ZINC OXIDE AND ZINC SULFATE AS ZINC SOURCES FOR *ZEA MAYS* AND *SORGHUM VULGARE*

by

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TABLE OF CONTENTS

Page

ACKNOWLEDGEMENTS vi

LIST OF FIGURES v

LIST OF TABLES vii

INTRODUCTION 1

REVIEW OF LITERATURE 3

Effect of Materials 3
Effect of Application Method. 8
Effect of Soil. 11
Effect of Soil Temperature. 12
Effect of Phosphorus. 14

METHODS AND MATERIALS. 16

Field Experiments 16

Growth Chamber Study. 25

Source of Materials 29

RESULTS AND DISCUSSION 31

Field Experiments 31

Comparisons on ZnO and $ZnSO_4$ as Sources of Zn for Corn. 31
Comparisons of $ZnSO_4$, ZnEDTA, and an Experimental Zn Source. 33
Comparisons of ZnO and $ZnSO_4$ for Grain Sorghum 35
Liquid versus Solid Sources of Zn for Grain Sorghum 35

Growth Chamber Experiments. 58

CONCLUSIONS. 65

Field Studies 65

Growth Chamber Study. 65

Page

LITERATURE CITED 67

VITA 71

APPENDIX 72

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LIST OF FIGURES

Figure		Page
1	Effects of two rates of Zn as ZnO and four sources of P on the P and Zn content of corn leaves. (Wallace County #1)	36
2	Effects of two rates of Zn as $ZnSO_4$ and three sources of P on the P and Zn content of corn leaves. (Wallace County #1)	37
3	Effects of two rates of Zn as ZnO and four sources of P and Zn content of corn leaves and grain. (Pawnee County #1).	38
4	Effects of two rates of Zn as $ZnSO_4$ and three sources of P on the P and Zn content of corn leaves and grain. (Pawnee County #1).	39
5	Effects of two rates of Zn as ZnO and four sources of P on the P and Zn content of corn leaves and grain. (Sedgwick County #1).	40
6	Effects of two rates of Zn as $ZnSO_4$ and three sources of P on the P and Zn content of corn leaves and grain. (Sedgwick County #1)	41
7	Effects of two sources of Zn, ZnO and $ZnSO_4$, and three sources of P on P and Zn content of corn leaves and grain. (Pottawatomie County).	42
8	Effects of two rates of Zn and ZnEDTA and two sources of P on P and Zn content of corn leaves. (Wallace County #2).	43
9	Effects of two rates of Zn as $ZnSO_4$ and two sources of P on P and Zn content of corn leaves. (Wallace County #2).	44
10	Effects of two rates of Zn as Coop-Zn and two sources of P on P and Zn content of corn leaves. (Wallace County #2).	45
11	Effects of two rates of Zn as ZnEDTA and two sources of P on P and Zn content of corn leaves and grain. (Pawnee County #2).	46
12	Effects of two rates of Zn as $ZnSO_4$ and two sources of P on P and Zn content of corn leaves and grain. (Pawnee County #2).	47

LIST OF FIGURES (Continued)

Figure — Page

13 - Effect of two rates of Zn as Coop-Zn and two sources of P on P and Zn content of corn leaves and grain. (Pawnee County #2). 48

14 - Effect of two rates of Zn as ZnEDTA and two sources of P on P and Zn content of corn leaves and grain. (Sedgwick County #2). 49

15 - Effect of two rates of Zn as $ZnSO_4$ and two sources of P on P and Zn content of corn leaves and grain. (Sedgwick County #2). 50

16 - Effect of two rates of Zn as Coop-Zn and two sources of P on P and Zn content of corn leaves and grain. (Sedgwick County #2). 51

17 - Effects of two sources of Zn as ZnO and $ZnSO_4$ and three sources of P on P and Zn content of grain sorghum leaves and grain. (Stafford County #2) . . . 52

18 - Effects of 5°C incubation temperature, 4 sources of Zn, 2 soil types, and 2 growing temperatures on the Zn and P content of corn plants grown in a growth chamber. 61

