VARIETAL RESPONSE AND EFFECTS OF DIFFERENT SOURCES OF ZINC ON SOYBEAN GROWTH AND YIELD

by

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To 'Deọla and Temitọpẹ
this work is dedicated.

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INTRODUCTION

Until recently, most of the research work on crop nutrition requirements focused attention on the macronutrients particularly nitrogen, phosphorus and potassium. This was perhaps justifiable considering the fact that crop plants require these elements in relatively larger amounts than the micronutrients. In an attempt to maximize yield, high analysis fertilizer materials have been employed with little consideration for the micro-elements. In many cases, this has precipitated an imbalance in the available micronutrients required for normal crop growth and development. High yields associated with macronutrient fertilization tended to deplete micronutrients in some cases. Problems with micronutrient availability have been aggravated by land levelling operations for irrigation purposes which inevitably remove the top soil high in organic matter and micronutrients.

In light of these considerations and realizing the fact that no one essential nutrient is more important in plant nutrition than any other, increasing interest has developed in the use of micronutrients in fertilizer formulations. One of these essential micronutrients is zinc. Land levelling operations frequently remove most of the soil's organic matter containing much of the available zinc. In some parts of Kansas, zinc availability may be lower in zones of calcium carbonate accumulation. Research at Kansas State University and other institutions has implicated high available soil phosphorus levels produced by fertilization or naturally high soil phosphorus as a possible cause of a more severe zinc deficiency on soils low in available zinc. Other predisposing factors could be genetic or environmental.

Deficiency of Zn has been reported in many areas of the state on corn, sorghum, pinto beans and soybeans with corn being the most sensitive crop. There have been relatively few studies on zinc nutrition of soybeans. Studies in Kansas and other states have shown that soybeans will respond to zinc fertilization. In pinto beans, some varietal differences have been observed in response to zinc fertilization. There is, however, limited information in this area for soybeans.

Although soybeans are not the most important crop in Kansas, they are a major cash crop. Average yields of about 818 million kg from about 420,000 hectares of land are recorded annually in Kansas. In many developing countries, soybeans are gradually becoming a major cash crop. In these places, the nutritive value of the crop in terms of the high protein and oil content to man and livestock cannot be emphasized too strongly. In an attempt to take advantage of the yield potential of the crop both in protein and in oil production, all environmental factors must be geared towards high productivity.

The most common source of zinc for correcting zinc deficiencies in Kansas and other Plains states in the U.S. has been $ZnSO_4$ applied either broadcast or banded. There are now increasing numbers of materials (organic and inorganic) which could be considered as sources of zinc for fertilization of any crop. Other Zn materials are frequently by-products of some industry. Some of these materials contain a higher percentage of zinc than $ZnSO_4$ (36%) and are comparable in cost. In some cases, however, their effeciency has not been established relative to $ZnSO_4$.

In order to insure higher yields from soybean zinc fertilization practices without sacrificing returns, greenhouse and field experiments were initiated with the following objectives:

1. To study the effect of zinc fertilization on the morphology and growth of the crop,
2. To investigate the yield response of the crop to zinc fertilization at different rates,
3. To compare varietal responses to zinc application, and
4. To compare and evaluate several zinc materials as possible sources of zinc for soybeans as indicated by effects on zinc concentration in the tissue and seed and final seed yields.

LITERATURE REVIEW

General

A wide range of plants are susceptible to Zn defiency which occurs in many soils throughout the world. In the U.S., Zn defiency was reported early in the lower Gulf Coastal Plain region and on the Pacific Coast. Many more areas including Kansas, have more recently reported deficiencies of Zn in a number of crops.

Historical Significance

The first indication that Zn may be essential in the nutrition of higher plants was first given by Raulin in 1869 on the growth of *Aspergillus niger*. This observation was not seriously considered until in 1912 when Javilles reported that treatment of the soil with $ZnSO_4$ increased plant growth. Maze in 1914 also provided convincing evidence to support the essentiality of the element but this finding, like most of the previous ones, did not meet wide acceptance. However, in 1926, these findings were confirmed by Sommer and Lipman who provided irrefutable evidence on the essentiality of the element in higher plant nutrition (63).

Role of Zn in Plant Nutrition

While there is a wide range in sensitivity of crop plants to Zn defiency, the role of Zn in plant nutrition has been firmly established. One of the most prominent roles of the nutrient seems to be as a metal activator of many enzymes such as enolase, yeast aldolase, oxaloacetic decarboxylase, lecithinase, cysteine desulfhydrase, histidine deaminase, carbonic anhydrase, dihydropeptidase etc. (64).

The importance of Zn in auxin synthesis and/or maintenance has been reported by many workers (47). It has been suggested to be necessary for the production of tryptophan, a necessary intermediate in indole acetic acid production. Although the role of auxin in water absorption cannot be ignored, Zn deficiency has been associated with a lower percentage of water when compared with the control tomato (Lycopersicon esculentum) plants (66).

Another major role of Zn is in chlorophyll formation as leaf chlorosis is one of the distinguishing symptoms of a deficiency. Naik and Asana (46) reported the effect of Zn deficiency on synthesis of protein. When plants were grown in culture solutions lacking in the element, the rate of protein synthesis was decreased and there was an accumulation of non-protein intermediates four weeks after germination. They also reported complete inhibition of P uptake and a decrease of N uptake when compared with normal cotton (Gossypium sp.) plants grown in the presence of 0.065 ppm Zn.

There is some indication that Zn is involved in cell division. Spiller and Terry (60) worked on Beta vulgaris and provided information which showed that Zn is necessary in cell division, cell expansion and dry matter accumulation of leaves. In agreement with this, Chang and Tyung (15) provided evidence to show that Zn is necessary during mitosis in the root tips of navy beans (Phaseolus vulgaris L.).

Ellis et al (21) reported the role of the element in seed and pod production of Phaseolus vulgaris. Fewer, smaller pods containing few seeds were produced in the field beans as a result of the Zn defiency. Abscission of the pods also occured very early in the development of Zn deficient beans.

Growth and nitrogen fixation by legumes could be limited by low zinc availability and by conditions that interfere with plant zinc nutrition (19,50). It is not clear, however, whether Zn defiency decreases nitrogen fixation directly by interfering with Rhizobium nutrition or indirectly by interfering with host plant nutrition or both. Many zinc containing enzymes function in micro-organisms including Rhizobia (51) so that Zn deficiency may affect nitrogen fixation directly. Yie (71) concluded that nitrogen fixation in Zn deficient soybeans (Glycine max.(L)Merr.) was limited both directly by Rhizobium requirement for Zn and indirectly by Zn nutrition of the host plant. In support of this, Demetrio et al (19) reported a reduction in nodule weights on two soybean varieties at the lowest Zn levels. In this same study, leghemoglobin concentration in the nodules was higher at the highest Zn levels.

Predisposing Factors to Zn Deficiency

Although crop plants vary in the degree of susceptibility, certain environmental factors have been established as possible predisposing conditions to a Zn defiency situation. Generally, high soil pH, high available soil P, low soil organic matter, cold and wet soil conditions, and low cation exchange capacity have been associated with Zn deficiency.

Plant Factor

Chapman (16) reported that for most crops, less than 20 ppm Zn in dry matter of leaves indicates deficiency or approaching deficiency. There have been reports of differential response of various genotypes of corn (Zea mays L.) and navy beans to Zn (26, 52).

Giordano and Mortvedt (27) studied the response of several rice (Oryza sativa) cultivars to Zn and reported that the early maturing varieties were less tolerant to low levels of the element in terms of dry matter production.

Polson and Adams (52) used various combinations of high and low levels of Zn to compare the response to Zn fertilization on navy beans (Phaseolus vulgaris). They reported that growth of Saginaw variety was extremely reduced at the same concentration. These differences were not related to differential absorption or distribution of the nutrients since the differences in the elemental composition of the two varieties was not biological ly significant. They, therefore, concluded that this may be due to differences in nutrient utilization. However, workers at Washington State (49) could not observe significant differences in the response of six soybean varieties following Zn application.

Soil Factors

The inverse relationship between soil pH and Zn availability has been recognized for some time (63). This relationship has been attributed to both direct absorption of Zn on calcite crystals and to a true pH effect. The effect of pH probably results from the differences in solubility of the various forms of Zn occuring in the soil. Zn^{++} was suggested by Thorne (63) to be the principal ionic form of the element assimilated by plant roots. He doubted whether roots can utilize the $ZnO_2^{=}$ form which occurs in alkaline conditions.

In agreement with this, Boawn et al (6) showed that both application and form of N can affect the uptake of Zn by plants and that to a large degree, these changes in Zn uptake were associated with changes in soil pH. In this case, Zn uptake increased as the soil became slightly acid and decreased as the soil was made alkaline.

The Zn-lime interaction has been recognized by many workers in terms of a pH phenomenon. In their report, Jurinak and Thorne (32) gave evidence to show that when $Ca(OH)_2$ is applied, apart from increasing the pH, there is formation of a low solubility calcium zincate. When $CaCO_3$ content of the soil was increased, there was a slight decrease in Zn content of sorghum (Sorghum vulgare). In contrast, there was a slight increase from the addition of $CaSO_4$ (63).

Although there appears to be more reports to justify the relationship of Zn availability to soil pH, there have been cases where such a relationship does not seem to occur. In

California, even though there was a relationship between response to Zn and soil content of Zn, there was no relationship between soil pH and plant response in 53 soils whose pH ranged from 4 - 8.3 (64).

Zn deficiencies have been reported in areas which have recently been prepared for irrigation, subjected to construction of terraces or to erosion control by land levelling operations. These practices necessarily involved the removal of the top soil high in micronutrients including zinc. Thus, crop plants grown on the exposed sub-soil usually have a tendency to be Zn deficient.

In a study of 78 soil profiles in Kansas, Travis and Ellis (65) reported that the available Zn concentration was greatest in the organic fraction of the soil profile and decreased as the free carbonate concentration increased.

There are also reports of Zn deficiency on soils high in organic matter resulting from treatments with plant residues. Jones, Gall and Barnette (29) indicated that the organic matter could be one of the most active fractions in the soil rendering Zn less available by influencing fixation of Zn. Although there is some evidence that micro-organisms may be involved (13), most work indicates some type of chelation by the organic fraction (20). The effects of organic matter on Zn availability cannot be separated from the effects of P and perhaps other constituents of the organic matter.

There are many references in the literature in regards to plant disorders that are associated with high levels of available P in the soil or application of P to the growth medium. This disorder can usually be corrected or prevented by Zn fertilization and consequently it is generally referred to as P-induced Zn deficiency.

In Florida and Tennessee, Zn deficiency has been associated with high soil P. Yield reductions of 20-30% and 30-50% on field beans and corn respectively, have been reportedly due to additions of 896 kg/ha of P_2O_5 (64).

The effect of P in depressing Zn concentration in plant tissues and depression of P concentration by Zn was demonstrated by Burleson et al (12) on kidney beans. Similar P-Zn interactions have been demonstrated in soybeans by Paulsen and Rotimi (50), in tomato by Martin et al. (41) and in corn by Ellis et al. (21).

Boawn and Leggett (7) concluded that an alteration of the P/Zn ratio is the dominant factor involved in the metabolic upset resulting from the interaction. He suggested that the critical ratio in Russet Burbank potato is 400. Plants with a ratio greater that this showed Zn deficiency symptoms. He arrived at this conclusion as a result of his inability to correlate either deficiency or elimination of the deficiency with changes in the Zn concentration in the stem and leaf tissues.

There are many factors affecting P-Zn interaction in plants. Greenhouse experiments with corn showed that soil compaction, soil moisture level, soluble P and Zn, soil pH, organic matter and clay contents, K saturation and titrable alkalinity can influence the relationship.

Ward et al. (70) reported that applied P reduced Zn concentration in corn. They also suggested that high K percentage saturation tends to reduce the effect of applied P in reducing plant utilization of Zn.

Sometimes there may not be dramatic plant symptoms despite a Zn deficiency situation. Nelson (48) reported a vegetative response of soybeans to Zn application (as $ZnSO_4$ and ES-Min-EL) although severe chlorosis of unfertilized plants did not occur. The Zn content of plants grown on Zn deficient soil was 15 ppm as compared to 30 ppm in plants receiving adequate Zn.

There is evidence (30,35) that the interaction is sensitive to phosphate carriers. Burleson et al. (12), Ellis et al. (21), Paulsen and Rotimi (50) also indicated that the rates of P application could affect the interaction. Terman and Allen (61) rated ammonium polyphosphate (APP) $>$ monoammonium phosphate (MAP) $>$ concentrated super phosphate (CSP) $>$ dicalcium phosphate in terms of effects on dry matter production and Zn uptake by corn. Also in a comparison by Judy et al. (30), Lessman and Ellis (35), pea beans were observed to produce slightly higher yields and have higher Zn concentrations when supplied with APP rather than with MAP.

Adriano and Murphy (3) found that banded application of APP in the presence of inadequate Zn induced more severe Zn deficiency and yield depressions than did similar applications of monoammonium phosphate. However, when adequate Zn was supplied, the two forms of P produced comparable plant growth responses and grain yield.

Another factor which could affect the occurrence of

P-induced Zn deficiency is temperature. Martin et al. (41) reported that at moderately low soil Zn level (0.9 ppm dithizone extractable Zn), P application induced Zn deficiency symptoms at 10°C and 15.5°C but not at 26.6°C. However, when the soil was acutely deficienct in Zn (0.1 ppm) P induced Zn deficiency at all observed temperatures on tomato plants. Similar observations were recorded on corn when the soil temperature was decreased from 23.9 to 12.8°C (27).

As a result of his studies on beans using radioautographic techniques to study Zn^{65} absorption and translocation, Biddulph (4) reported that P precipitated Zn in the veins of the plants.

Apart from the interaction with P predisposing plants to Zn deficiency, iron has also been implicated in accentuating Zn deficiency in plants. Chandry and Wallace (14) reported that high concentrations of iron in submerged soil depressed Zn uptake in flooded rice (Orvza sativa L.). They explained that iron has a competitive effect on Zn translocation from the roots to the shoots. However, in another experiment using acid Yola loam soil containing high level of available Zn, iron did not depress Zn uptake by rice. In contrast to this, on a calcareous soil low in available zinc and iron, iron strongly depressed Zn uptake when supplied.

Apart from the predisposing factors noted above, there are also some reports which seem to implicate heavy metals in precipitating a Zn deficiency situation. In Kenya, Bock et al. (8) reported that spraying fungicides containing Hg in organic combination induced Zn deficiency on coffee (Coffee arabica).

Shoots exposed to direct sunlight seemed to suffer most severely. Similar Zn deficiency symptoms have been observed in Congo on coffee following sprays containing arsenic.

Effect of Zn Sources

Although plant absorption and utilization of Zn is affected by the changing soil conditions, methods and rates of application there is evidence which indicates preferences between various sources of Zn. Among the inorganic sources, $ZnSO_4$ has been found to be a satisfactory material for correcting Zn deficiency. However, this material has some disadvantages such as the possibility of its being rapidly converted in the soil to forms not available to plants thus resulting in a low efficiency of use. As a result of this possibility, there are several materials available (mostly organic chelates) which are intended to release Zn slowly, possibly when actual root contact occurs, thereby reducing loss by rapid conversion to unavailable forms. There are also some industrial by-product sources of Zn, which if effective, could reduce the costs of Zn application.

Several research workers have compared the effectiveness of organic and inorganic sources of Zn. In a comparison study of ZnO, $ZnCl_2$, $ZnSO_4$ and Zn-EDTA on rice in Louisiana (57) from 1968 - 1970, ZnO increased yields more than the other sources on a sandy loam soil. However, there was no statisticall significant difference among the sources. Similar non-significant differences were observed by Gallagher (24) on corn and sorghum when he compared both organic and inorganic sources of Zn, although there was increased Zn uptake with Zn-EDTA, $ZnSO_4$ and Coop-Zn. Cook (18) compared Ethasene-Zn, Zn-EDTA, Zn-DTPA, ZnHEEDTA, Orzan-Zn (Ammoniumligin sulfate) and Del. Mo. Z ($ZnSO_4$ + $Zn(OH)_2$ + $CaSO_4$) with $ZnSO_4$ on neutral and slightly acidic sandy soils. From both soil and spray applications, the chelates did not show significant superiority when used on Vinifera grapes (Vitis vinifera).

In contrast, the superiority of Zn chelates particularly Zn-EDTA has been demonstrated by some workers. Boawn (5) reported that from a 2 ppm soil application rate, a Zn uptake increase of 108 μg per crock of five plants was obtained from Zn-EDTA as compared with 31 μg for $ZnSO_4$ on Red Mexican beans (Phaseolus vulgaris).

In a comparison of Zn-EDTA and $ZnSO_4$ as sources of Zn for alfalfa grown on neutral soil, Holden and Brown (28) observed that the Zn concentration from Zn-EDTA treatment doubled that from $ZnSO_4$. On a calcareous soil, the Zn concentration was about 6 times more than that from $ZnSO_4$.

Wallace et al. (69) reported more Zn absorption from Zn-HEEDTA than from $ZnSO_4$ when soybeans were grown on Hacienda loam (32% $CaCO_3$). However, this behavior was reversed when grown on a non-alkaline loam soil.

In another study, Boawn (5) compared Zn-EDTA, two smelter by-products (stripping acid residue and blast furnace slag) three insoluble Zn compounds (ZnO, $Zn_3(PO_4)_2$ and $ZnCO_3$), Zn frits and commercial Zn granules with $ZnSO_4$ on sorghum. He reported the greatest Zn uptake from the chelate. Uptake from stripping acid residue, ZnO, $Zn_3(PO_4)_2$, $ZnCO_3$ and Zn granules was about the same as $ZnSO_4$. There was no uptake from the frit materials.

In a comparison of seven zinc sources for soybeans, Salako (56) reported that Zn-EDTA was significantly more efficient in increasing seed yield when compared with a Zn frit. It was not, however, significantly better than ZnO, $ZnSO_4$, $Zn\text{-}NH_3$ complex ($Zn\text{-}NH_3$), Urea-ZnO and an experimental ZnO. In this study, Zn-EDTA, ZnO, $Zn\text{-}NH_3$ and experimental ZnO were all applied as finely divided materials in a fluid fertilizer. Urea-ZnO and Zn frit were granular so that differences observed may have been due to particle size. The Zn frit represented the poorest source of zinc.

