain sorghum as did Na_2ZnEDTA and NaFeDTPA when these forms of the micronutrients were applied with monoammonium phosphate.

The concentrations of zinc and iron in the leaves of the plants where the sulfate forms of zinc and iron were applied with ammonium polyphosphate did not differ markedly from the concentrations in the leaves of those plants where the chelate forms of zinc and iron were applied with monoammonium phosphate. The rate of zinc or iron applied had more significant effects on the concentrations of these elements in the leaves of the plants. When high rates of zinc and iron (2.0 and 3.0 pounds per acre) were applied with the phosphatic fertilizer carriers, the plants receiving the treatments with ammonium polyphosphate had higher leaf contents of phosphorus than the plants receiving the treatments with monoammonium phosphate.

Banded applications of phosphatic fertilizers in the absence of added zinc tended to magnify zinc deficiency problems in irrigated corn.