19 - Effects of 30°C incubation temperature, 4 sources of Zn, 2 soil types, and 2 growing temperatures on the Zn and P content of corn plants grown in a growth chamber. 62

20 - Effects of 4 sources of Zn, 2 soil types, 2 incubation temperatures, and 2 growing temperatures on the dry weight of corn plants grown in a growth chamber 63

LIST OF TABLES

Table		Page
1	Soil analysis of experimental sites	17
2	Treatments used in Comparisons of Liquid and Solid Sources of Zinc for Irrigated Grain Sorghum, Stafford Co., 1969.	18
3	Treatments used in Comparison of Zinc and Phosphorus Sources for Irrigated Corn (Pottawatomie Co.) and Irrigated Grain Sorghum (Stafford Co.), 1969	19
4	Treatments Employed in Comparisons of Zinc and Phosphorus Carriers for Irrigated Corn in Wallace (1969), Sedgwick (1970), and Pawnee Counties (1970).	21
5	Treatments Employed in Comparisons of Zinc and Phosphorus Carriers for Irrigated Corn in Wallace (1969), Sedgwick (1970), and Pawnee Counties (1970)	22
6	Crop, Herbicide, Insecticide, and Row Spacing for Studies, 1969-1970	24
7	Plant Nutrient Concentrations Used in Growth Chamber Study.	27
8	Zinc and Temperature Variables Used in Growth Chamber study.	28
9	Yield of Irrigated Corn on Three Experimental Sites in Kansas. Yield in kg/ha. Comparisons of Zn sources and P sources.	53
10	Effects of ZnO and $ZnSO_4$ and three sources of P on the yield of irrigated grain sorghum and corn	54
11	Effect of three sources of Zn and two sources of P on the yield of irrigated corn.	55
12	Nutrient content of leaves and grain of irrigated grain sorghum as affected by source, form, and method of application. Stafford Co., 1969	56
13	Yield of irrigated grain sorghum as affected by source, form, and method of Zn application. Stafford Co., 1969	57

LIST OF TABLES (Continued)

Table		Page
14	Uptake of P and Zn by corn plants grown 34 days in growth chambers at two different growing temperatures and two soil types.	64
I	Effects of P carriers, Zn carriers, and rates of Zn application of the yield and composition of irrigated corn, Wallace county, 1969	73
II	Effects of P carriers, Zn carriers, and rates of Zn application on the yield and composition of irrigated corn, Pawnee county, 1970.	74
III	Effects of P carriers, Zn carriers, and rates of Zn application on the yield and composition of irrigated corn, Sedgwick county, 1970.	75
IV	Comparisons of three forms of Zn, and two forms of P on the yield and composition of irrigated corn, Wallace county, 1969	76
V	Comparison of three forms of Zn, and two forms of P on the yield and composition of irrigated corn, Pawnee county, 1970.	77
VI	Comparisons of three forms of Zn, and two forms of P on the yield and composition of irrigated corn, Sedgwick county, 1970.	78
VII	Comparisons of two forms of Zn and two forms of P on the yield and composition of irrigated corn, Pottawatomie county, 1969	79
VIII	Comparisons of two forms of Zn and two forms of P on the yield and composition of irrigated grain sorghum, Stafford county, 1969.	80
IX	Effects of P form, Zn carriers, and rates of Zn application on the yield and composition of irrigated grain sorghum, Stafford county, 1969	81
X	Nutrient content of corn plants grown 34 days in growth chambers at 2 different growing temperatures and on an acid soil type.	83
XI	Nutrient content of corn plants grown 34 days in growth chambers at 2 different growing temperatures and on a calcareous soil.	84

INTRODUCTION

Research conducted by the Department of Agronomy at Kansas State University and other midwest institutions has shown the need for zinc on a sizeable acreage of irrigated corn and grain sorghum. These problems have usually appeared on land that has been leveled for furrow irrigation as this sometimes requires the removal of considerable amounts of topsoil which includes much of the soil organic matter and available zinc.