Lingle and Holmberg (37) observed little difference between Zn sources at a low rate of Zn application (6 kg/ha). However, at a relatively high rate of application of 28 kg/ha, they reported that Zn-EDTA and ZnO were superior to $ZnSO_4$ on sweet corn. ZnO and Zn-EDTA were considered to be about equal as sources of Zn.

Anderson (2) compared various sources of Zn in both greenhouse and field trials in Colorado. He found that a low rate of 1.12 kg/ha Zn as Zn-EDTA was sufficient to control Zn deficiency in the greenhouse. On the other hand, three times this amount of Rayplex Zn material was required for the same effectiveness. He also reported that Rayplex was lost from solution most rapidly. He therefore, concluded that in calcareous soils, relative effectiveness of the sources was Zn-EDTA > $ZnSO_4$ > Rayplex. Vinande et al. (68) and Judy et al. (31) similarly reported superiority for Zn-EDTA over $ZnSO_4$ and other inorganic sources for navy beans. However, $ZnSO_4$ and ZnO were also good sources of Zn for corn (24).

Following a general review of micronutrient correction with fertilizers, Murphy and Walsh (45) were of the opinion that by-product lignin-sulfonates and polyflavonoids could be good sources of Zn with low phytotoxic effects but the disadvantage is that they are not as stable as the organic chelates. They also concluded that $ZnSO_4$ and Zn-EDTA were the best inorganic and organic sources, respectively.

Method and Rate of Application

It is essential to know how best to apply Zn from the standpoint of maximum yield in view of the increasing evidence of Zn deficiency and changing fertilizer technology.

Viets et al. (67) reported that Zn placed with N fertilizer near the seed was effective in correcting Zn deficiency in tomatoes. Lingle et al. (38) reported that side-dressing did not provide satisfactory correction for Zn deficiency. In another study using Zn^{65}, Shaw and Dean (58) found that Zn mixed with the soil was slightly more effectively utilized than when banded for citrus seedlings and corn.

Pumphrey et al. (53) reported that broadcast applications of $ZnSO_4$ incorporated into the soil were superior to any form of banding with or without N fertilizer. Chesnin (17) reported that organic sources of Zn are generally more effective than inorganic sources when banded under the seed.

Brown and Krantz (11) found that when the Zn fertilizer materials were well mixed with the soil, $ZnSO_4$ and organic sources such as Zn-EDTA and Rayplex Zn were equivalent in their effectiveness for correction of Zn deficiency. However, when banded under the seed, Zn-EDTA was more effective than the inorganic sources. They also found that granulation reduced the effectiveness of $ZnSO_4$, $ZnNH_4PO_4$ and Rayplex Zn.

Brown and Krantz findings agree with Sorensen et al. (59) who reported that Zn does not move appreciably in the soil. Hence wider distribution of low analysis materials aids in root fertilizer contact as a result of the increased number of particles.

Apart from soil applications, foliar and seed treatments have been evaluated in terms of their effects on yield where a Zn deficiency problem arises. In a field experiment with tomatoe in California, Lingle et al. (38) reported satisfactory correction of Zn deficiency by foliar sprays. He showed that $ZnSO_4$ sprays were superior to Zn-EDTA sprays, ZnO dust or $ZnSO_4$ side-dressing. Ananth et al. (1) produced indications of the effectiveness of $ZnSO_4$ as a foliar treatment for correcting Zn deficiency in coffee. The concentration used was 0.25% Zn. They als concluded that foliar spray was more economical than soil application.

Leyden and Toth (36) studied the absorption and translocation of Zn^{65} from root and foliage applications to soybeans, tomato and corn in a sand solution culture. They observed that with soybeans and tomato, the amount of Zn^{65} absorbed by foliage was considerably less than that absorbed through the roots. However, the corn absorbed more through the foliage.

Even though there are reports of occasional favorable response to foliar application, Boehle and Lindsay (9) suggest that such applications should be considered as emergency treatments since they are usually made after the occurrence of deficiency symptoms. In support of their suggestion, Boawn and Leggett (7) could not control Zn deficiency on Russet Burbank potatoes (Solanum tuberosum L) with Zn sprays after symptoms developed.

Various attempts have been made to pretreat seeds with Zn powders or solutions before planting. In most cases, this approach proved rather ineffective as it was not able to meet plants requirements beyond the seeding stage. Rasmussen and Boawn (55) reported poor response to Zn seed treatment of beans using powdered $ZnSO_4$. Even though the amount of Zn applied was enough for the total Zn uptake by the crop, they observed insufficiency of Zn uptake to meet the plants requirement after the 3 compound leaf stage.

Thompson et al. (62) studied the effect of Zn seed coating on rice, corn and beans on growth and Zn absorption using Zn lignin sulfonate, ZnO, $ZnSO_4$ and Zn-EDTA. At rates equivalent to 0.55 and 1.1 kg/ha, they reported that Zn coating increased Zn uptake and crop yield of each species and there was no deficiency symptoms on plants receiving these treatments.

In view of the present available information, Murphy and Walsh (45) agreed that Zn-seed treatment will not probably be generally important in the future as compared with the soil and foliar application methods.

A major consideration in the application of micronutrients is obtaining a uniform distribution in the field. This has necessitated micronutrient application with macronutrient fertilizers for effective and economical use.

Mortvedt and Giordano (43) concluded that the effectiveness of Zn applied depends upon the products of the reaction between the Zn source and the macronutrient fertilizer and how these products are distributed in the soil. They also suggested that ammonium nitrate (AN), triple superphosphate (TSP), monoammonium phosphate (MAP), and ammonium polyphosphate (APP) are suitable macronutrient carriers when $ZnSO_4$ is the Zn source. In another study, they reported that APP and TSP are also effective for ZnO. However, they gave the impression that ammoniated fertilizers were rather inferior as Zn carriers probably as a result of the reaction with Zn to form insoluble products during manufacture or after soil application.

Mortvedt and Giordano (44) also reported that Zn chelates are suitably compatible with most fertilizers although they suggested some caution during preparation in order to prevent a possible decomposition of the chelates.

Ellis et al. (22) demonstrated some reduction in water solubility and Zn uptake as a result of incorporation of ZnO or $ZnSO_4$ into fertilizer granules. Handmixing the Zn carrier with fertilizer at planting time increased Zn uptake.

In agreement with this, Giordano and Mortvedt (25) proved that finely ground Zn sources mixed alone with the soil were more effective than a granular macronutrient fertilizer containing Zn. This was especially true when low rates were employed.

Giordano and Mortvedt (25) also compared the effectiveness of ortho and polyphosphate fertilizers as possible Zn carriers. Liquid orthophosphate and polyphosphates were equally effective when they were mixed with the soil. In contrast, when band treatments were used, the ortho material was less effective probably because of the lower solubility of ZnO in the ortho solution. Whether band applied or mixed with the soil, they observed that ammonium tripolyphosphate was superior to monoammonium phosphate as a ZnO carrier.

The source of material, method of application, soil type and the crop involved are major considerations in determining the rate of Zn application. Generally, for soil application, the rates are usually less for organic than for the inorganic sources. For inorganic sources, these may range from 2 to 22 kg Zn/ha and 0.3 to 6 kg Zn/ha for the organic sources (45). Judy et al. (30) recommended between 3.36 - 4.48 kg Zn/ha of inorganic source and about 1/5 of this for chelates when used for pea beans. Salako (56) reported that an application rate of 2.2 to 4.5 kg Zn/ha will promote good soybean production.

Martens et al (40) proved the importance of a consideration of the method of application in determining the rate of Zn to be applied. They stated that in order to correct Zn deficiency on corn, a lower Zn rate of 6.7 kg Zn/ha when band applied will be more effective than a higher rate of 26.9 kg Zn/ha broadcast.

Residual Effects and Toxicity

The availability of residual Zn over long periods of time has been reported frequently (6, 56). This is especially true when previous large applications of Zn are involved.

After 5 years of Zn application to a Ritzville sandy loam soil, Boawn (6) still reported high percentages of Zn from 9 and 18 kg/ha treatment. Ellis, Murphy and Whitney (23) provided evidence to show that methods of soil application do not seem to influence the occurrence and availability of residual Zn. In a fertilization study on corn, Zn was still detectable by both soil and plant analysis two years following initial application rates of 11 and 22 kg Zn/ha of $ZnSO_4$.

Brown, Krantz and Martin (10) recorded corn dry weight yields in a greenhouse study which indicated that 2.5 ppm Zn application was adequate for 6 or 7 successive crops. In this same study, pots receiving a 12.5 ppm rate were not deficient even after 10 crops.

The normal range of total Zn in soils is 10 - 300 ppm and there are rather few reports of Zn toxicity in the literature (45). While it is beneficial to have high amounts of available Zn, excessive amounts could be toxic to crops and, in fact, could create an imbalance in the nutrient status in both plant and soil.

Plants vary in their ability to absorb and accumulate available Zn before any notable toxic effects occur. Sometimes, the present crop may not be affected but the productivity of the succeeding crops may be seriously hindered by large amounts of available Zn.

Residual Zn from Zn spray materials in South Carolina peach orchard soils influenced the growth of cotton after peach orchard removal (33). In this case, the cotton leaves were yellow and seedlings were stunted. Zn has been shown to induce symptoms apparently identical to Fe deficiency when grown on sand and water cultures (42). The presence of excess Zn in the growth media probably interferes with Fe metabolism resulting in leaf chlorosis similar to Fe deficiency.

Several explanations on this Fe-induced deficiency have been advanced. One of these relates to the competition between Zn and Fe in the enzyme systems that are involved in chlorophyll formation or the activation of an enzyme system influencing the Fe^{+2} - Fe^{+3} equilibrium (34).

Lee and others (34) reported competition between Zn^{+2} and Fe^{+3} in a nutrient solution study using a two zone root technique. This competition was very significant when a relatively low iron concentration (0.1 ppm Fe to 5.0 ppm Zn) was used. They indicated that this competition occurred at the root absorption sites and concluded that Zn appeared to interfere with Fe uptake whereas iron did not interfere with Zn uptake.

Chapman (16) also reported that Zn prevented Fe from being translocated from the extension of the root cells to the vascular system in orange (Citrus sinensis). Lingle (39) also observed a similar case in soybeans. In Lingle's case, Zn reduced the translocation of Fe to soybean tops as well as reduced root absorption.

Adriano and Murphy (3) have also shown that high levels of Zn in the growth medium can reduce the concentration of both P and Fe in plant tissues.

In a study of the soybean responses to 6 applications of various levels of boron, copper and zinc, Martens et al. (40) reported that neither plant growth nor seed yield was decreased where as high as 3.3 kg and 8.4 kg Cu and 11.1 kg Zn/ha were applied annually for six years on Davidson clay loam and sandy loam soils. They however, related the relatively tolerant levels to decreased uptake at the near neutral pH level of the soils.

Rauterberg and Bussler (54) suggested that the unfavorable effects from toxic amounts of Zn may be alleviated by displacement with $CaSO_4$ and $CaCl_2$ solutions. They further recommended the treatment of the soil with K before cropping.

MATERIALS AND METHODS

Greenhouse Experiments

Two greenhouse studies were conducted with the following objectives:

1. To investigate the varietal response of soybeans to zinc nutrition, and
2. To evaluate different sources of Zn for soybean fertilization.

A. Varietal Study

For this first portion of the work, soil was collected from a marginally zinc deficient Pawnee county site and is described in Table 1.

Table 1. Greenhouse soil and field plot information.

Location	O.M.	pH	Avail. P kg/ha	Exch. K kg/ha	Avail. Zn (ppm)
Pawnee County	1.2	7.1	23.5	560	0.60
Republic County	-	6.6	49.3	599	0.73
Scandia Irr. Exp. Field	1.2	7.2	70.6	857	0.44
McPherson County	-	6.2	44.0	554	0.60

Soil Type

Pawnee County - Carwille loamy fine sand (Typic Argioqualls, fine, mixed, thermic)

Republic County - Muir silt loam (Pachic haplustolls, fine, silty, mixed, mesic)

Scandia Irr. Exp. Field	- Crete silty clay loam (Pachic argiustolls, fine, montmorillonitic, mesic)
McPherson County	- Goessel silty clay loam (Udic Pellusterts, fine, montmorillonitic, mesic.)

The soil was dried at room temperature and seived through a stainless steel sieve. One kilogram of soil was potted in plastic pots previously washed in 0.1 N HCl and 0.1 M EDTA.

Seven soybean varieties representing those grown in Kansas were used in the experiment. $Zn\text{-}NH_3$ complex was applied at five rates as the source of Zn (Table 3). Constant rates of N, P, K, and S were supplied as indicated in Table 2.

Table 2. Plant nutrient concentrations in the varietal study.

Nutrient	Concentration	Materials
N*	100 ppm	Urea
P	80 ppm	11-16-0
K	100 ppm	KCl
S	20 ppm	12-0-0-26S

*Partly supplied by $Zn\text{-}NH_3$ complex, 11-16-0 (APP), 12-0-0-26S (ammonium thiosulfate), and Urea.

All the glassware used in the preparation of the nutrients and in the analyses later were thoroughly washed successively with 0.1 M EDTA, distilled water, 10% (v.v.) HNO_3 and deionized water. Care was also taken to avoid contamination when the Zn sources were applied to the soil.

All the materials were formulated to a constant volume for application to each pot. From each pot the weighed soil was poured onto a separate clean sheet of plastic material and nutrient solution was applied slowly while turning and mixing the soil. Before returning to the pot, further soil mixing was carried out to ensure an even distribution of the nutrients within the soil mass.

Each treatment was replicated three times for every zinc rate and variety (Table 3).

Table 3. Varieties and zinc rates in the first greenhouse study.

Varieties	Zn application rates (ppm)
Clark 63	0, 0.5, 1.0, 2.0 and 4.0 ppm
Amsoy	0, 0.5, 1.0, 2.0 and 4.0 ppm
Williams	0, 0.5, 1.0, 2.0 and 4.0 ppm
Columbus	0, 0.5, 1.0, 2.0 and 4.0 ppm
Cutler	0, 0.5, 1.0, 2.0 and 4.0 ppm
Calland	0, 0.5, 1.0, 2.0 and 4.0 ppm
Pomona	0, 0.5, 1.0, 2.0 and 4.0 ppm

Six seeds were planted per pot to a depth of 2 cm and immediately watered with 200 mls of deionized, distilled water. The pots were randomly arranged in the greenhouse. Two days after emergence, the seedlings were thinned to three plants per pot, care being taken to ensure a comparable plant spacing in all the pots. During the first week, the pots were maintained at a constant weight with deionized distilled water. After this, constant amounts were applied to the seedlings daily. Regular observations of the growth and performance of the seedlings, especially in regards to Zn deficiency symptoms were made throughout the growth period.

The plants were harvested after 28 days growth in the greenhouse by excising 1 cm above the soil surface with stainless steel scissors. The harvested tops from each pot were separately washed in deionized, distilled water and dried in an oven at 70°C for 48 hours. The dried plants were ground through a small Wiley Mill with stainless steel knives and a 2 mm stainless steel screen.

From each ground tissue sample, 0.5 gm portion was weighed into a 250 ml digestion beaker and digested by the nitric acid-perchloric acid procedure. The ternary mixture for the digestion was made up of a mixture of equal volumes of concentrated nitric acid, 75% perchloric acid and deionized distilled water. The samples were evaporated to near dryness, the residue was taken up with 0.1 N HCl and the solution was filtered with Whatman 42 filter paper. The filtrate was made up to 25 ml volume with 0.1 N HCl. Zn concentration in this stock solution was determined by atomic absorption spectrophotometry using a model 303 Perkin-Elmer instrument.

The vanadate molybdate yellow color procedure was used to determine the phosphorus concentration in the stock solution. A 2-ml aliquot of this solution was transferred to a clean EDTA washed test tube. Ten mls of the ammonium vanadate molybdate reagent was added. This solution was mixed and after 30 minutes, absorbance was read at 390 mμ wavelength on a Bausch and Lomb Model 88 spectrophotometer.

B. Zinc Carrier Study

The characteristics of the soil used in this study (Scandia) are given in Table 1. The objective of this study was to evaluate different sources of Zn in terms of soybean growth and Zn uptake at the different rates of application.

The soil was ground, sieved with a stainless steel sieve and 1 kilogram weighed into plastic pots which had been previously washed with 0.1 N HCl and 0.1 M EDTA solutions.

Treatments consisted of eight zinc sources, four application rates with three replications (Table 4). The zinc sources were Zn-EDTA, NZN[1], experimental Zn $ZnCl_2$, Kemin[2], $ZnSO_4$, ZnO and Rayplex Zn[3], $Zn\text{-}NH_3$[4] applied in the forms indicated below:

MATERIAL	FORM	% Zn
Zn-EDTA	Fertilizer grade	9.0
$Zn\text{-}NH_3$	" "	10.0
$ZnCl_2$	" "	13.0
Kemin	" "	5.6
Rayplex	" "	10.9
ZnO	Reagent grade	78.0
$ZnSO_4$	" "	36.0
NZN	Fertilizer grade	5.5

[1]Product of Allied Chemical Company containing 22% N and 5.5 Zn.

[2]Product of Georgia-Pacific Corporation (ligninsulfonate).

[3]Product of Ruffin-AgKem, Inc. (polyflavonoid).

[4]$ZnSO_4$ in NH_4OH, 10% N, 10% Zn, Nutra-Flow Chemical Co.

Table 4. Treatments used in the greenhouse Zn material study.

Zn Carrier	Zn Rate	Zn Carrier	Zn Rate
Control	0		
Zn-EDTA	0.125 ppm	Kemin	0.125 ppm
	0.25 ppm		0.25 ppm
	0.50 ppm		0.50 ppm
	1.0 ppm		1.0 ppm
$Zn\text{-}NH_3$	0.125 ppm	Rayplex	0.125 ppm
	0.25 ppm		0.25 ppm
	0.50 ppm		0.50 ppm
	1.0 ppm		1.0 ppm
NZN	0.125 ppm	$ZnSO_4$	0.25 ppm
	0.25 ppm		0.50 ppm
	0.50 ppm		1.0 ppm
	1.0 ppm		2.0 ppm
$ZnCl_2$	0.125 ppm	ZnO	0.25 ppm
	0.25 ppm		0.50 ppm
	0.50 ppm		1.0 ppm
	1.0 ppm		2.0 ppm

Phosphorus	Liquid ammonium polyphosphate 11-16-0 (liquid)
Nitrogen*	Urea
Sulphur	Liquid ammonium thiosulfate 12-0-0-26S

*Partly supplied by 11-16-0, Zn-NH_3, $ZnCl_2$, NZN, 12-0-0-26S and urea.