Most of the work to date in Kansas, as well as other plains states, has employed $ZnSO_4$ as the standard material to correct zinc deficiencies. Responses to both broadcast and banded applications of Zn in this form have been good (Kansas Fertilizer Handbook, 1969, 1970). Recently, however, the need for information pertaining to the effectiveness of ZnO has arisen because of the increased use of this material by fertilizer manufacturers. The oxide is about equal in cost to $ZnSO_4$ but contains about 72-80% Zn as opposed to 36% Zn in $ZnSO_4$. Zinc oxide is available as a finely divided powder, 200 mesh, and mixes easily with other solid or liquid materials.

Because of the acid solubility of ZnO, information is needed in Kansas, concerning the availability of ZnO on irrigated soils high in pH and free carbonates. Since much of the irrigated soil in Kansas is located on soils of this type, the need for comparisons of ZnO and $ZnSO_4$ is even more important.

Much of the Zn research (Adriano, 1970, Webb, 1970) at Kansas State University has been related to the P-Zn relationships reported by several other experiment stations in this country. Prior work

has shown that banded applications of P in the absence of sufficient Zn may produce even more severe Zn deficiencies than those occurring in plants that received no P. Further, field and growth chamber investigations have indicated that ammonium polyphosphates may induce even more severe Zn deficiencies than ammonium orthophosphates (Webb, 1970). Ortho and poly-phosphates may induce different soil pH values in the area of application so it is desirable to know what additional affect P carrier may exert on the relative availability of ZnO and $ZnSO_4$.

Based on the need for information in these areas, an investigation was initiated to: 1) compare ZnO and $ZnSO_4$ as sources of Zn for irrigated corn and grain sorghum both in the field and growth chamber; 2) observe possible interactions between Zn sources and types of P carriers; 3) study the effect of broadcast ZnO and $ZnSO_4$ in increasing the Zn uptake by corn and grain sorghum plants; 4) evaluate applications of ZnO and $ZnSO_4$ in fluid fertilizers.

REVIEW of LITERATURE

Early History

The value of Zn as a plant nutrient and also its toxic effects are not new discoveries although the extensive use of Zn salts for nutrient purposes on crops in the field dates from about 1931. Some of the earliest references to the value of Zn as a nutrient occur in the literature on Aspergillus spp. about 1900. Javillier started working with Zn about 1907 and by 1912 he recommended the use of Zn as a fertilizer material for corn and some other crops. However, not until the work conducted in 1926 and 1928 by Sommer and Lipman was reported was Zn widely accepted as a plant nutrient (Camp, 1945).

Effect of Materials

Zinc deficiencies in corn, grain sorghum, and other field crops have been reported with increasing frequency in several states in recent years (Lindsay and Romsdal, 1965; Jackson, Hay, and Moore, 1967; Vinande, et al., 1967; Wear and Evans, 1968; Travis and Ellis, 1965). In all, 36 states have reported Zn deficiencies on at least one crop (Boehle and Lindsay, 1969). All indications point to a continuation of this trend as a result of the increased use of lime and higher analysis fertilizers and subsequent higher yields.

Much research has been conducted on the relative efficiency of various Zn carriers for crop production. Boawn, Viets, and Crawford (1954) tested eight different Zn sources; Zn-EDTA,[1] stripping acid residue (11.6% Zn), ZnO, $Zn_3(PO_4)_2$, $ZnCO_3$, blast

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[1] EDTA is an ethylene diamine tetracetate chelate

furnace slag[2] (17% Zn), zinc frits, (18.4% and 4% Zn), and Zn granules (5% Zn). Zinc sulfate and checks were included as criteria for evaluation. They reported that Zn utilization was greater from the chelate than from any other material including $ZnSO_4$. Uptake from the stripping acid residue, ZnO, $Zn_3(PO_4)_2$ and $ZnCO_3$ was comparable and of about the same magnitude as from $ZnSO_4$. Blast furnace slag was ineffective and there was no utilization from the three frit materials. The zinc granules were equal to or only slightly less effective than $ZnSO_4$.

Boawn, et al. (1954) reported that where the plots didn't receive N 3.5 times as much Zn was absorbed as the chelate form as from the inorganic forms and 2.4 times greater on the N treated plots. This increased uptake was attributed to the plants' being able to absorb more of the chelate because the inorganic soluble forms of zinc were rapidly converted to exchangeable or acid-soluble forms, both of which were considered to be only partially available for root absorption. Boawn and co-workers felt that the EDTA complex would remain completely dissolved in the soil solution and would act as a mobile element and move to all parts of the soil mass. They felt $ZnSO_4$ and ZnO would be immobilized and subject only to absorption through root contact with the soil particles a premise which agreed with the postulates of Brown, Krantz, and Martin (1962). However, in 1955, Alben made the interesting observation that zinc chelate was ineffective on alkaline soils.

Anderson (1964) tested several Zn sources, primarily chelates,

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[2]Both stripping acid residue and slag are smelter by-products.

in eastern Colorado both in field and greenhouse trials and found that the chelated Zn sources were generally much more effective at low rates than were the $ZnSO_4$ fertilizers. EDTA tended to alleviate the deficiency at 1.12 kg/ha Zn whereas $ZnSO_4$ and Zn-Rayplex[3] required 3.36 kg/ha Zn in a greenhouse study where the Zn was applied to simulate band application. In this study Anderson concluded that the effectiveness of Zn sources in calcareous soils was EDTA $ZnSO_4$ Rayplex with Rayplex losing Zn from solution most rapidly.

Judy (1967) compared $ZnSO_4$ and ZnEDTA in experiments with pea beans (Phaseolous vulgaris L.). In the field experiments where ZnEDTA was applied at rates as high as 1.8 kg/ha Zn and $ZnSO_4$ at 3.36 and 4.48 kg/ha the Zn uptake and yield was higher with ZnEDTA treatments. In a greenhouse study where Zn was applied at rates from 5.6 to 53.7 kg/ha, Anderson observed that more Zn was taken up and concentrated in the youngest growth portions of plants grown on ZnEDTA than in plants grown on $ZnSO_4$.

Experiments were conducted in Michigan during 1967 (Vinande, et al., 1967) to study the effectiveness of several Zn carriers, Zn interactions with other elements (Fe and P), and methods of Zn application. The researchers found that when Zn was applied at a 1:5 ratio, 0.67 kg/ha Zn from chelate and 3.36 kg Zn/ha from inorganic Zn carriers, chelate sources were as effective as were inorganic forms of Zn such as ZnO and $ZnSO_4$. The relatively insoluble forms of Zn can be effective carriers to correct Zn deficiency and the residual effect of Zn broadcast and plowed under will remain

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[3]Polyflavanoid metal complex.

at least three years according to Jackson, et al. (1967). Zinc at 4.47 kg/ha as $ZnSO_4$ gave maximum statistically significant yields to sweet corn (Jackson, et al., 1967).

Shulka and Morris (1967) studied several sources of Zn for corn. They found no significant differences among the Zn sources in their effect on corn growth on a Red Bay silt loam (0.29ppm available Zn extracted by 0.6N acetic acid) but recorded higher yields of corn on a Norfolk loamy fine sand (0.35ppm available Zn extracted by 0.6N acetic acid) produced by $ZnSO_4$ than by the other sources of Zn they used, especially when lime was applied. Shulka and Morris attributed the differential response of Zn sources obtained on the two soils to the slight Zn deficiency on the Red Bay soil which was corrected sufficiently by any of the Zn sources. Larger amounts of Zn were required to correct the deficiency on the Norfolk soil. Plant Zn content and Zn uptake were increased much more by $ZnSO_4$ and ZnO than by organic or chelate Zn. They reported equal effect of $ZnSO_4$ and ZnO on the unlimed Norfolk soil and found $ZnSO_4$ to be superior to ZnO on the limed soils. Shulka and Morris applied lower rates of total Zn as the chelated and organic sources than as ZnO and $ZnSO_4$. They felt that equivalent rates of organic materials would have indicated no differences among sources but the high cost of the organic forms of Zn would make it uneconomical to use these sources to supply Zn in mixed fertilizers.

Field experiments conducted in central and western Kansas (Cherian, 1969) showed that applications of macronutrients and/or micronutrients increased the amount of micronutrients in the grain and leaves, but the degree of increase of the micronutrients varied

with soil type. One kilogram of Rayplex-Zn was approximately equal to three kilograms of Zn supplied as $ZnSO_4$ so far as the Zn uptake of the sorghum plant was concerned.