Phosphorus, nitrogen and sulphur were applied at constant rates of 40, 24 and 20 ppm, respectively.

Calland variety was used for this experiment.

Application of the nutrients to the soil, watering, planting and thinning and harvesting operations were executed in the same manner as outlined for the varietal study.

A completely randomized design was used in the arrangement of the pots in the greenhouse.

The plants were harvested after 30 days. Drying, grinding and analysis for Zn and P were carried out as reported earlier.

Field Study

Four field sites were chosen for soybean Zn nutrition studie with the main objective of evaluating the effectiveness of zinc materials applied alone or in combination with some carrier fertilizer.

The study at the Scandia and Pawnee county sites involved a comparison of six Zn carriers (Table 5). Zinc frit 247 was used in the Pawnee county study instead of NZN used at the Scandia location. Three replications of a randomized complete block design were used.

Table 5. Zinc treatments used in Pawnee county and Scandia Irrigation Experimental Field Zn carrier evaluation studies.

Stan Compton Farm, Radium and Scandia Irrigation Exp. Field

Treatments Zn kg/ha	Zn Carrier
0	- - - -
0.28	Zn-EDTA
0.56	Zn-EDTA
1.12	Zn-EDTA
2.24	Zn-EDTA
0.28	Kemin
0.56	Kemin
1.12	Kemin
2.24	Kemin
0.28	$Zn-NH_3$
0.56	$Zn-NH_3$
1.12	$Zn-NH_3$
2.24	$Zn-NH_3$
0.28	Rayplex
0.56	Rayplex
1.12	Rayplex
2.24	Rayplex
0.28 or 0.56	NZN or Frit 247
0.56 or 1.12	NZN or Frit 247
1.12 or 2.24	NZN or Frit 247
2.24 or 4.48	NZN or Frit 247
0.56	$ZnSO_4$
1.12	$ZnSO_4$
2.24	$ZnSO_4$
4.48	$ZnSO_4$

A similar study consisting of four replications was established in McPherson county. In this study, both NZN and Frit 247 were included in the Zn carriers (Table 6).

The Zn carriers were applied in N-P-S suspensions consisting of 56 kg/ha N, 39 kg/ha P as 11-16-0, 22.4 kg/ha of S as 12-0-0-26S. All the materials were broadcast preplant, and incorporated by tillage.

At a site in Republic county, three zinc carriers were applied in two different fertilizer materials (Table 7). The fertilizer materials were either a urea-ammonium nitrate (UAN) suspension (32% N) or an ammonium polyphosphate (APP 10-15-0). In each case, the Zn material was well mixed into the fertilizers immediately before application. Clay was included at 2% in the APP suspension. The UAN suspension was formulated by the TVA

Phosphorus and nitrogen were applied at constant rates of 39.0 kg/ha P and 56 kg/ha N. Where N solution (32-0-0) was used to carry the Zn, P was broadcast as 11-16-0 before seeding and incorporated by discing. The zinc-containing mixtures were banded to the side of the seed at planting. Each treatment was replicated four times in a randomized complete block design.

A second Pawnee county study was carried out to determine the effects of residual Zn and P (applied in 1974) on irrigated soybeans planted in 1975.

Ammonium polyphosphate (APP) and ammonium orthophosphate (AOP) were supplied at three rates of P and two rates of Zn (Table 8) with three replications. These treatments were

Table 6. Zinc treatments used in the McPherson county zinc carrier evaluation study. Eugene Goering Farm, Moundridge.

Zn Carrier	Zn Rate	Zn Carrier	Zn Rate
- - - -	0		
Zn-EDTA	0.28 kg/ha 0.56 kg/ha 1.12 kg/ha 2.24 kg/ha	NZN	0.28 kg/ha 0.56 kg/ha 1.12 kg/ha 2.24 kg/ha
Kemin	0.28 kg/ha 0.56 kg/ha 1.12 kg/ha 2.24 kg/ha	Frit 247	0.56 kg/ha 1.12 kg/ha 2.24 kg/ha 4.48 kg/ha
$Zn\text{-}NH_3$	0.28 kg/ha 0.56 kg/ha 1.12 kg/ha 2.24 kg/ha	$ZnSO_4$	0.56 kg/ha 1.12 kg/ha 2.24 kg/ha 4.48 kg/ha
Rayplex	0.28 kg/ha 0.56 kg/ha 1.12 kg/ha 2.24 kg/ha		

Table 7. Republic county zinc carrier treatments.

Don Charles Farm, Republic		
Treatments Zn kg/ha	Zn Carrier	Zn Carrier Applied in.
0	- - - -	32-0-0
0.56	Kemin	32-0-0
1.12	Kemin	32-0-0
2.24	Kemin	32-0-0
4.48	Kemin	32-0-0
0.56	Kemin	10-15-0
1.12	Kemin	10-15-0
2.24	Kemin	10-15-0
4.48	Kemin	10-15-0
0.56	Zn-EDTA	32-0-0
1.12	Zn-EDTA	32-0-0
2.24	Zn-EDTA	32-0-0
4.48	Zn-EDTA	32-0-0
0.56	Zn-EDTA	10-15-0
1.12	Zn-EDTA	10-15-0
2.24	Zn-EDTA	10-15-0
4.48	Zn-EDTA	10-15-0
0.56	$Zn\text{-}NH_3$	32-0-0
1.12	$Zn\text{-}NH_3$	32-0-0
2.24	$Zn\text{-}NH_3$	32-0-0
4.48	$Zn\text{-}NH_3$	32-0-0
0.56	$Zn\text{-}NH_3$	10-15-0
1.12	$Zn\text{-}NH_3$	10-15-0
2.24	$Zn\text{-}NH_3$	10-15-0
4.48	$Zn\text{-}NH_3$	10-15-0
0	- - -	10-15-0

Table 8. Residual zinc and phosphorus treatments in Pawnee county.

Stan Compton Farm, Radium

	Treatment kg/ha		Carriers	
	P_2O_5	Zn	P	Zn
1.	0	0	-	-
2.	44.8	0	APP	-
3.	89.6	0	APP	-
4.	134.4	0	AOP	-
5.	44.8	0	AOP	-
6.	89.6	0	AOP	-
7.	134.4	0	AOP	-
8.	44.8	8.96	APP	$Zn-NH_3$
9.	89.6	8.96	APP	"
10.	134.4	8.96	APP	"
11.	44.8	8.96	AOP	"
12.	89.6	8.96	AOP	"
13.	134.4	8.96	AOP	"

Nitrogen and sulphur were applied at a constant rate of 168 kgN/ha (partly supplied by P, S, and Zn carriers and urea-ammonium nitrate solution), 22.4 kg S/ha as ammonium thiosulfate.

P supplied as 11-16-0 (TVA).

N supplied as 28% N solution.

Zn supplied as $Zn-NH_3$.

S supplied as 12-0-0-26S.

applied in 1974 and no further fertilization was carried out in 1975.

Williams variety was planted at the Pawnee county site but at all the other sites, Calland variety was used. The seeding rate was 67.2 kg/ha and the weeds were effectively controlled with Treflan herbicide.

Plant tissue samples were collected at the Pawnee county and Scandia locations at early bloom and at early pod stages of growth. At the McPherson and Republic county sites and in the residual study, plant tissue samples were taken only at the early pod stage. Plant tissue samples consisted of 12 youngest, fully developed trifoliates per plot.

The samples were washed separately with deionized, distilled water before drying at 70°C for 48 hours. Grinding and the analysis for both Zn and P were conducted as described earlier.

At maturity, the plots were mechanically harvested (combine) and the seed samples from each plot analyzed for Zn and P by the same procedures outlined earlier.

RESULTS AND DISCUSSION

Greenhouse Experiments

Varietal zinc study. Observations during the growth period in the greenhouse revealed a mild chlorosis on some of the varieties at rates up to 1.0 ppm Zn. Cutler, Calland and Amsoy varieties seemed to be more affected than the others but the magnitude was not of such a significance as to warrant routine scoring. The low incidence is probably related to the comparably short growth period as compared to a field investigation.

The effects of the treatments indicated no significant differences in plant height at harvesting (Table 9). When averaged over all the rates, significant varietal differences were observed. The highest and lowest values were recorded for Calland and Columbus varieties, respectively. Rates of Zn application also had significant effects on the plant heights (Fig. 1). Although significantly better than the control, Zn application rates were not significantly different.

The dry weights of the plant tops increased significantly as a result of the zinc treatments (Table 10), but the rate effects were not significant. When the varieties were compared across all Zn rates, Williams and Clark produced significantly more dry matter than Pomona, Cutler or Columbus. Amsoy, Calland and Columbus were intermediate in terms of plant growth. Columbus and Cutler tended to show less Zn affect that did other varieties such as Williams and Pomona.

All the varieties had comparable levels of zinc at harvest

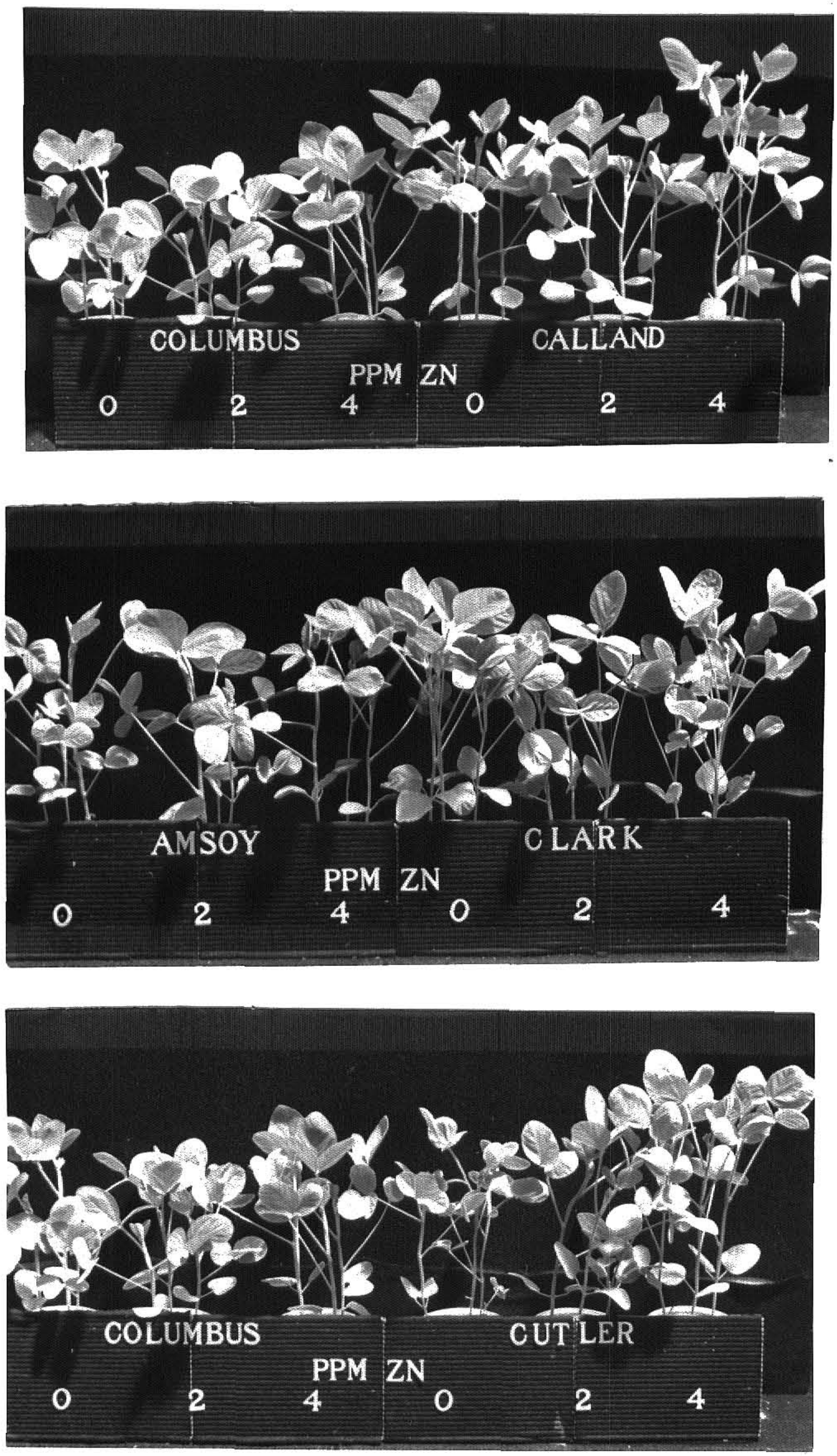

Fig. 1. Effect of rates of zinc application on plant height.

Table 9. Effect of zinc treatments on plant height (cm). Greenhouse study.

Variety	Zn Application Rates (ppm)					Variety Means
	0	0.5	1.0	2.0	4.0	
Clark	31.5	34.1	34.9	35.1	34.0	33.9
Amsoy	31.8	32.6	34.1	32.6	33.9	33.0
Williams	30.4	31.5	33.1	31.3	30.4	31.3
Columbus	29.8	31.0	30.8	30.0	34.2	31.2
Cutler	31.7	34.1	34.7	35.0	37.7	34.7
Calland	32.3	35.5	36.1	35.7	37.1	35.3
Pomona	28.4	32.6	33 5	33.5	34.2	32.4
Rate Means	30.8	33.1	33.9	33.3	34.5	

$LSD_{.05}$	Variety	1.8
	Rates	1.5
	Variety X Rate	NS

Table 10. Effects of zinc treatments on plant top dry weights (gm). Greenhouse study.

Variety	Zn Application Rates (ppm)					Variety Means
	0	0.5	1.0	2.0	4.0	
Clark	2.23	2.50	2.82	2.73	2.83	2.62
Amsoy	2.32	2.81	2.67	2.61	2.58	2.60
Williams	2.42	2.91	2.57	2.96	2.78	2.73
Columbus	2.32	2.49	2.38	2.43	2.34	2.40
Cutler	2.36	2.18	2.32	2.54	2.52	2.38
Calland	2.38	2.57	2.53	2.66	2.71	2.57
Pomona	2.08	2.08	2.65	2.39	2.67	2.37
Rate Means	2.30	2.51	2.56	2.62	2.63	

$LSD_{.05}$	Variety	0.19
	Rate	0.22
	Variety X Rate	NS

(Table 11). This non-significant varietal zinc concentration difference to increasing rates following zinc application is in agreement with the results of other workers at Washington State on six varieties of soybeans (49). Although interaction was not significant, responses to increasing rates of application were significant. Plant zinc concentrations showed a positive correlation with increasing rates of application although 1.0 ppm and 2.0 ppm rates produced about equal effects. Significant increase in plant zinc concentration was still recorded at 4 ppm rate. Except for the Calland variety, there was a general increase in plant zinc concentration in all the varieties with increasing rates of application.

Plant zinc uptake data indicated no significant interaction between variety and rates of Zn application (Table 12). Plant zinc uptake also generally increased with increasing rates of application in all of the varieties.

Unlike the plant zinc concentration data, varietal effects were significant for plant zinc uptake. Zinc uptake by Williams was significantly greater than those of Calland, Amsoy, Cutler and Columbus varieties but about the same as Clark and Pomona. Differences observed were due both to the relatively higher dry weight and zinc concentration of the Williams variety.

Zinc treatments did not produce consistant differences in plant phosphorus concentrations (Table 13). Although the varietal effects were not significant, there was a general decline in phosphorus concentration in Pomona, Cutler and Columbu with increasing rates of zinc application. In Amsoy, there seeme

Table 11. Effect of Zn treatment on plant zinc concentration (ppm). Greenhouse study.

Variety	Zn Application Rates (ppm)					Variety Means
	0	0.5	1.0	2.0	4.0	
Clark	21.9	25.4	28.9	32.7	43.6	30.5
Amsoy	19.2	24.1	26.5	28.8	39.7	27.7
Williams	21.2	28.7	26.7	32.6	42.9	30.4
Columbus	22.6	23.8	25.3	32.0	40.9	28.9
Cutler	22.9	25.4	28.4	31.9	41.2	29.9
Calland	23.5	26.8	32.8	25.9	31.8	28.2
Pomona	24.1	30.2	29.9	33.4	40.5	31.6
Rate Means	22.2	26.3	28.4	31.1	40.1	

$LSD_{.05}$	Variety	NS
	Rate	2.5
	Variety X Rate	NS

Table 12. Effect of Zn treatments on plant zinc uptake (mgm Zn) per pot. Greenhouse study.

Variety	Zn Application Rates (ppm)					Variety Means
	0	0.5	1.0	2.0	4.0	
Clark	49.2	63.0	79.5	89.4	123.8	81.0
Amsoy	44.5	68.2	70.7	75.2	102.6	72.2
Williams	51.3	83.4	69.5	96.4	120.5	84.2
Columbus	52.3	58.9	61.5	77.6	96.1	69.3
Cutler	53.7	55.2	66.2	80.9	103.3	71.9
Calland	56.1	69.9	82.9	69.0	88.1	73.2
Pomona	49.3	62.6	78.9	79.9	104.7	75.0
Rate Means	50.9	65.9	72.7	81.2	105.6	

$LSD_{.05}$	Variety	10.1
	Rate	8.6
	Variety X Rate	NS

Table 13. Effect of Zn treatment on plant phosphorus concentrati (ppm). Greenhouse study.

Variety	Zn Application Rate (ppm)					Variety Means
	0	0.5	1.0	2.0	4.0	
Clark	1880	1785	1785	1380	1952	1757
Amsoy	1380	1666	1667	1785	1666	1633
Williams	1166	1952	952	1190	1976	1447
Columbus	2380	1261	1571	1523	1095	1566
Cutler	2023	1737	1976	1737	1642	1823
Calland	1642	1595	1952	1071	1547	1561
Pomona	1904	1737	1714	1642	1523	1704
Rate Means	1768	1676	1659	1476	1629	

$LSD_{.05}$ Variety NS

Rate NS

Variety X Rate NS

Table 14. Effect of Zn treatment on plant phosphorus uptake (mgm P/pot). Greenhouse study.

Variety	Zn Application Rate (ppm)					Variety Means
	0	0.5	1.0	2.0	4.0	
Clark	4118	4285	4824	3792	5482	4500
Amsoy	3072	4753	4484	4625	4382	4263
Williams	2810	5678	2463	2534	3525	3402
Columbus	4824	3123	3854	3696	2590	3617
Cutler	4751	3789	4547	4384	4030	4300
Calland	3882	4159	4927	2858	3853	3936
Pomona	3898	3630	4554	3909	3288	3856
Rate Means	3908	4202	4236	3685	3879	

$LSD_{.05}$ Variety NS

Rate NS

Variety X Rate NS

to be an enhancement of P concentration in the tissues following zinc application. In the other varieties, no definite trends could be observed. Overall effects indicate a negative correlation with plant P concentration although this is not statistically significant.

Phosphorus uptake results indicate a similar trend as observed for plant P concentration (Table 14). Increasing rates of zinc application did not produce notable effects on P uptake. In Amsoy, increasing rates of zinc application tended to favor plant P uptake.

Zinc carrier study. During the thirty-day growth period in the greenhouse, no visual symptoms of zinc deficiency were observed on the seedlings in the zinc treated or control pots. There were no significant differences in plant height and dry matter production of the tops when compared with the control (Tables 15 and 16). Failure to record notable differences may be related to the relatively short growth period in the greenhouse and warmer summer temperatures in the greenhouse as compared with the earlier studies.

Significant differences were observed in the effects of the different Zn carriers on plant zinc concentration (Table 17). Zinc-EDTA produced significantly higher concentrations than all other carriers. $ZnCl_2$ represented the poorest source of zinc. $ZnSO_4$, Kemin and NZN produced about equal plant zinc concentrations. Zinc sulfate was, however, significantly better than Rayplex (Zn-poly flavonoid), ZnO, $Zn\text{-}NH_3$ and $ZnCl_2$. This may be related to the higher rates of zinc sulfate used in addition

Table 15. Effect of zinc treatments on plant height (cm). Greenhouse study.

Carrier	Zn Application Rate (ppm)					Carrier Means
	.125	.25	.5	1.0	2.0	
Zn-EDTA	31.8	32.4	31.3	32.0	-	31.9
$Zn-NH_3$	32.1	32.3	30.2	31.9	-	31.6
NZN	32.0	33.4	32.6	33.0	-	32.8
$ZnCl_2$	32.1	32.9	31.5	30.9	-	31.8
Kemin	32.0	31.1	31.2	31.3	-	31.4
Rayplex	32.5	30.9	32.5	31.1	-	31.8
$ZnSO_4$	-	30.3	31.4	31.3	31.2	31.0
ZnO	-	31.9	30.9	32.4	30.5	31.4
Rate Means	32.1	32.1	31.6	31.7	-	
	-	31.1	31.1	31.8	30.9	

Control 31.8

$LSD_{.05}$	Carrier	NS
	Rate (all except $ZnSO_4$ and ZnO)	NS
	Rate ($ZnSO_4$ and ZnO)	NS
	Carrier X Rate	NS

Table 16. Effect of zinc treatments on plant dry weight (gm). Greenhouse study.

Carrier	Zn Application Rate (ppm)					Carrier Means
	.125	.25	.50	1.0	2.0	
Zn-EDTA	4.10	4.20	4.18	4.39	-	4.22
$Zn-NH_3$	3.90	4.00	4.60	4.65	-	4.30
NZN	4.10	4.27	3.98	4.34	-	4.18
$ZnCl_2$	3.99	4.11	4.00	4.24	-	4.09
Kemin	4.27	3.94	3.93	3.96	-	4.02
Rayplex	4.25	4.25	4.69	4.35	-	4.39
$ZnSO_4$	-	4.19	4.10	3.62	4.40	4.08
ZnO	-	4.03	4.09	4.18	4.45	4.19
Rate Means	4.10	4.13	4.23	4.32	-	
	-	4.10	4.09	3.90	4.43	

Control: 4.10

$LSD_{.05}$	Carrier	NS
	Rate (all except $ZnSO_4$ and ZnO)	NS
	Rate ($ZnSO_4$ and ZnO)	NS
	Carrier X Rate	NS

Table 17. Effect of zinc treatments on plant zinc concentration (ppm). Greenhouse study.

Carrier	Zn Application Rates (ppm)					Carrier Means	
	.125	.25	.50	1.0	2.0	Comparable rates	All rates
Zn-EDTA	18.2	22.9	35.2	32.5	-	30.2	27.2
Zn-NH_3	17.7	21.2	20.2	21.6	-	21.0	20.2
NZN	19.3	19.1	23.9	25.5	-	22.8	21.9
$ZnCl_2$	17.2	19.2	18.7	19.9	-	19.3	18.8
Kemin	19.8	21.5	21.0	26.0	-	22.8	22.1
Rayplex	19.3	18.7	22.5	23.7	-	21.7	21.1
$ZnSO_4$	-	19.1	20.1	26.3	30.2	21.9	24.0
ZnO	-	20.9	18.6	21.6	22.5	20.4	20.9
Rate Means	18.6	20.4	23.6	24.9	-		
	-	20.0	19.4	24.0	26.3		
	-	20.3	22.5	24.6	-		

Control: 17.2

		All Rates	Comparable Rates
$LSD_{.05}$	Carrier	2.4	3.0
	Rate (all carriers except $ZnSO_4$ and ZnO)	2.1	1.8
	Rate ($ZnSO_4$ and ZnO)	2.7	
	Carrier X Rate	4.8	5.2

to its high solubility which is conducive to greater root absorption. At comparable rates, all the carriers except Zn-EDTA produced similar zinc concentrations.

Increasing rates of application significantly increased plant zinc concentrations. When averaged over all carriers except $ZnSO_4$ and ZnO, 0.5 ppm and 1.0 ppm gave significantly higher zinc concentrations in comparison with the lower rates. However, increasing the rate of application beyond .5 ppm did not produce further significant increase.

There was a significant interaction between carrier and rates of application. This is probably due to differential absorption or availability of the carriers. This is evidenced by the dramatic increase in leaf zinc concentration for some carriers such as Zn-EDTA while in others such as $ZnCl_2$ very little changes occurred with increasing rates of application.

A similar trend was observed in a comparison of the other inorganic sources of zinc. Application of $ZnSO_4$ and ZnO at 1 ppm and 2 ppm rates produced about equal results but were significant over the lower rates. Carrier-rate interaction was also significant. Generally, there was an increase in plant zinc concentration with increasing rates of applied zinc.

The zinc carriers showed significantly different effects on zinc uptake by the plants (Table 18). Zn-EDTA was significantly more efficient than the other carriers. All other carriers except $ZnCl_2$ produced similar zinc uptake values although $ZnSO_4$, NZN and Kemin were significantly higher than the others. Zinc uptake was also significantly increased by increasing rates

Table 18. Effect of zinc treatments on plant zinc uptake (mgm Zn/pot). Greenhouse study.

Carrier	Zn Application Rates (ppm)					Carrier Means	
	.125	.25	.50	1.0	2.0	Comparable rates	All rates
Zn-EDTA	74.3	96.6	147.9	142.5	-	129.0	115.3
$Zn\text{-}NH_3$	68.3	85.7	93.2	100.7	-	93.2	87.0
NZN	78.1	81.9	94.3	115.5	-	97.2	92.4
$ZnCl_2$	68.7	79.4	74.7	84.3	-	79.5	76.8
Kemin	84.6	84.8	82.6	104.2	-	90.5	89.0
Rayplex	82.1	79.8	103.8	102.2	-	95.3	92.0
$ZnSO_4$	-	80.3	83.2	94.9	133.2	86.2	97.9
ZnO	-	84.2	75.2	89.3	99.8	82.9	87.1
Rate Means	76.0	84.7	99.4	108.2	-		
	-	82.2	79.2	92.1	116.5		
	-	84.1	94.4	104.2	-		

Control: 71.4

		All Rates	Comparable Rates
$LSD_{.05}$	Carrier	13.1	16.3
	Rate (all except $ZnSO_4$ and ZnO)	11.1	10.0
	Rate ($ZnSO_4$ and ZnO)	17.8	
	Carrier X Rate	NS	NS

of Zn application. When the rates are compared in $ZnSO_4$ and ZnO, 2 ppm application rate remarkably increased zinc uptake over the lower rates. In the other materials, 0.5 and 1 ppm applications produced about the same results as observed in the plant zinc concentration data. Overall effects of the carriers at comparative rates indicates efficiency ratios of 1.8, 1.4, 1.4, 1.2, 1.3 1.4 and 1.3 for Zn-EDTA, Zn-NH_3, NZN, $ZnCl_2$, Kemin, Rayplex and ZnO respectively relative to $ZnSO_4$ (Table 19). Zn-EDTA had efficiency ratios of 1.2, 1.8, and 1.5 at increasing comparative rates, relative to $ZnSO_4$. Other carriers except $ZnCl_2$ were about equal in efficiency.

Plant P concentrations were generally but not significantly depressed by increasing rates of Zn application (Table 20). Plant P uptake was not appreciably depressed by the zinc treatments. Zinc carrier effects on plant P concentration and uptake (Table 21) were nonsignificant. This may indicate that the P-Zn interaction reported by many workers is not so strong in soybeans especially at increasing rates of Zn relative to P as used in this study.

Analysis of the soil after harvest indicated a significantly higher available zinc in the soil from $ZnSO_4$ application (Table 22 when averaged over all rates. The higher available Zn from $ZnSO_4$ relative to Zn-EDTA chelate is partially due to the higher rates of Zn applied for the inorganic source. ZnEDTA and Zn-NH_3 produced comparatively high available zinc levels. Trends toward higher zinc uptake from these carriers may be related to their high availability for root absorption. Although zinc availability

Table 19. Efficiency of various Zn carriers in plant zinc uptake relative to $ZnSO_4$. Greenhouse study.

Carrier	Relative Zn Application Rates [a](kg/ha)									Overall
	.25/.25	.5/.25	1.0/.25	.25/.5	.5/.5	1.0/.5	.25/1.0	.50/1.0	1.0/1.0	Rates
Zn-EDTA	1.2	0.9	0.5	2.4	1.8	0.9	4.0	3.2	1.5	1.8
$Zn-NH_3$	1.1	0.6	0.3	2.0	1.1	0.6	3.6	2.0	1.1	1.4
NZN	1.0	0.6	0.4	2.0	1.1	0.7	3.6	2.0	1.2	1.4
$ZnCl_2$	1.0	0.5	0.3	2.0	0.9	0.5	3.2	1.6	0.9	1.2
Kemin	1.1	0.5	0.3	2.0	1.0	0.7	3.6	1.8	1.1	1.3
Rayplex	1.0	0.3	0.3	2.0	1.2	0.6	3.2	2.2	1.1	1.4
ZnO	1.0	0.9	1.1	1.0	0.9	1.1	0.9	0.8	0.9	1.0

[a]Zn rate applied/ rate of $ZnSO_4$.

Table 20. Effect of zinc treatments on plant phosphorus concentration (ppm P). Greenhouse study.

Carrier	Zn Application Rates (ppm)					Carrier Means
	.125	.25	.50	1.0	2.0	
Zn-EDTA	1387	1359	1251	1169	-	1291
$Zn\text{-}NH_3$	1251	1414	1169	1196	-	1257
NZN	1332	1305	1468	1414	-	1380
$ZnCl_2$	1414	1196	1142	1060	-	1203
Kemin	1332	1332	1305	1223	-	1298
Rayplex	1223	1251	1169	1142	-	1196
$ZnSO_4$	-	1387	1550	1305	1223	1366
ZnO	-	1468	1441	1251	1223	1346
Rate Means	1323	1310	1251	1201	-	
	-	1427	1495	1278	1223	

Control: 1496

$LSD_{.05}$	Carrier	NS
	Rate (all except $ZnSO_4$ and ZnO)	NS
	Rate ($ZnSO_4$ and ZnO)	NS
	Carrier X Rate	NS

Table 21. Effect of zinc treatment on plant phosphorus uptake (mgm P/pot). Greenhouse study.

Carrier	Zn Application Rate (ppm)					Carrier Means
	.125	.25	.50	1.0	2.0	
Zn-EDTA	5936	5705	5216	5126	-	5496
$Zn-NH_3$	4766	5681	5368	5581	-	5349
NZN	5401	5392	5830	6388	-	5753
$ZnCl_2$	5724	4784	4570	4494	-	4893
Kemin	5687	5253	4976	4849	-	5191
Rayplex	5202	5185	5486	4975	-	5212
$ZnSO_4$	-	5702	6416	4633	5432	5546
ZnO	-	5884	5727	5214	5441	5567
Rate Means	5452	5333	5241	5235	-	
	-	5793	6071	4924	5437	

Control: 6003

$LSD_{.05}$		
	Carrier	NS
	Rate (all except $ZnSO_4$ and ZnO)	NS
	Rate ($ZnSO_4$ and ZnO)	NS
	Carrier X Rate	NS

Table 22. Effects of zinc treatments on residual soil zinc concentration (DTPA extractable Zn). Greenhouse study.

Carrier	Zn Application Rates (ppm)					Carrier Means	
	.125	.25	.50	1.0	2.0	Comparable rates	All rates
			(ppm DTPA Zn)				
Zn-EDTA	.72	.75	.85	1.31	-	.98	.91
$Zn\text{-}NH_3$	.81	.92	.83	.96	-	.91	.88
NZN	.68	.71	.82	.93	-	.83	.79
$ZnCl_2$	.55	.75	.82	.92	-	.84	.76
Kemin	.74	.83	.87	.97	-	.90	.86
Rayplex	.66	.77	.78	.86	-	.81	.77
$ZnSO_4$	-	.82	.95	1.20	1.28	1.0	1.10
ZnO	-	.72	.88	.90	.94	.84	.86
Rate Means	.69	.79	.84	1.00	-		
	-	.77	.92	1.05	1.12		
	-	.80	.86	1.01	-		

Control: 0.67

$LSD_{.05}$		All Rates	Comparable Rates
	Carrier	.12	NS
	Rates (all except $ZnSO_4$ and ZnO)	.09	.09
	Rates ($ZnSO_4$ and ZnO)	.21	
	Carrier X Rate	NS	NS

from the carriers was not significant at comparative rates, $ZnSO_4$, Zn-EDTA, $Zn-NH_3$ and Kemin gave slightly higher residual zinc concentration in the soil at harvest.

The significant effects of increasing rates of Zn application is also reflected in the residual Zn status of the soil. More available Zn was present in the soil from increasing rates of application. Results suggest that residual effects of Zn carriers may tend toward equality regardless of whether sources are organic or inorganic and is dependent largely on rates applied.

Field Experiments

Field studies were carried out in Pawnee, McPherson, and Republic counties. Except for the Pawnee county residual zinc study and the Don Charles site in Republic county, six or more zinc carriers were evaluated as possible sources of zinc for soybeans. Site information is reported in Table 1. Selection of the fields was based on previous history of zinc deficiency, land leveling and low soil Zn values.

Pawnee county study. Six zinc carriers were evaluated as possible sources for soybean zinc nutrition. Youngest fully developed trifoliates were analyzed for Zn and P concentrations at early bloom and at early pod development. The seeds were also analyzed for the same elements after harvest. Dry weights of twelve trifoliates were not significantly affected at either sampling date by the rates of zinc applied (Tables 23 and 24).

Zinc concentrations in trifoliates at both sampling dates indicated no significant interaction between carrier and rates

Table 23. Effect of zinc treatments on dry weights (gm) of twelve trifoliates. Pawnee County, 11 July 1975.

Carrier	Zn Application Rates (kg/ha)					Carrier Means
	.28	.56	1.12	2.24	4.48	
Zn-EDTA	4.2	3.6	4.3	4.0	-	4.0
Kemin	4.7	4.4	4.6	4.8	-	4.6
Zn-NH_3	3.6	3.8	4.7	4.0	-	4.0
Rayplex	4.1	3.7	5.1	4.3	-	4.3
$ZnSO_4$	-	3.9	3.8	4.0	4.3	4.0
Zn-frit 247	-	3.7	4.5	3.7	5.0	4.2
Rate Means	4.1	3.9	4.7	4.3	-	
	-	3.8	4.2	3.9	4.7	

Control 3.8

$LSD_{.05}$	Carrier	NS
	Rate (all except $ZnSO_4$ and Zn-frit)	NS
	Rate ($ZnSO_4$ and Zn frit)	NS
	Carrier X Rate	NS

Table 24. Effect of zinc treatments on dry weight (gm) of twelve trifoliates. Pawnee County, 12 August 1975.

Carrier	Zn Application Rates (kg/ha)					Carrier Means
	.28	.56	1.12	2.24	4.48	
Zn-EDTA	4.7	4.9	4.8	4.9	-	4.9
Kemin	4.3	5.0	4.7	4.6	-	4.7
$Zn\text{-}NH_3$	4.8	5.0	4.7	4.8	-	4.8
Rayplex	3.8	4.3	4.3	5.8	-	4.5
$ZnSO_4$	-	4.9	5.0	4.9	5.5	5.1
Zn-frit 247	-	4.6	4.7	4.9	4.7	4.7
Rate Means	4.4	4.8	4.6	5.0	-	
	-	4.8	4.9	4.9	5.1	

Control: 4.8

$LSD_{.05}$		
	Carrier	NS
	Rate (all except $ZnSO_4$ and Zn-frit)	NS
	Rate ($ZnSO_4$ and Zn-frit)	NS
	Carrier X Rate	NS

of application (Tables 25 and 26). At the first sampling date, the other carriers tended to increase plant zinc concentration more than Zn-frit which gave the lowest concentration. At the second sampling date, a similar trend was observed but these differences were not significant when compared with each other (Table 26). This may be due to the fact that analysis of the control indicated some residual zinc in the soil. However, at comparative rates, ZnEDTA was significantly better than the other carriers in increasing leaf Zn concentration at both sampling dates.

Increasing rates of application appeared to increase plant zinc concentration in all the carriers but this was not statistically significant. Relatively higher rates of $ZnSO_4$ and Zn frit applied did not produce any marked effect when compared with the other carriers. ZnEDTA applied at 1.12 kgZn/ha was still slightly better than $ZnSO_4$ applied at 2.24 kg Zn/ha. There was little change in zinc concentration of the plant from increasing rates of Zn frit application except at the highest rate (Table 26).