Wallace and Romney (1970), working with a Dinuba fine sandy loam soil known to be Zn deficient, reported that ZnEDTA at 1.12 kg/ha rate increased the Zn content of sweet corn more than did 11.2 kg/ha of $ZnSO_4$.

Schnappinger, Martens, and Hawkins (1969) reported on the effects of various rates of ZnEDTA and $ZnSO_4$. They found that the yield of corn was increased by broadcast applications of 7 and 14 kg Zn/ha as $ZnSO_4$ and 4.48 kg Zn/ha as ZnEDTA, but 2.24 kg Zn/ha as ZnEDTA was inadequate. They noted higher yields where $ZnSO_4$ was broadcast at a rate of 14 kg/ha Zn than where ZnEDTA was broadcast at a rate of 4.48 kg Zn/ha. This they attributed to the very high available P content (98.2 ppm) and slightly alkaline pH (7.2) of the Litz silt loam soil they used (1.9 ppm available Zn).

Schnappinger and co-workers also noted on another soil, Norfolk loamy fine sand (P content 96.0 ppm. pH 6.3, 1.2 ppm available Zn), yield was increased by broadcast applications of 7 and 14 kg Zn/ha as $ZnSO_4$ and 2.24 kg Zn/ha as ZnEDTA. A lower rate of banded ZnEDTA of 1.12 kg Zn/ha also increased yield. Their data show that banded ZnEDTA was more effective in supplying Zn to corn plants than broadcast ZnEDTA. They did not record an increase in Zn in the leaf tissue with either the sulfate or chelate on the Norfolk soil.

Norvell and Lindsay (1969) found that the EDTA chelate was most stable in the soil with a pH between 6.1 and 7.3 at lower

pH the Zn was displaced by iron while at the higher pH the metal was displaced by calcium. Many comparative studies have established that chelates are superior to inorganic forms of Zn in some instances. However, the high cost of the chelated Zn compounds, coupled with the higher analysis of either the oxide or the sulfate, and the generally excellent preformance of the inorganics have brought these inorganic Zn sources to the foreground.

Effect of Application

With the increasing occurrence of Zn deficiency in the field it is essential to know how to apply Zn. One of the major problems of applying micronutrients on a field basis is getting uniform distribution of the nutrient. Application with macronutrient fertilizers may be the most economical and effective means to supply micronutrients to crops. For example, Zn recommendations usually range from 3.34 to 22.2 kg/ha Zn. Spreading this amount of material would be difficult.

Mortvedt and Giordano (1967a) investigated the application of Zn with macronutrient fertilizers. They concluded that the effectiveness of the applied Zn depends on the nature of the Zn-fertilizer reaction products and on their distribution in the soil. When $ZnSO_4$ is the Zn source, ammonium nitrate (AN), triple super phosphate (TSP), monoammonium phosphate (MAP), ammonium polyphosphate (APP), and urea were satisfactory macronutrient carriers. However, the incorporation of $ZnSO_4$ in some materials resulted in poor physical condition of the fertilizer so that they would not be suitable for field application.

Mortvedt and Giordano (1969) reported that TSP and APP are the most effective macronutrient carriers of ZnO. In general, ammoniated fertilizers were inferior as Zn carriers because they react with the Zn to form insoluble products either during the manufacturing process or at the granule site after application (Mortvedt, 1968). Hossner and Blancher (1969) attributed this to pH changes at or near the granule and found that as the pH increased the Zn residue decreased. Work by Elgawhay, Lindsay, and Kemper (1970) also confirms this.

Mortvedt and Giordano (1967b) found chelated Zn sources to be compatible with most fertilizers, but said precautions should be taken so that these organic compounds are not decomposed during the manufacturing process. Richards (1969) also concluded that both the Zn source and conditions of incorporation have important effects on the level of water soluble Zn.