Differences between carriers and application rates in increasing plant zinc uptake were not significant at the first sampling date (Table 27). Overall effect at comparative rates tends to indicate that Zn frit is equally efficient when compared with $ZnSO_4$. Other carriers were only slightly more efficient (Table 28). Rates of application but not carriers significantly increased plant zinc uptake at the second sampling date in ZnEDTA, Kemin, $Zn\text{-}NH_3$ and Rayplex. At comparative rates, the same carriers gave significantly higher zinc uptake concentrations

Table 25. Effect of zinc treatments on plant zinc concentration (ppm). Pawnee County, 11 July 1975.

Carrier	.28	.56	1.12	2.24	4.48	Carrier Means: Comparable rates	Carrier Means: All rates
Zn-EDTA	31.1	40.5	42.3	38.0	-	40.3	38.0
Kemin	34.1	30.5	36.5	35.3	-	34.1	34.1
Zn-NH_3	28.5	32.8	33.5	37.6	-	34.6	33.1
Rayplex	42.7	36.6	36.7	36.2	-	36.5	38.0
$ZnSO_4$	-	30.1	32.9	41.9	35.3	35.0	35.1
Zn-frit 247	-	19.6	29.2	29.6	34.9	26.1	28.3
Rate Means	34.1	35.1	37.2	36.8	-		
	-	24.9	31.0	35.8	35.1		
	-	31.7	35.2	36.4	-		

Control: 22.0

$LSD_{.05}$		All Rates	Comparable Rates
	Carrier	6.1	7.8
	Rate (all except $ZnSO_4$ and Zn-frit)	NS	NS
	Rate ($ZnSO_4$ and Zn-frit)	NS	
	Carrier X Rate	NS	NS

Table 26. Effect of zinc treatments on plant zinc concentration (ppm). Pawnee County, 12 August 1975.

Carrier	Zn Application Rate (kg/ha)					Carrier Means	
	.28	.56	1.12	2.24	4.48	Comparable rates	All rates
Zn-EDTA	23.1	31.6	37.6	33.4	-	34.2	34.1
Kemin	26.2	28.9	27.5	28.1	-	28.2	27.6
$Zn\text{-}NH_3$	26.1	31.0	22.3	35.1	-	29.5	28.6
Rayplex	32.5	28.8	32.3	35.1	-	32.0	32.1
$ZnSO_4$	-	23.5	25.9	29.3	30.9	26.2	27.4
Zn-frit 247	-	26.7	25.0	24.5	28.0	25.4	26.1
Rate Means	27.0	30.1	29.9	32.9	-		
	-	25.1	25.5	26.9	29.4		
	-	28.4	28.4	30.9	-		

Control: 23.6

$LSD_{.05}$		All Rates	Comparable Rates
	Carrier	NS	5.8
	Rate (all except $ZnSO_4$ and Zn-frit)	NS	NS
	Rate ($ZnSO_4$ and Zn-frit)	NS	
	Carrier X Rate	NS	NS

Table 27. Effect of zinc treatments on plant zinc uptake (mgm Zn) of twelve trifoliates. Pawnee County, 11 July 1975.

Carrier	Zn Application Rates (kg/ha)					Carrier Means	
	.28	.56	1.12	2.24	4.48	Comparable rates	All rates
Zn-EDTA	88.8	145.9	180.0	152.6	-	159.5	141.8
Kemin	157.5	130.0	172.9	174.3	-	159.0	158.6
$Zn-NH_3$	101.2	124.1	160.0	149.9	-	145.0	134.1
Rayplex	175.4	139.4	197.5	155.0	-	163.9	166.8
$ZnSO_4$	-	113.1	90.5	181.8	156.2	128.5	135.4
Zn-frit	-	72.4	136.4	109.2	174.9	106.0	123.2
Rate Means	130.7	134.8	177.8	158.0	-		
	-	92.7	113.4	145.5	165.6		
	-	120.8	156.4	153.8	-		

Control: 83.6

$LSD_{.05}$		All Rates	Comparable Rates
	Carrier	NS	NS
	Rate (all except $ZnSO_4$ and Zn frit)	NS	NS
	Rate ($ZnSO_4$ and Zn frit)	NS	
	Carrier X Rate	NS	NS

than $ZnSO_4$ and Zn frit (Table 29). The overall effect of the carriers indicates that Zn-EDTA, Kemin, Zn-NH_3, Rayplex and Zn frit were 2.0, 1.6, 1.7, 1.6, and 1.4 X respectively more efficient than $ZnSO_4$ in increasing plant zinc uptake (Table 30).

The zinc treatments did not exert a strong effect on phosphorus absorption. Indreasing rates of Zn at both sampling dates did not produce any significant effect on phosphorus concentration (Tables 31 and 32).

Seed zinc concentration was significantly increased by zinc application from the various carriers over the control (Table 33). Although the differences in the carrier effects were not significant, Zn frit tended to produce the lowest zinc concentration in the seeds. When rates of application are considered for $ZnSO_4$ and Zn frit, increasing rates of application significantly increased zinc concentration of the seeds. No significant increase in seed zinc concentration was obtained beyond 2.24 kg^{Zn}/ha in $ZnSO_4$. In contrast to this, the differences in seed zinc with increasing rates of application were not significant for ZnEDTA, Zn-NH_3, Rayplex and Kemin. At comparative rates, Zn-EDTA and Zn-NH_3 significantly increased seed Zn concentration over Zn frit. Effects of Zn application rates and Zn carriers on seed phosphorus concentration were not significant (Table 34).

All the carriers were about equal in increasing the seed yield significantly over the control. Efficiency of the carriers relative to $ZnSO_4$ is also about equal. Zn-EDTA and Zn-NH_3 which produced the relatively highest seed zinc concentrations also

Table 28. Efficiency of various Zn carriers in zinc uptake relative to $ZnSO_4$. Pawnee County, 11 July 1975.

Carrier	Relative Zn Application Rates [a] (kg/ha)									Overall
	.56/.56	1.12/.56	2.24/.56	.56/1.12	1.12/1.12	2.24/1.12	.56/2.24	1.12/2.24	2.24/2.24	Ratio
Zn-EDTA	1.3	0.8	0.3	3.2	2.0	0.9	3.2	2.0	0.8	1.6
Kemin	1.1	0.8	0.4	2.8	1.9	1.0	2.8	2.0	1.0	1.5
Zn-NH_3	1.1	0.7	0.3	2.8	1.8	0.9	2.8	1.8	0.8	1.6
Rayplex	1.2	0.9	0.4	3.0	2.2	0.9	3.2	2.2	0.9	1.6
Zn-frit	0.6	0.6	0.3	1.6	1.5	0.6	1.6	1.6	0.6	1.0

[a] Zn rate applied/ rate of $ZnSO_4$.

Table 29. Effect of zinc treatments on plant zinc uptake (mgm Zn) of twelve trifoliates. Pawnee County, 12 Aug. 1975.

Carrier	Zn Application Rates (kg/ha)					Carrier Means	
	.28	.56	1.12	2.24	4.48	Comparable rates	All rates
Zn-EDTA	78.6	152.5	181.3	163.5	-	165.7	143.9
Kemin	113.1	146.9	125.2	129.4	-	133.9	128.7
$Zn-NH_3$	123.6	154.9	105.9	166.5	-	142.5	137.7
Rayplex	121.3	118.2	136.2	201.2	-	151.9	144.2
$ZnSO_4$	-	114.2	79.7	142.2	170.2	112.0	126.5
Zn-frit	-	119.8	116.6	118.4	132.0	118.3	121.7
Rate Means	109.2	143.1	137.2	165.1	-		
	-	117.0	98.2	130.2	151.1		
	-	134.4	124.2	153.5	-		

Control: 113.3

		All Rates	Comparable Rates
$LSD_{.05}$	Carrier	NS	33.0
	Rate (all except $ZnSO_4$ and Zn-frit)	30.1	NS
	Rate ($ZnSO_4$ and Zn-frit)	NS	
	Carrier X Rate	NS	NS

Table 30. Efficiency of various Zn carriers in zinc uptake relative to $ZnSO_4$. Pawnee County, 12 Aug. 1975.

Carrier	Relative Zn Application Rates[a] (kg/ha)									Overall
	.56/.56	1.12/.56	2.24/.56	.56/1.12	1.12/1.12	2.24/1.12	.56/2.24	1.12/2.24	2.24/2.24	Ratio
Zn-EDTA	1.3	0.8	0.4	3.8	2.3	1.1	4.4	2.6	1.1	2.0
Kemin	1.3	0.6	0.3	3.6	1.6	0.8	4.0	1.8	0.9	1.6
$Zn-NH_3$	1.4	0.5	0.4	3.8	1.3	1.1	4.4	1.4	1.2	1.7
Rayplex	1.0	0.6	0.5	3.0	1.7	1.3	3.2	2.0	1.4	1.6
Zn frit	1.0	0.5	0.3	3.0	1.5	0.8	3.2	1.6	0.8	1.4

[a]Zn rate applied/ rate of $ZnSO_4$.

Table 31. Effect of zinc treatments on phosphorus concentration (ppm) of twelve trifoliates. Pawnee county, 11 July 1975.

Carrier	Zn Application Rate (kg/ha)					Carrier Means
	.28	.56	1.12	2.24	4.48	
Zn-EDTA	2664	2448	2484	2448	-	2511
Kemin	1944	2304	2304	2628	-	2295
$Zn-NH_3$	2880	2592	2340	2664	-	2619
Rayplex	2592	2700	2520	2448	-	2646
$ZnSO_4$	-	2556	2700	2700	2628	2646
Zn-frit 247	-	2736	2700	2700	2124	2565
Rate Means	2520	2511	2412	2547	-	
	-	2646	2700	2700	2376	

Control: 3024

$LSD_{.05}$		
	Carrier	NS
	Rates (all except $ZnSO_4$ and Zn-frit)	NS
	Rates ($ZnSO_4$ and Zn-frit)	NS
	Carrier X Rate	NS

Table 32. Effect of zinc treatment on phosphorus concentration (ppm) of twelve trifoliates. Pawnee County, 12 August 1975.

Carrier	Zn Application Rate kg/ha)					Carrier Means
	.28	.56	1.12	2.24	4.48	
Zn-EDTA	2448	2376	2232	2268	-	2331
Kemin	2376	2412	2160	2124	-	2268
$Zn-NH_3$	2196	2304	1872	2052	-	2106
Rayplex	2304	2448	2376	2302	-	2357
$ZnSO_4$	-	2016	2484	2124	2448	2268
Zn-frit 247	-	2664	2448	2412	2268	2448
Rate Mean	2331	2385	2160	2186	-	
	-	2340	2466	2268	2358	

Control: 2772

$LSD_{.05}$	Carrier	NS
	Rate (all except $ZnSO_4$ and Zn-frit)	NS
	Rate ($ZnSO_4$ and Zn-frit)	NS
	Carrier X Rate	NS

Table 33. Effects of zinc treatments on soybean seed zinc concentration (ppm). Pawnee County, 1975.

Carrier	Zn Application Rate (kg/ha)					Carrier Mean	
	.28	.56	1.12	2.24	4.48	Comparable rates	All rates
Zn-EDTA	34.9	37.6	42.0	37.4	-	39.0	38.1
Kemin	36.2	36.2	31.7	38.6	-	35.5	35.7
$Zn\text{-}NH_3$	32.7	38.5	38.2	36.9	-	37.9	36.6
Rayplex	37.0	32.8	38.0	36.9	-	35.9	36.2
$ZnSO_4$	-	27.9	27.8	41.0	36.9	32.2	33.4
Zn-frit 247	-	22.5	30.5	34.6	40.5	29.2	32.1
Rate Mean	35.2	36.3	37.5	37.5	-		
	-	25.2	29.2	37.8	38.7		
	-	32.6	34.7	37.6	-		

Control: 22.6

$LSD_{.05}$		All Rates	Comparable Rates
	Carrier	NS	6.7
	Rate (all except $ZnSO_4$ and Zn-frit)	NS	NS
	Rate ($ZnSO_4$ and Zn-frit)	5.5	
	Carrier X Rate	NS	NS

Table 34. Effect of zinc treatment on soybean seed phosphorus concentration (ppm P). Pawnee County, 1975.

Carrier	Zn Application Rate (kg/ha)					Carrier Mean
	.28	.56	1.12	2.24	4.48	
Zn-EDTA	2758	2862	3792	3096	-	3627
Kemin	4175	3705	4001	3723	-	3901
$Zn-NH_3$	3932	4158	3514	3601	-	3801
Rayplex	3827	3636	3549	3619	-	3658
$ZnSO_4$	-	3897	3166	3810	3827	3675
Zn-frit 247	-	4158	4280	3653	3444	3884
Rate Mean	3923	3840	3714	3510	-	
	-	4027	3723	3731	3636	

Control: 4281

$LSD_{.05}$		
	Carrier	NS
	Rate (all except $ZnSO_4$ and Zn-frit)	NS
	Rate ($ZnSO_4$ and Zn-frit)	NS
	Carrier X Rate	NS

Table 35. Effect of zinc treatments on soybean seed yield (kg/ha). Pawnee County, 1975.

Carrier	Zn Application Rate (kg/ha)					Carrier Mean	
	.28	.56	1.12	2.24	4.48	Comparable rates	All rates
Zn-EDTA	2486	2486	2419	2956	-	2620	2587
Kemin	2016	2553	2284	2755	-	2530	2402
$Zn\text{-}NH_3$	2217	2755	2956	2352	-	2687	2570
Rayplex	1276	1818	1747	3091	-	2218	1983
$ZnSO_4$	-	2284	2755	2284	2419	2441	2435
Zn-frit 247	-	2352	2284	2889	2217	2508	2435
Rate Mean	1998	2403	2351	2788	-		
	-	2318	2519	2586	2318		
	-	2374	2407	2721	[illegible]		

Control: 1747

$LSD_{.05}$		All Rates	Comparable Rates
	Carrier	NS	NS
	Rates (all except $ZnSO_4$ and Zn-frit)	NS	NS
	Rates ($ZnSO_4$ and Zn-frit)	NS	
	Carrier X Rate	NS	940

Table 36. Efficiency of various Zn carriers in seed yield relative to $ZnSO_4$. Pawnee County Study.

Carrier	Relative Zn Application Rates [a] (kg/ha)									Overall
	.56/.56	1.12/.56	2.24/.56	.56/1.12	1.12/1.12	2.24/1.12	.56/2.24	1.12/2.24	2.24/2.24	Ratio
Zn-EDTA	1.1	0.6	0.3	1.8	0.9	0.6	4.4	2.2	1.3	1.5
Kemin	1.1	0.5	0.3	1.8	0.8	0.5	4.4	2.0	1.2	1.4
$Zn-NH_3$	1.2	0.7	0.3	2.0	1.1	0.5	4.8	2.6	1.0	1.6
Rayplex	0.8	0.4	0.4	1.4	0.6	0.6	3.2	1.6	1.4	1.2
Zn frit	1.0	0.5	0.3	1.8	0.8	0.5	4.0	2.0	1.3	1.5

[a] Zn rate applied/ rate of $ZnSO_4$.

gave the highest seed yields (Tables 35 and 36).

McPherson county study. Seven zinc carriers were evaluated as sources of Zn for soybeans as in the Pawnee county study. The dry weights of twelve trifoliates sampled at the early bloom stage indicated no significant differences as a result of the treatments when compared with the control. Carrier and rate effects were also not significant (Table 37).

Increasing rates of Zn application increased plant zinc concentration but the differences were again non-significant (Table 38). There was no further trend toward increased Zn concentration beyond the 2.24 kg Zn/ha application rate. Carrier and rate effects were similarly non-significant in plant zinc uptake concentration (Table 39). The efficiency ratios of the carriers did not indicate significant advantage over $ZnSO_4$ in increasing zinc uptake of the trifoliates (Table 40).

Plant phosphorus concentration was generally depressed by increasing rates of zinc application but the differences were also not appreciable (Table 41). Carrier effects were, however, significant in this regard. Yields were lost at this site due to heavy hail damage in late summer.

Republic county, Scandia irrigation experiment field. The treatments in this study were similar to the McPherson county study but Zn frit was included in the evaluation of the carriers. Samples of youngest developed trifoliates were taken at early bloom and early pod development stages and analyzed for zinc and P concentration. A similar analysis was made on the seeds at harvest.

Table 37. Effect of zinc treatment on dry weight (gm) of twelve trifoliates. McPherson County, 1975.

Carrier	Zn Application Rate (kg/ha)					Carrier Mean
	.28	.56	1.12	2.24	4.48	
Zn-EDTA	3.76	3.61	4.05	3.75	-	3.79
Keymin	3.29	3.52	3.32	3.33	-	3.36
$Zn-NH_3$	3.48	3.32	3.74	3.41	-	3.49
Rayplex	3.10	3.46	3.69	3.52	-	3.44
NZN	3.70	3.61	3.98	3.14	-	3.86
$ZnSO_4$	-	3.72	3.71	3.79	3.89	3.78
Zn-frit	-	3.69	3.77	3.95	3.64	3.77
Rate Mean	3.47	3.51	3.76	3.63	-	
	-	3.71	3.74	3.87	3.77	

$LSD_{.05}$ NS

Control: 3.41

Carrier	NS
Rate	NS
$ZnSO_4$ + Zn-frit	NS
Carrier X Rate	NS

Table 38. Effect of zinc treatments on plant zinc concentration (ppm). McPherson County, 1975.

Carrier	Zn Application Rate (kg/ha) .28	.56	1.12	2.24	4.48	Carrier Means: Comparable rates	All rates
Zn-EDTA	28.9	26.6	31.1	35.3	-	31.0	30.5
Kemin	30.5	33.3	36.2	30.0	-	33.2	32.5
$Zn\text{-}NH_3$	29.8	29.9	35.9	31.9	-	32.6	31.9
Rayplex	27.6	33.6	26.5	32.3	-	30.8	30.0
NZN	27.8	28.5	30.8	28.3	-	29.3	29.2
$ZnSO_4$	-	29.7	29.1	37.3	36.0	32.0	33.0
Zn-frit	-	30.2	34.5	35.8	34.2	33.5	33.7
Rate Mean	29.2	30.4	32.1	31.6	-		
	-	20.0	31.8	36.5	35.1		
	-	30.3	32.0	33.0	-		

Control: 27.4

$LSD_{.05}$		All Rates	Comparable Rates
	Carrier	NS	NS
	Rate (all except $ZnSO_4$ and Zn-frit)	NS	NS
	Rate ($ZnSO_4$ and Zn-frit)	NS	
	Carrier X Rate	NS	NS

Table 39. Effect of zinc treatments on zinc uptake (mgm Zn) of twelve trifoliates. McPherson County, 1975.

Carrier	Zn Application Rate (kg/ha)					Carrier Means	
	.28	.56	1.12	2.24	4.48	Comparable rates	All rates
Zn-EDTA	106.9	93.8	123.6	132.3	-	116.6	114.1
Kemin	99.0	117.9	121.0	98.3	-	112.4	109.1
$Zn\text{-}NH_3$	103.7	100.5	134.2	109.8	-	114.9	112.1
Rayplex	87.0	115.8	98.4	111.6	-	108.6	103.2
NZN	108.1	99.4	123.0	114.8	-	112.4	111.3
$ZnSO_4$	-	113.2	107.0	139.5	140.0	119.9	124.9
Zn-frit	-	112.1	138.1	138.7	123.5	129.6	128.1
Rate Means	101.0	105.5	120.0	113.4	-		
	-	112.7	122.5	139.1	131.7		
	-	107.5	120.8	120.7	-		

Control: 93.4

		All Rates	Comparable Rates
$LSD_{.05}$	Carrier	NS	NS
	Rate (all except $ZnSO_4$ and Zn-frit)	NS	NS
	Rate ($ZnSO_4$ and Zn-frit)	NS	
	Carrier X Rate	NS	NS

Table 40. Efficiency of various Zn carriers in zinc uptake relative to $ZnSO_4$. McPherson County.

Carrier	Relative Zn Application Rates [a] (kg/ha)									Overall
	.56/.56	1.12/.56	2.24/.56	.56/1.12	1.12/1.12	2.24/1.12	.56/2.24	1.12/2.24	2.24/2.24	Ratio
Zn-EDTA	0.8	0.5	0.3	1.8	1.2	0.6	2.8	1.8	0.9	1.2
Kemin	1.0	0.6	0.2	2.2	1.1	0.5	3.2	1.8	0.7	1.2
$Zn-NH_3$	0.9	0.6	0.3	1.8	1.3	0.5	2.8	2.0	0.8	1.2
Rayplex	1.0	0.5	0.3	2.2	0.9	0.5	3.2	1.4	0.8	1.3
NZN	0.9	0.6	0.3	1.8	1.1	0.6	2.8	1.8	0.8	1.3
Zn frit	1.0	0.6	0.6	2.0	1.3	0.7	3.2	2.0	1.0	1.4

[a] Zn rate applied/ rate of $ZnSO_4$.

Table 41. Effect of zinc treatment on plant phosphorus concentration (ppm P). McPherson County, 1975.

Carrier	Zn Application Rate (kg/ha)					Carrier Means
	.28	.56	1.12	2.24	4.48	
Zn-EDTA	1670	1744	2301	2078	-	1948
Kemin	1856	1930	2153	2079	-	2004
$Zn-NH_3$	2524	2487	2190	2115	-	2329
Rayplex	2152	2672	2487	2375	-	2422
NZN	2412	2115	1930	2091	-	2137
$ZnSO_4$	-	2932	2301	2524	2115	2468
Zn-frit	-	2190	2178	2264	2635	2317
Rate Mean	2123	2190	2212	2148	-	
	-	2561	2239	2394	2375	

Control: 2700

$LSD_{.05}$	Carrier	340
	Rate (all except $ZnSO_4$ and Zn-frit)	NS
	Rate ($ZnSO_4$ and Zn-frit)	NS
	Carrier X Rate	NS

Although there was a slight increase in leaf dry weights at the early pod stage, all the treatments gave comparable values at both sampling dates (Tables 42 and 43). Carrier and rate effects did not produce any notable differences when compared with the control.

The various Zn carriers increased leaf zinc concentration in a similar manner and the differences were not significant (Tables 44 and 45). However, Zn-EDTA, Rayplex and $Zn\text{-}NH_3$ tended to produce the highest tissue zinc concentrations. The Zn rate effects were also not significant.

The leaf zinc concentrations at the early pod stage were lower than in the early bloom sampling probably due to the dilution effect because of greater plant growth and nutrient translocation to the seed due to late sampling. Similar results were obtained in the plant zinc uptake data (Tables 46 and 48). At .56 kgZn/ha but not at higher rates Rayplex was 1.4 and 1.6 X more efficient than $ZnSO_4$ in plant zinc uptake at the early bloom and early pod stages respectively. Other carriers gave about the same efficiency as $ZnSO_4$ in increasing plant zinc uptake (Tables 47 and 49).

Plant phosphorus concentrations were significantly depressed by the Zn treatments in the first sampling date (Table 50). There was a slight reduction in P concentration with increasing rates of application. However at the second sampling date, plant P concentration was not significantly affected (Table 51). This may also have been due to P translocation to the seeds as well as dilution.

Table 42. Effect of zinc treatments on dry weights (gm) of twelve trifoliates. Date 1. Scandia Exp. Field.

Carrier	Zn Application Rate (kg/ha)					Carrier Means
	.28	.56	1.12	2.24	4.48	
Zn-EDTA	3.36	3.41	3.06	3.72	-	3.39
Kemin	2.71	3.30	3.18	2.86	-	3.01
$Zn-NH_3$	3.85	3.25	3.93	3.36	-	3.60
Rayplex	2.61	3.33	2.87	2.72	-	2.89
NZN	3.12	3.11	4.21	3.50	-	3.48
$ZnSO_4$	-	3.40	3.87	3.11	3.21	3.40
Rate Mean	3.13	3.28	3.45	3.23	-	

Control: 3.65

$LSD_{.05}$	Carrier	NS
	Rate (all except $ZnSO_4$)	NS
	Carrier X Rate	NS

Table 43. Effects of zinc treatments on dry weight (gm) of eighteen trifoliates. Date 2. Scandia Exp. Field.

Carrier	Zn Application Rate (kg/ha)					Carrier Means
	.28	.56	1.12	2.24	4.48	
Zn-EDTA	5.38	5.35	5.19	5.67	-	5.40
Kemin	5.43	6.55	5.45	5.83	-	5.81
Zn-NH_3	6.58	5.67	5.80	6.16	-	6.05
Rayplex	5.97	7.22	5.90	6.34	-	6.36
NZN	6.60	7.23	6.52	6.54	-	6.72
$ZnSO_4$	-	6.96	5.64	6.80	6.57	6.49
Rate Mean	5.99	6.40	5.77	6.11	-	

Control: 5.06

$LSD_{.05}$	Carrier	NS
	Rate (except $ZnSO_4$)	NS
	Carrier X Rate	NS

Table 44. Effect of zinc treatments on leaf zinc concentration (ppm). Date 1. Scandia Exp. Field.

Carrier	Zn Application Rate (kg/ha)					Carrier Means	
	.28	.56	1.12	2.24	4.48	Comparable rates	All rates
Zn-EDTA	26.4	22.5	21.2	22.0	-	21.9	23.0
Kemin	20.4	23.6	21.9	19.9	-	21.8	21.5
Zn-NH_3	23.0	20.5	24.7	25.8	-	23.7	23.5
Rayplex	19.8	30.5	20.7	19.9	-	23.7	22.7
NZN	26.4	23.6	21.2	20.5	-	21.8	22.9
$ZnSO_4$	-	21.1	19.5	18.9	23.0	19.8	20.6
Rate Mean	23.2	24.1	21.9	21.6	-		
	-	23.7	21.5	21.2	-		

Control: 19.1

$LSD_{.05}$		All Rates	Comparable Rates
	Carrier	NS	NS
	Rate (except $ZnSO_4$)	NS	NS
	Carrier X Rate	NS	NS

Table 45. Effect of zinc treatments on leaf zinc concentration (ppm). Date 2. Scandia Exp. Field.

Carrier	Zn Application Rate (kg/ha)					Carrier Means	
	.28	.56	1.12	2.24	4.48	Comparable rates	All rates
Zn-EDTA	15.6	17.0	21.3	17.5	-	18.6	17.9
Kemin	16.3	18.0	15.2	17.3	-	16.8	16.7
$Zn-NH_3$	16.7	14.9	18.6	17.4	-	17.0	16.9
Rayplex	14.6	20.2	16.5	17.3	-	18.0	17.2
NZN	18.4	16.2	15.3	16.2	-	15.9	16.5
$ZnSO_4$	-	14.2	18.3	13.1	24.9	15.2	17.6
Rate Mean	16.3	17.2	17.3	16.5	-		
	-	16.7	17.5	16.5	-		

Control: 15.4

$LSD_{.05}$		All Rates	Comparable Rates
	Carrier	NS	NS
	Rate (all except $ZnSO_4$)	NS	NS
	Carrier X Rate	NS	NS

Table 46. Effect of zinc treatments on zinc uptake (mgm) of twelve trifoliates. Date 1. Scandia Exp. Field.

Carrier	Zn Application Rates (kg/ha)					Carrier Means	
	.28	.56	1.12	2.24	4.48	Comparable rates	All rates
Zn-EDTA	88.5	78.4	67.5	81.4	-	75.8	78.9
Kemin	59.4	76,2	70.1	55.6	-	67.3	65.3
$Zn-NH_3$	89.5	67.0	96.6	88.3	-	84.0	85.3
Rayplex	51.9	101.3	59.3	55.0	-	71.9	66.9
NZN	84.7	73.8	95.2	75.3	-	81.4	82.2
$ZnSO_4$	-	72.4	75.5	60.5	77.5	69.4	71.4
Rate Means	74.8	79.3	77.8	71.1	-		
	-	78.2	77.4	69.3	-		

Control. 58.4

$LSD_{.05}$		All Rates	Comparable Rates
	Carrier	NS	NS
	Rate (except $ZnSO_4$)	NS	NS
	Carrier X Rate	NS	NS

Table 47. Efficiency of various Zn carriers on zinc uptake relative to $ZnSO_4$. Scandia Exp. Field. Date 1.

Carrier	Relative Zn Application Rates[a] (kg/ha)									Overall
	.56/.56	1.12/.56	2.24/.56	.56/1.12	1.12/1.12	2.24/1.12	.56/2.24	1.12/2.24	2.24/2.24	Ratio
Zn-EDTA	1.1	0.5	0.3	2.0	0.9	0.6	5.2	2.2	1.4	1.6
Kemin	1.1	0.5	0.2	2.0	0.9	0.4	5.2	2.4	0.9	1.5
$Zn-NH_3$	0.9	0.6	0.3	1.8	1.3	0.6	4.4	3.2	1.5	1.6
Rayplex	1.4	0.4	0.2	2.6	0.8	0.4	6.8	2.0	0.9	1.7
NZN	1.0	0.7	0.3	2.0	1.3	0.5	4.8	3.2	1.2	1.7

[a] Zn rate applied/ rate of $ZnSO_4$.

Table 48. Effect of zinc treatments on zinc uptake (mgm) of eighteen trifoliates. Date 2. Scandia Exp. Field.

Carrier	Zn Application Rates (kg/ha)					Carrier Means	
	.28	.56	1.12	2.24	4.48	Comparable rates	All rates
Zn-EDTA	84.4	100.4	128.7	95.3	-	108.1	102.2
Kemin	95.2	117.3	86.5	99.8	-	101.2	99.7
$Zn-NH_3$	109.1	84.5	108.5	107.4	-	100.1	102.4
Rayplex	87.4	152.6	94.3	110.8	-	119.2	111.3
NZN	106.8	112.4	102.2	109.5	-	108.2	107.7
$ZnSO_4$	-	98.4	100.8	88.3	116.1	95.8	100.9
Rate Means	96.6	113.4	104.0	104.6	-		
	-	110.9	103.5	101.8	-		

Control: 77.9

$LSD_{.05}$		All Rates	Comparable Rates
	Carrier	NS	NS
	Rate (all except $ZnSO_4$)	NS	NS
	Carrier X Rate	NS	NS

Table 49. Efficiency of various Zn carriers in zinc uptake relative to $ZnSO_4$. Scandia Exp. Field. Date 2.

Carrier	Relative Zn Application Rates [a] (kg/ha)									Overall
	.56/.56	1.12/.56	2.24/.56	.56/1.12	1.12/1.12	2.24/1.12	.56/2.24	1.12/2.24	2.24/2.24	Ratio
Zn-EDTA	1.0	0.7	0.3	2.0	1.3	0.5	4.4	3.0	1.1	1.6
Kemin	1.2	0.5	0.3	2.4	0.9	0.5	5.2	2.0	1.1	1.6
$Zn-NH_3$	0.9	0.6	0.3	1.6	1.1	0.5	4.0	2.4	1.2	1.4
Rayplex	1.6	0.5	0.3	3.0	0.9	0.6	6.8	2.0	1.3	1.9
NZN	1.1	0.5	0.3	2.2	1.0	0.6	5.2	2.4	1.2	1.6

[a] Zn rate applied/ rate of $ZnSO_4$.

Table 50. Effect of zinc treatments on plant phosphorus concentration (ppm). Date 1. Scandia Exp. Field.

Carrier	Zn Application Rates (kg/ha)					Carrier Means
	.28	.56	1.12	2.24	4.48	
Zn-EDTA	3000	2400	2300	3100	-	2600
Kemin	2500	2300	2700	2200	-	2400
$Zn-NH_3$	2900	2900	2300	3000	-	2800
Rayplex	2600	3000	1900	1800	-	2200
NZN	2800	2900	2000	3000	-	2600
$ZnSO_4$	-	3100	2600	2600	2500	2800
Rate Mean	2800	2700	2200	2600	-	

Control: 2600

$LSD_{.05}$		
	Carrier	NS
	Rate (all except $ZnSO_4$)	300
	Carrier X Rate	700

Table 51. Effect of zinc treatments on plant phosphorus concentration (ppm). Date 2. Scandia Exp. Field

Carrier	Zn Application Rate (kg/ha)					Carrier Means
	.28	.56	1.12	2.24	4.48	
Zn-EDTA	2200	2100	2000	2300	-	2100
Kemin	2400	2100	2300	2300	-	2200
$Zn-NH_3$	2200	2400	2000	2600	-	2300
Rayplex	2300	2500	1900	2200	-	2200
NZN	2500	2200	2300	2500	-	2300
$ZnSO_4$	-	2100	2300	2400	2400	2300
Rate Mean	2300	2300	2100	2400	-	

Control: 2200

$LSD_{.05}$		
	Carrier	NS
	Rate (all except $ZnSO_4$)	NS
	Carrier X Rate	NS

Analysis of the seed at harvest revealed that the Zn treatments produced significant changes in seed composition (Table 52). Seed zinc concentration increased significantly with increasing rates of application. When the rates are compared over all carriers except $ZnSO_4$, there was no appreciable increase beyond .56 kgZn/ha rate. Another interesting observation was that Zn-EDTA applied at this rate produced a higher seed zinc concentration when compared with $ZnSO_4$ applied at 4.48 kgZn/ha. Zn-EDTA was significantly better than the other materials which produced about equal effects. Overall effects of the carriers at comparable rates, indicates that Zn-EDTA was 1.3 X more efficient than $ZnSO_4$ in increasing seed Zn concentration. Treatments had little effect on seed phosphorus concentrations (Table 53).

The zinc carrier effects on seed yield were equal but yields were extremely poor due to late seeding (Tables 54 and 55). Despite some significant differences among the various treatments, few trends were obtained from these data.

Republic county study (Don Charles farm). In this study, urea ammonium nitrate suspension (2% clay 32-0-0) and ammonium polyphosphate (APP) suspension (2% clay 10-15-0) were used as transport agents for $Zn\text{-}NH_3$, Zn-EDTA and Zn lignin sulfonate (Kemin). Zinc was banded to the side of the seed at planting.

The dry weights of the trifoliates at the early pod stage did not indicate any significant differences due to rates of application (Table 56). The zinc carriers means indicated significant differences. Kemin was significantly better than

Table 52. Effect of zinc treatments on seed zinc concentration (ppm). Scandia Exp. Field.

Carrier	Zn Application Rate (kg/ha)					Carrier Mean	
	.28	.56	1.12	2.24	4.48	Comparable rates	All rates
Zn-EDTA	36.3	45.6	45.7	43.9	-	45.1	42.9
Kemin	32.9	37.2	38.8	37.1	-	37.7	36.5
$Zn\text{-}NH_3$	33.6	39.6	40.4	38.4	-	39.5	38.0
Rayplex	31.9	38.5	38.1	36.6	-	37.7	36.2
NZN	35.1	35.8	37.4	37.7	-	37.0	36.5
$ZnSO_4$	-	31.9	33.2	37.8	40.9	35.0	36.5
Rate Mean	33.9	39.3	40.1	38.7	-		
	-	38.1	39.3	38.6	-		

Control: 33.1

		All Rates	Comparable Rates
$LSD_{.05}$	Carrier	3.9	3.6
	Rate (except $ZnSO_4$)	3.1	NS
	Carrier X Rate	NS	NS

Table 53. Effect of zinc treatments on seed phosphorus concentration (ppm). Scandia Exp. Field.

Carrier	Zn Application Rate (kg/ha)					Carrier Mean
	.28	.56	1.12	2.24	4.48	
Zn-EDTA	4832	4720	4544	4512	-	4652
Kemin	4832	4816	4368	4784	-	4700
$Zn-NH_3$	4592	4864	4624	4400	-	4620
Rayplex	4704	5216	4448	4608	-	4744
NZN	4816	4720	4592	4432	-	4640
$ZnSO_4$	-	4752	4800	4816	4304	4668
Rate Mean	4754	4856	4565	4506	-	

$LSD_{.05}$ Carrier NS — Control: 4831

Rate (all except $ZnSO_4$) NS

Carrier X Rate NS

Table 54. Effect of zinc treatments on seed yield (kg/ha). Scandia Exp. Field.

Carrier	Zn Application Rate (kg/ha)					Carrier Mean	
	.28	.56	1.12	2.24	4.48	Comparable rates	All rates
Zn-EDTA	920	1028	577	732	-	779	814
Kemin	826	1337	786	712	-	945	915
$Zn-NH_3$	1283	722	833	994	-	849	958
Rayplex	987	1196	638	577	-	803	849
NZN	1102	1142	1202	1296	-	1213	1185
$ZnSO_4$	-	1377	1310	1001	745	1229	1108
Rate Mean	1023	1085	807	862	-		
	-	1133	891	885	-		

Control: 672

		All Rates	Comparable Rates
$LSD_{.05}$	Carrier	NS	NS
	Rate (all except $ZnSO_4$)	NS	NS
	Carrier X Rate	NS	645

Table 55. Efficiency of various Zn carriers in seed yield relative to $ZnSO_4$. Scandia Exp. Field.

Carrier	Relative Zn Application Rates [a] (kg/ha)									Overall
	.56/.56	1.12/.56	2.24/.56	.56/1.12	1.12/1.12	2.24/1.12	.56/2.24	1.12/2.24	2.24/2.24	Ratio
Zn-EDTA	0.7	0.2	0.1	1.6	0.4	0.3	4.0	1.2	0.7	1.0
Kemin	1.0	0.3	0.1	2.0	0.6	0.3	5.2	1.6	0.7	1.3
$Zn-NH_3$	0.5	0.3	0.2	1.2	0.6	0.4	2.8	1.6	1.0	1.0
Rayplex	0.9	0.3	0.1	1.8	0.5	0.2	4.8	1.2	0.6	1.2
NZN	0.8	0.5	0.2	1.8	0.9	0.5	4.4	2.4	1.3	1.4

[a] Zn rate applied/ rate of $ZnSO_4$.

Table 56. Effect of zinc treatment on dry weight (gm) of twelve trifoliates. Republic County, Don Charles farm.

Zn Carrier and Transport Agent	Zn Application Rate (kg/ha) .56	1.12	2.24	4.48	Carrier and Transport Agent	Carrier Means
Kemin + 32-0-0	2.58	3.66	3.66	2.77	3.09	
Kemin + 10-15-0	3.10	3.01	3.22	3.48	3.20	3.14
Zn-EDTA + 32-0-0	2.61	2.53	2.99	2.87	2.75	
Zn-EDTA + 10-15-0	2.63	2.60	2.50	2.71	2.61	2.68
$Zn\text{-}NH_3$ + 32-0-0	2.74	2.37	2.87	2.91	2.78	
$Zn\text{-}NH_3$ + 10-15-0	2.80	2.88	2.75	3.08	2.88	2.83
Rate Mean	2.74	2.88	2.95	2.97		

$LSD_{.05}$				
	Carrier	.25	32-0-0	2.87
	Transport Agent	NS	10-15-0	2.90
	Rate	NS	No Zn 32-0-0	2.89
	Carrier X Transp. Agent	NS		
	Carrier X Transp. Agent X Rate	NS	No Zn 10-15-0	3.21

Zn-EDTA and $Zn-NH_3$ which produced comparable dry weights. There were no notable differences between the mean effects of the two transport agents, however, apparently the presence of P in the polyphosphate form exerted neither beneficial or detrimental effects on Zn availability as measured by trifoliate weights.

DTPA soil extraction before commencement of the experiment indicated a low zinc status of the soil (Table 1). Leaf zinc concentrations were not in the deficient range, however, the three zinc carriers were essentially equal in their effects on leaf zinc concentrations (Table 57). Kemin was slightly better than the other two sources. Transport agent effects were not significant. Although not consistent in all the carriers, zinc concentration increased with increasing rates of application; zinc applied at 4.48 kg/ha produced significantly higher concentrations than the lower rates.

Zinc carrier-transport agent interaction was significant. Kemin in combination with 10-15-0 produced the highest leaf zinc concentration. Kemin in 32-0-0 produced generally lower Zn concentrations. It is doubtful that this difference was due to formation of a reaction product between the Kemin and the APP since APP plus the other Zn carriers had no positive affect.

The phosphorus concentration of the trifoliates was not appreciably affected by the zinc source or application rates (Table 58).

Seed zinc concentration was not affected by the Zn carrier o transport agent but was increased by higher rates of Zn applicatio (Table 59). 4.48 kg/ha zinc significantly increased seed zinc

Table 57. Effect of zinc treatments on plant zinc concentration (ppm). Republic County, Don Charles farm.

Zn Carrier and Transport Agent	Zn Application Rate (kg/ha) .56	1.12	2.24	4.48	Carrier and Transport Agent Means	Carrier Means
Kemin + 32-0-0	31.6	34.8	31.9	36.1	33.5	
Kemin + 10-15-0	29.4	38.6	35.1	41.8	38.7	36.2
Zn-EDTA + 32-0-0	33.3	32.0	36.5	39.1	35.2	
Zn-EDTA + 10-15-0	31.5	33.3	36.9	37.1	34.8	35.0
$Zn-NH_3$ + 32-0-0	33.3	34.8	34.7	40.7	35.9	
$Zn-NH_3$ + 10-15-0	34.7	35.5	34.4	34.6	34.7	35.3
Rate Mean	34.0	34.7	34.8	38.5		

$LSD_{.05}$	Carrier	NS	32-0-0	34.9
	Transport Agent	NS	10-15-0	36.1
	Rate	2.7	No Zn 32-0-0	32.9
	Carrier X Transp. Agent	3.3		
	Carrier X Transp. Agent X Rate	NS	No Zn 10-15-0	32.3

Table 58. Effect of zinc treatments on plant phosphorus concentration (ppm). Republic County, Don Charles farm.

Zn Carrier and Transport Agent	Zn Application Rate (kg/ha) .56	1.12	2.24	4.48	Carrier and Transport Agent Means	Carrier Means
Kemin + 32-0-0	2891	2596	2537	2891	2728	
Kemin + 10-15-0	2684	2684	3186	2978	2883	2806
Zn-EDTA + 32-0-0	2891	2507	2419	2773	2647	
Zn-EDTA + 10-16-0	3127	2950	2979	3156	3053	2850
$Zn\text{-}NH_3$ 32-0-0	2537	2743	2537	2507	2581	
$Zn\text{-}NH_3$ 10-15-0	2891	2891	2773	3038	2898	2739
Rate Mean	2836	2738	2738	2890		

$LSD_{.05}$	Carrier	NS	32-0-0	2652
	Transport Agent	190	10-15-0	2944
	Rate	NS		
	Carrier X Transport Agent	NS	No Zn 32-0-0	2979
	Carrier X Transp. Agent X Rate	NS	No Zn 10-15-0	2507

Table 59. Effect of zinc treatments on seed zinc concentration (ppm). Republic County, Don Charles farm.

Zn Carrier and Transport Agent	Zn Application Rate (kg/ha) .56	1.12	2.24	4.48	Carrier and Transport Agent Means	Carrier Means
Kemin + 32-0-0	34.7	35.2	34.9	39.5	36.1	
Kemin + 10-15-0	38.2	35.5	36.6	41.1	37.9	37.0
Zn-EDTA + 32-0-0	34.9	37.8	39.2	30.9	38.2	
Zn-EDTA + 10-15-0	35.1	37.4	37.4	40.1	37.5	37.8
$Zn\text{-}NH_3$ + 32-0-0	34.9	36.2	37.2	40.9	37.3	
$Zn\text{-}NH_3$ 10-15-0	39.2	38.0	32.7	37.7	36.9	37.1
Rate Mean	36.2	36.7	36.3	40.0		

$LSD_{.05}$				
	Carrier	NS	32-0-0	37.2
	Transport Agent	NS	10-15-0	37.4
	Rate	2.4	No Zn 32-0-0	31.7
	Carrier X Transport Agent	NS		
	Carrier X Transp. Agent X Rate	NS	No Zn 10-15-0	32.8

concentrations.

Source of zinc and rates of application had little significance on seed phosphorus concentration (Table 60). Some differences within treatments and between rates could have been related to the depressing effect of zinc application but these differences were variable and not statistically significant. Banded applications of 10-15-0 significantly increased seed phosphorus concentration when compared with urea ammonium nitrate (32-0-0). As observed for Zn concentrations in leaves, the effects of Kemin on seed Zn concentrations were lowered when this carrier was applied in the urea ammonium nitrate suspension.

A comparison of the zinc carrier effects on seed yield produced highly variable results. Kemin and zinc EDTA produced the highest seed yields (Table 61). Kemin yields were significantly higher than Zn-NH_3. This may be related to the increased zinc uptake from the zinc source as evidenced in the leaf and seed analysis. Although differences in seed yields due to rate effects are not significant, zinc applied at 2.24 kg/ha produced the highest seed yield. A slightly higher yield was recorded with 32-0-0 transport agent which was not expected in light of Zn concentrations in the plant tissue.

Pawnee county residual study. The treatments in this study were applied in 1974 to evaluate Zn combinations with ammonium polyphosphate (APP) and ammonium orthophosphate (AOP) supplied at three rates of phosphorus and two rates of zinc. In 1974, no significant yield responses or differences in plant phosphorus concentrations were noted from the treatments (Tables 63 and 64).

Table 60. Effect of zinc treatment on seed phosphorus concentration (ppm). Republic County, Don Charles farm.

Zn Carrier and Transport Agent	Zn Application Rate (kg/ha) .56	1.12	2.24	4.48	Carrier and Transport Agent Means	Carrier Means
Kemin + 32-0-0	4716	4188	3720	4104	4128	
Kemin + 10-15-0	4752	4728	4860	4752	4773	4477
Zn-EDTA + 32-0-0	4464	4512	4020	3864	4215	
Zn-EDTA + 10-15-0	4512	4716	4644	4212	4521	4368
$Zn\text{-}NH_3$ + 32-0-0	4620	4644	4236	4740	4560	
$Zn\text{-}NH_3$ + 10-15-0	4860	3768	4284	4848	4440	4500
Rate Mean	4654	4426	4294	4420		

$LSD_{.05}$	Carrier	NS	32-0-0	4319
	Transport Agent	214	10-15-0	4578
	Rate	NS	No Zn 32-0-0	5028
	Carrier X Transp. Agent	371		
	Carrier X Transp. Agent X Rate	NS	No Zn 10-15-0	4896

Table 61. Effect of zinc treatments on seed yield (kg/ha). Republic County, Don Charles farm.

Zn Carrier and Transport Agent	Zn Application Rate (kg/ha) .56	1.12	2.24	4.48	Carrier and Transport Agent Means	Carrier Means
Kemin + 32-0-0	2284	2284	3561	1991	2530	
Kemin + 10-15-0	1545	1545	1747	1747	1646	2088
Zn-EDTA + 32-0-0	2419	1411	1545	1344	1679	
Zn-EDTA + 10-15-0	1747	2016	1881	2217	1965	1822
$Zn-NH_3$ + 32-0-0	1814	1612	1612	1276	1578	
$Zn-NH_3$ + 10-15-0	1209	1411	1881	1478	1494	1536
Rate Mean	1836	1713	2037	1677		

$LSD_{.05}$	Carrier	336	32-0-0	1881
	Transport Agent	NS	10-15-0	1680
	Rate	NS	No Zn 32-0-0	1948
	Carrier X Transport Agent	818		
	Carrier X Transp. Agent X Rate	873	No Zn 10-15-0	1612

Table 62. Pawnee county residual study. Leaf Zn concentration (ppm).

Treatment	Rates of P Application (kg/ha) 1974 19.6	1974 39.2	1974 58.7	1975 19.6	1975 39.2	1975 58.7
APP	15.6	17.0	20.2	32.4	22.9	22.3
APP + 8.96 kgZn/ha	25.3	25.9	30.2	36.3	40.0	48.2
AOP	15.5	14.1	10.0	24.6	28.6	27.8
AOP + 8.96 kgZn/ha	28.1	30.3	31.4	44.7	42.2	42.4
Rate Mean	21.1	21.8	22.9	34.5	33.3	35.2

	1974	1975
P carrier mean APP	22.4	33.7
AOP	21.6	35.0
Zn application		
0 kgZn/ha	15.4	26.4
8.96 kgZn/ha	28.5	42.3
Control (No Zn, No P)	24.2	32.0

$LSD_{.05}$	1974	1975
Treatment	11.7	11.7
Rates	NS	NS
P carrier	NS	NS
Zn rate	4.9	4.9

Table 63. Pawnee county residual study. Leaf phosphorus concentration (%P).

Treatment	Rates of P Application (kg/ha) 1974 19.6	39.2	58.7	1975 19.6	39.2	58.7
APP	.23	.31	.38	.39	.38	.38
APP + 8.96 kgZn/ha	.27	.26	.28	.38	.37	.40
AOP	.29	.33	.33	.38	.38	.39
AOP + 8.96 kgZn/ha	.25	.31	.32	.36	.38	.35
Rate Mean	.26	.30	.33	.38	.38	.38

	1974	1975
P carrier mean APP	.29	.39
AOP	.31	.38
Zn application		
0 kgZn/ha	.31	.39
8.96 kgZn/ha	.28	.38
Control (No Zn, No P)	.28	.35

$LSD_{.05}$	1974	1975
Treatment	NS	NS
Rates	.09	NS
P carrier	NS	NS
Zn rate	NS	NS

Table 64. Pawnee county residual study. Seed yield (kg/ha).

Treatment	Rates of P Application (kg/ha) 1974 19.6	1974 39.2	1974 58.7	1975 19.6	1975 39.2	1975 58.7
APP	1948	1948	2083	2284	2352	2217
APP + 8.96 kgZn/ha	2419	2352	2150	2553	2486	2553
AOP	2352	1612	2016	2486	2284	2284
AOP + 8.96 kgZn/ha	1747	2553	2150	2419	3360	2217
Rate Mean	2116	2116	2099	2435	2620	2317

	1974	1975
P carrier mean APP	2150	2407
AOP	2071	2508
Zn application		
0 kgZn/ha	1993	2317
8.96 kgZn/ha	2228	2598
Control (No Zn, No P)	1948	2352

$LSD_{.05}$	1974	1975
Treatment	NS	NS
Rates	NS	NS
P carrier	NS	NS
Zn rate	NS	NS

The residual effects of applied zinc have been reported by several workers on many crops including soybeans. Similar effects were demonstrated in the leaf composition data of soybeans grown in 1975 on plots which had received Zn in 1974. In fact, leaf Zn concentration was increased by approximately 16 ppm as a result of the residual effects of 8.96 kgZn/ha applied in 1974 (Table 62). Phosphorus applied either as APP or AOP depressed leaf zinc concentrations when no zinc was applied. The severity tended to increase with increasing rates of P application. Plant zinc concentrations, however, increased with increasing rates of P application when applied with zinc. P-Zn interaction has been observed on several crops under similar circumstances. The present study provides further evidence of this relationship in soybeans.

Increasing rates of P application significantly increased leaf P concentration in 1974 but not as much in 1975 (Table 63). However, there was more P in the tissues in 1975. This may be due to increased availability of previously applied P and/or native P. There was no significant difference between AOP and APP in tissue composition and yield in both years.

Residual P and Zn generally increased soybean seed yield (Table 64). There was a general positive response to zinc application in both years. This is manifested in the increase in yield from P and Zn applications as compared to when P was the only treatment.

CONCLUSIONS

Greenhouse studies indicated that a comparatively longer growth period (greater than 28 days) will probably be required for notable visual symptoms of a zinc deficiency situation to develop in soybeans especially if the soil is not acutely zinc deficient. This is related to the fact that the soybean accumulates a considerable amount of zinc in the seeds at harvest to satisfy the immediate needs of the seedling.

All the varieties responded to zinc application especially at the higher rates. Significant increases in plant height, dry matter accumulation, tissue zinc concentration and uptake were recorded. However, significant varietal differences in dry weight and plant height were due to zinc treatments alone. All the varieties contained about the same level of zinc in vegetative tissue. Varietal consideration may not be important in zinc fertilization of soybeans.

Zn-EDTA, Kemin, Zn-NH_3 and NZN were fairly good sources of zinc in the greenhouse. Overall effects indicate that Zn EDTA was significantly better than $ZnCl_2$ (1.4X) and was comparatively more efficient than $ZnSO_4$ and ZnO even though these were applied at relatively higher rates. These data confirm the efficiency of the chelate as a good source of zinc for soybeans. Relatively lower rates of Zn application as the chelate will probably be possible in comparison with the inorganic sources. However, calculation of efficiency ratio for Zn EDTA versus $ZnSO_4$ indicated that the chelate was less than 4 X as efficient as $ZnSO_4$.

Ratios were calculated on the basis of Zn uptake over all combinations of three rates of applied Zn. Calculating the ratio of Zn uptake and dividing that ratio by the quotient of the rates of applied Zn gave values no higher than 3.6.

Zinc treatments exerted some depression on phosphorus concentration and uptake. Magnitude of these depressions generally increased with increasing rates of zinc application in Pomona, Cutler and Columbus varieties. On the other hand, Zn enhanced P uptake in the Amsoy variety. Form of applied Zn had little effect. Generally, the P-Zn interaction does not seem to be as strong in soybeans as in corn.

Residual soil zinc at the end of the greenhouse study was still sufficient for the next crop. $ZnSO_4$ and Zn EDTA produced the highest residual soil zinc levels. $ZnCl_2$ produced the lowest tissue zinc content and also the lowest residual soil zinc suggesting generally poor performance.

Dry weights of the twelve trifoliates in the field was a poor indicator of Zn response. Field zinc applications responses were measurable by leaf zinc concentrations. Zn EDTA, $ZnSO_4$, Kemin and Rayplex were good sources of zinc when compared with Zn frit which produced comparatively low zinc values in the leaves. Leaf Zn concentrations responded to increasing rates of Zn application up to 4.48 kg/ha Zn although in some cases there was no significant response beyond 2.24 kg/ha Zn. Results obtained from the Scandia field study at a late sampling date indicate lowered Zn and P in the leaves due to dilution and translocation to the seed. Phosphorus concentrations were only slightly affected by the zinc application.

Seed zinc concentration increased with zinc applications. Significant differences in Zn materials were recorded. Zn EDTA produced higher values than the other sources but Rayplex and $Zn-NH_3$ also produced high seed zinc concentrations. The Zn frit was least efficient in this regard. For the materials just mentioned, efficiency over $ZnSO_4$ ranged only up to a maximum of 3.6 with Zn EDTA.

Yield responses were similar for all carriers with Zn EDTA tending slightly higher.

Applications of Kemin (Zn ligninsulfonate) in liquid APP were superior to applications in 32-0-0 suspension in forms of tissue Zn concentration and seed zinc concentration but not in yield. Banded application of APP with Kemin increased the uptake of P which may have increased the absorption of Zn from the readily available Kemin source. Results of a residual study in Pawnee county indicate that P applied either as AOP or APP without zinc application depressed zinc concentration in the plant. The severity increased with increasing rates of P application. This conforms to similar P-Zn interactions in other crops.

Second year residual effects of 8.96 kg/ha Zn produced leaf zinc concentration 16 ppm higher the second year. This demonstrates that residual zinc is dependable following high rates of application. Since different crops vary in their zinc requirement and differences exist in sources of zinc in terms of availability, there will still be need for routine soil analysis in a judicious fertilization program.

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APPENDIX

Table I. Effect of rates of Zn application on the growth and composition of seven soybean varieties. Greenhouse study.

Variety	Zn Rate ppm	Height cm	Dry Wt. gm	Zn Conc. ppm Zn	Zn Uptake mgm Zn/pot	P Conc. ppm P	P Uptake mgm P/pot
Clark	0	31.5	2.23	21.9	49.2	1880	4118
	0.5	34.1	2.50	25.4	63.5	1785	4285
	1.0	34.9	2.82	28.9	79.5	1785	4285
	2.0	35.1	2.73	32.7	89.4	1380	3792
	4.0	34.0	2.83	43.6	123.8	1952	3282
Amsoy	0	31.8	2.32	19.2	44.5	1380	3072
	0.5	32.6	2.81	24.1	68.2	1666	4753
	1.0	34.1	2.67	26.5	70.7	1667	4484
	2.0	32.6	2.61	28.8	75.2	1785	4625
	4.0	33.9	2.58	39.7	102.6	1666	3282
Williams	0	30.4	2.42	21.2	51.3	1166	2810
	0.5	31.5	2.91	28.7	83.4	1952	5678
	1.0	33.1	2.57	26.7	69.5	952	2463
	2.0	31.3	2.96	32.6	96.4	1190	2534
	4.0	30.4	2.78	42.9	120.5	1976	3525
Columbus	0	29.8	2.32	22.6	52.3	2380	4824
	0.5	31.0	2.49	23.8	58.9	1261	3123
	1.0	30.8	2.38	25.3	61.5	1571	3854
	2.0	30.0	2.43	32.0	77.6	1523	3696
	4.0	34.2	2.34	40.9	96.1	1095	2590
Cutler	0	31.7	2.36	22.9	53.7	2023	4751
	0.5	34.1	2.18	25.4	55.2	1737	3789
	1.0	34.7	2.32	28.4	66.2	1976	4547
	2.0	35.0	2.54	31.9	80.9	1737	4384
	4.0	37.7	2.52	41.2	103.3	1642	4030
Calland	0	32.3	2.38	23.5	56.1	1642	3882
	0.5	35.5	2.57	26.8	69.9	1595	4159
	1.0	36.1	2.53	32.8	82.9	1952	4927
	2.0	35.7	2.66	25.9	69.0	1071	2858
	4.0	37.1	2.71	31.8	88.1	1547	3853
Pomona	0	28.4	2.08	24.1	49.3	1904	3898
	0.5	32.6	2.08	30.2	62.6	1737	3630
	1.0	33.5	2.65	29.9	78.9	1714	4554
	2.0	33.5	2.39	33.4	79.9	1642	3909
	4.0	34.2	2.67	40.5	104.7	1523	3288
$LSD_{.05}$	Treatment	NS	NS	NS	NS	NS	NS
	Varieties	1.8	0.22	NS	10.1	NS	NS
	Rates	1.5	.19	2.5	8.6	NS	NS

Table II. Effects of Zn carriers and rates of application on soybean growth and composition. Greenhouse study.

Zn Carrier	Rate (ppm)	Height (cm)	Dry Wt. (gm)	Zn Conc. (ppm)	Zn Uptake (mgm) Zn/pot	P Conc. ppm P	P Uptake (mgm) P/pot	Res. Zn (ppm)
--	0	31.1	4.10	17.2	71.4	1496	6003	.67
Zn EDTA	.125	31.8	4.10	18.2	74.3	1387	5936	.72
	.25	32.4	4.20	22.9	96.6	1359	5705	.75
	.50	31.3	4.18	35.2	147.9	1251	5216	.85
	1.0	32.0	4.39	32.5	142.5	1169	5126	1.31
Zn NH_3	.125	32.1	3.90	17.7	68.3	1251	4766	.81
	.25	32.3	4.00	21.2	85.7	1414	5681	.92
	.50	30.2	4.60	20.2	93.2	1169	5368	.83
	1.0	31.9	4.65	21.6	100.7	1196	5581	.96
NZN	.125	32.0	4.10	19.3	78.1	1332	5401	.68
	.25	33.4	4.27	19.1	81.9	1305	5392	.71
	.50	32.6	3.98	23.9	94.3	1468	5830	.82
	1.0	33.0	4.34	25.5	115.5	1414	6388	.93
$ZnCl_2$	.125	32.1	3.99	17.2	68.7	1414	5724	.55
	.25	32.9	4.11	19.2	79.4	1196	4784	.75
	.50	31.5	4.00	18.7	74.7	1142	4570	.82
	1.0	30.9	4.24	19.9	84.3	1060	4494	.92
Kemin	.125	32.0	4.27	19.8	84.6	1332	5687	.74
	.25	31.1	3.94	21.5	84.8	1332	5253	.83
	.50	31.2	3.93	21.0	82.5	1305	4976	.87
	1.0	31.2	3.96	26.0	104.2	1223	4849	.97
$ZnSO_4$	.25	32.5	4.19	19.1	80.3	1387	5702	.82
	.50	30.9	4.10	20.1	83.2	1550	6416	.95
	1.0	32.5	3.62	26.3	94.9	1305	4633	1.20
	2.0	31.1	4.40	30.2	133.2	1223	5432	1.28
Zn O	.25	30.3	4.03	20.9	84.2	1468	5884	.72
	.50	31.4	4.09	18.6	75.2	1441	5727	.88
	1.0	31.3	4.18	21.5	89.3	1251	5214	.90
	2.0	31.2	4.45	22.4	99.8	1223	5441	.94
Rayplex	.125	32.5	4.25	19.3	82.1	1223	5202	.66
	.25	30.9	4.25	18.7	79.8	1251	5185	.77
	.50	32.5	4.69	22.5	103.8	1169	5480	.78
	1.0	31.1	4.35	23.7	102.2	1142	4975	.86
$LSD_{.05}$	Treatment	NS	NS	4.8	NS	NS	NS	NS
	Carriers	NS	NS	2.4	13.1	NS	NS	.12
	Rates	NS	NS	2.1	11.1	NS	NS	.09
	Rates (ZnO_4-$ZnSO_4$)	NS	NS	2.7	17.8	NS	NS	.21

Table III. Effects of six zinc carriers on soybean tissue composition and yield. Pawnee study.

Treatment		Date 1 Leaf Composition Dry Wt.	Date 1 Leaf Composition ppm Zn	Date 1 Leaf Composition % P	Date 2 Leaf Composition Dry Wt.	Date 2 Leaf Composition ppm Zn	Date 2 Leaf Composition % P	Yield kg/ha
Control		3.8	22.0	.30	4.8	23.6	.28	1747
Zn EDTA	.28 kg/ha	4.2	31.1	.27	4.7	23.1	.24	2486
	.56	3.6	40.5	.24	4.9	21.7	.24	2486
	1.12	4.3	42.3	.25	4.8	37.6	.21	2419
	2.24	4.0	38.0	.24	4.9	33.4	.23	2956
Kemin	.28 kg/ha	4.7	34.1	.19	4.3	26.2	.24	2016
	.56	4.4	30.5	.25	5.0	28.9	.24	2553
	1.12	4.6	35.5	.23	4.7	27.5	.22	2284
	2.24	4.8	35.3	.26	4.6	28.1	.21	2755
$Zn-NH_3$	.28 kg/ha	3.6	28.5	.29	4.8	26.1	.22	2217
	.56	3.8	32.8	.25	5.0	31.9	.23	2755
	1.12	4.7	33.5	.23	4.7	22.3	.19	2956
	2.24	4.0	37.6	.27	4.8	35.1	.20	2352
Rayplex	.28 kg/ha	4.1	42.7	.26	3.8	32.7	.23	1276
	.56	3.7	36.6	.27	4.3	28.8	.25	1818
	1.12	5.1	36.7	.25	4.3	32.3	.24	1747
	2.24	4.3	36.2	.24	5.8	35.8	.23	3091
$ZnSO_4$	.56 kg/ha	3.9	30.1	.25	4.9	23.5	.20	2284
	1.12	3.8	32.9	.27	5.0	25.9	.25	2755
	2.24	4.0	41.9	.27	4.9	29.5	.21	2284
	4.48	4.3	35.3	.26	5.5	30.9	.24	2419
Zn frit	.56 kg/ha	3.7	22.9	.27	4.6	32.7	.23	2352
	1.12	4.5	29.2	.27	4.7	28.8	.24	2284
	2.24	3.7	29.6	.27	4.9	32.3	.24	2889
	4.48	5.0	34.9	.21	4.7	35.8	.23	2217
$LSD_{.05}$	Treatment	NS	NS	NS	NS	NS	NS	940
	Carrier	NS	5.9	NS	NS	NS	NS	NS
	Rate	NS	NS	NS	NS	NS	NS	NS

Table IV. Effects of seven zinc carriers on soybean tissue composition and dry weight. McPherson study.

Treatment		Dry Wt. (gm)	Leaf Zn Conc. (ppm)	Leaf P. Conc. % P
---		3.43	27.4	.27
Zn-EDTA	.28 kg/ha	3.76	28.9	.17
	.56	3.61	26.6	.17
	1.12	4.05	31.1	.23
	2.24	3.75	35.3	.21
Kemin	.28 kg/ha	3.29	30.5	.19
	.56	3.52	33.3	.19
	1.12	3.32	36.2	.22
	2.24	3.33	30.0	.21
$Zn\text{-}NH_3$	.28 kg/ha	3.48	29.8	.25
	.56	3.32	29.9	.25
	1.12	3.74	35.9	.22
	2.24	3.41	31.9	.21
NZN	.28 kg/ha	3.70	27.8	.24
	.56	3.61	28.5	.21
	1.12	3.98	30.6	.19
	2.24	3.14	28.3	.21
$ZnSO_4$	.56	3.72	29.7	.29
	1.12	3.71	29.1	.23
	2.24	3.78	37.3	.25
	4.48	3.89	36.0	.21
Zn frit	.56 kg/ha	3.69	30.2	.22
	1.12	3.77	36.9	.22
	2.24	3.95	35.8	.23
	4.48	3.64	34.2	.26
Rayplex	.28 kg/ha	3.01	27.6	.22
	.56	3.46	33.6	.27
	1.12	3.69	36.5	.25
	2.24	3.52	32.3	.24
$LSD_{.05}$	Treatment	NS	NS	NS
	Rate	NS	NS	NS
	Carrier	NS	NS	.03

Table V. Effect of six zinc carriers on plant composition and yield. Scandia study.

Treatment		Date 1		Date 2		
		Leaf Zn Conc. (ppm Zn)	Leaf P. Conc. (%P)	Leaf Zn Conc. (ppm Zn)	Leaf P. Conc. (%P)	Yield (kg/ha)
Control		19.1	.26	15.4	.22	672
Zn-EDTA	.28 kg/ha	26.4	.30	15.6	.22	920
	.56	22.5	.24	17.0	.21	1028
	1.12	21.2	.23	21.3	.20	577
	2.24	22.0	.31	17.5	.23	732
Kemin	.28 kg/ha	20.4	.25	16.3	.24	826
	.56	23.6	.23	18.0	.21	1337
	1.12	21.9	.22	17.3	.23	712
	2.24	19.9	.22	17.3	.23	712
$Zn-NH_3$	.28 kg/ha	23.0	.29	16.7	.22	1283
	.56	20.5	.29	14.9	.24	772
	1.12	24.7	.23	18.6	.20	833
	2.24	25.8	.30	17.4	.26	994
Rayplex	.28 kg/ha	19.8	.26	14.6	.23	987
	.56	20.5	.30	20.2	.25	1196
	1.12	20.7	.19	16.5	.19	638
	2.24	19.9	.18	17.3	.22	577
NZN	.28 kg/ha	26.4	.28	18.4	.25	1102
	.56	23.6	.29	16.2	.22	1142
	1.12	21.2	.20	15.3	.23	1202
	2.24	20.5	.30	16.2	.25	1296
$ZnSO_4$	.56 kg/ha	21.1	.31	14.2	.21	1377
	1.12	19.5	.26	18.3	.23	1310
	2.24	18.9	.26	13.1	.24	1001
	4.48	23.0	.25	24.9	.24	745
$LSD_{.05}$	Treatment	NS	.07	NS	NS	645
	Rate	NS	.03	NS	NS	NS
	Carrier	NS	NS	NS	NS	NS

Table VI. Effect of three zinc sources and two carriers on plant composition and yield. Republic study.

Zn Source	Rate (kg/ha)	Carrier	Leaf Zn Conc. (ppm Zn)	Leaf P. Conc. (%P)	Yield (kg/ha)
---	---	32-0-0	34.9	.27	1881
---	---	10-34-0	36.1	.29	1680
Kemin	.56	32-0-0	31.6	.29	2284
	1.12		34.8	.26	2284
	2.24		31.9	.25	3561
	4.48		36.1	.29	1881
	.56	10-15-0	39.4	.27	1545
	1.12		38.6	.27	1545
	2.24		35.1	.32	1747
	4.47		41.8	.30	1747
Zn EDTA	.56	32-0-0	33.3	.29	2419
	1.12		32.0	.25	1411
	2.24		26.5	.24	1545
	4.48		39.1	.29	1344
	.56	10-15-0	31.5	.31	1747
	1.12		33.3	.30	2016
	2.24		36.9	.30	1881
	4.48		37.1	.32	2217
Zn NH_3	.56	32-0-0	33.3	.25	1814
	1.12		34.8	.27	1612
	2.24		34.7	.25	1612
	4.48		40.7	.25	1276
	.56	10-15-0	34.7	.29	1209
	1.12		35.5	.29	1411
	2.24		34.4	.29	1881
	4.48		34.6	.28	1478
$LSD_{.05}$ Treatment			NS	NS	873
Zinc Source			NS	NS	336
Rate			2.7	NS	NS
Carrier			NS	0.02	NS
Source and Carrier			3.3	NS	818

Table VII. Effect of residual zinc and phosphorus applications on plant composition and yield.

Treatments (kg/ha)		Carriers		Yield (kg/ha)		Tissue Composition			
						1974		1975	
P_2O_5	Zn	P	Zn	1974	1975	%P	ppm Zn	%P	ppm Zn
0	0	--	--	1948	2352	.28	24.2	.35	32.0
44.8	0	APP	--	1948	2284	.23	15.6	.39	32.4
89.6	0		--	1948	2352	.31	17.0	.38	22.9
134.4	0		--	2083	2217	.38	20.2	.38	22.3
44.8	0	AOP	--	2352	2486	.29	15.5	.38	24.6
89.6	0		--	1612	2284	.33	14.1	.38	28.6
134.4	0		--	2016	2284	.33	10.1	.39	27.8
44.8	8.96	APP	Zn NH_3	2419	2553	.27	25.3	.38	36.3
89.6	8.96			2352	2486	.26	25.9	.37	40.0
134.4	8.96			2150	2553	.28	30.2	.40	48.2
44.8	8.96	AOP	Zn NH_3	1747	2419	.25	28.1	.36	44.7
89.6	8.96			2553	3360	.31	30.3	.38	42.2
134.4	8.96			2150	2217	.32	31.4	.35	42.4
$LSD_{.05}$	Treatment			NS	NS	NS	11.7	NS	11.7
	P_2O_5 Rate			NS	NS	.06	NS	NS	NS
	P Carrier			NS	NS	NS	NS	NS	NS
	Zn Rate			NS	NS	NS	4.9	NS	4.9

VARIETAL RESPONSE AND EFFECTS OF DIFFERENT SOURCES OF ZINC ON SOYBEAN GROWTH AND YIELD

by

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ABSTRACT

The response of seven soybean varieties to four rates of zinc application was studied in the greenhouse. All the varieties responded to zinc applications especially at increasing Zn rates as demonstrated by the increase in height and dry matter production over the controls. Zinc concentration in the tissues also increased but was about the same in all the varieties and was not significant at .05 level. There was a slight decrease in P concentration in some varieties due to Zn application but this interaction was not significant.

Several zinc carriers were studied both in the greenhouse and in the field. Materials included a chelate, by-product organics and inorganic sources. Weights per 12 trifoliates were only slightly affected by Zn application. Phosphorus concentration of the tissues were only slightly affected by the zinc treatments. Overall, Zn EDTA was the most efficient source of zinc in increasing the tissue zinc concentration and uptake, seed zinc concentration and yield. $Zn-NH_3$, Kemin and Rayplex were also comparatively good sources. Relatively higher rates of $ZnSO_4$ and ZnO (2.24 - 4.48 kg/haZn) were required for the same efficiency when compared with the chelate at .56 - 1.12 kg/haZn. $ZnCl_2$ and Zn frit 247 represented comparatively less efficient sources of zinc.

Zinc EDTA produced the highest seed yields but differences between carriers were not significant. Yield responses indicates that application rates around 2.24 kg Zn/ha may be

sufficient for soybeans.

In a comparison study of liquid ammonium polyphosphate (APP) and 32-0-0 suspension as possible transport agents for zinc using Kemin, $Zn-NH_3$ and Zn-EDTA, slightly higher yield was obtained with 32-0-0. In combination with Kemin, 32-0-0 depressed zinc concentration in the tissue. Kemin was significantly better than $Zn-NH_3$ but equal to Zn-EDTA in increasing tissue zinc concentration.

Residual soil Zn applied in the preceeding year was effective in increasing leaf zinc concentrations. Phosphorus applied either as AOP or APP without Zn depressed Zn concentration in plants with the severity increasing with increasing P rates. Zn application (8.96 kg^{Zn}/ha) eliminated this effect.

Results of this study indicate that soybeans will respond to zinc fertilization. Differences in varietal response may not be significant. Zn-EDTA is a good source of Zn but Kemin, $Zn-NH_3$ and $ZnSO_4$ are also good sources and could be considered since the yield is comparable. Applications of zinc especially at high rates can provide sufficient residual zinc in the following years.