In another study, Giordano and Mortvedt (1966) worked on movement of Zn from granules in the soil. They found that movement of Zn from either the oxide or the sulfate in concentrated superphosphate extended to 1 cm from the granule the first day but did not move beyond this distance even after four weeks. After one week Zn had moved 2 cm from ammonium nitrate (Mortvedt and Giordano 1967b). When they incorporated an equal amount of ZnO in soil granules the extent of movement was 0.5 cm from the granule. This, they explained, resulted from the greater water solubility of $ZnSO_4$ than of ZnO.

Giordano and Mortvedt, 1966, showed that granular macronutrient fertilizers containing Zn are not as effective as finely ground Zn

sources mixed alone with the soil, especially when applied at low rates. Mortvedt and Giordano found, as did Penas (1966), that ZnO was equal to $ZnSO_4$ when finely ground and mixed alone or in concentrated superphosphate and APP granules but was poorer when applied with AN. However, previous work by Terman, Allen, and Bradford (1966) indicated that AN was a better carrier that concentrated superphosphate or APP when $ZnSO_4$ was the source. Work at TVA (Mortvedt and Giordano, 1967c) has shown that when ZnO is added to AN products of rather low solubility can form. Despite the low solubility of these products they were still more effective as sources of Zn than ZnS (Giordano and Mortvedt, 1966).

Mortvedt and Giordano (1967a) compared the effects of ZnO as applied in liquid and granular fertilizers. They observed that crop response was greater with mixed than with band or spot placement. They attributed the greater response to the better distribution of Zn throughout the soil. Results of their study revealed that, because of the low solubility of Zn, crop response was related to the volume of Zn affected soil. Because most of the fertilizers used in this study were neutral or basic the carrier may have had a greater influence on the applied ZnO when band applied. This would tend to reduce the solubility of the applied Zn.

The effectiveness of various ortho and polyphosphate fertilizers as Zn carriers were compared by Mortvedt and Giordano (1967a). When mixed with the soil, the liquid orthophosphates were as effective as the polyphosphate solutions. However, the ortho material was much less effective when band applied because the solubility of ZnO in the ortho solutions was very low. Granular ammonium

tripolyphosphate was superior to monocammonium phosphate as a carrier of ZnO with either placement method.

Giordano, Mortvedt, and Papendick (1967) reported on Zn as affected by source and placement of nitrogen. They concluded that the source of N influences the responses of plants to Zn primarily by altering the soil pH. Because of this, they concluded, application of Zn with sources such as anhydrous ammonia, with an alkaline reaction, would not appear to be as effective in correcting Zn deficiency. They went on to say that if the alkaline zone were broken mechanically to distribute the Zn throughout the soil then anhydrous ammonia may be acceptable as a Zn carrier.

There is evidence that the N carrier effect of Zn uptake can vary according to the plant species involved (Boawn, et al., 1960). Their data show that Zn uptake by both sorghum and potatoes was influenced to a marked degree by changes in soil pH resulting from the various N carriers used. Ammonium sulfate increased Zn uptake as compared to $Ca(NO_3)_2$. In contrast, the soil changes induced by their treatments had only slight influence on the amount of Zn taken up.

Effect of Soil

Zinc deficiencies have been reported in many states: Kansas' deficiencies are most commonly reported on corn and grain sorghum. These deficiencies normally occur only on sites which have had the organic matter-containing "A" soil horizon removed during leveling. Travis and Ellis (1965) tested 78 soil cores collected on calcareous and non-calcareous soils from northeastern, north central, and

western Kansas. Their data indicate the available Zn concentration is associated with the organic fraction of the soil profile and varies inversely with the free carbonate concentration. Ravikovitch, Margolin, and Navrot (1968) also noted this effect on soils high in $CaCO_3$ in Israel. Both studies indicated that under alkaline conditions, due to the presence of free carbonates, available Zn is converted to forms unavailable for plant absorption.

Clark and Graham (1968) found that as pH increased in a Ca-H system, both adsorption and precipitation cause the concentration of Zn to decline, it first precipitates as $Zn(OH)_2$ and eventually as calcium zincate. They noted that at high pH the uptake of Zn by plants was limited by its rate of transfer to root surfaces.

The correlation of the soil Zn content with the organic matter and clay content suggest that these two soil components are primarily responsible for the retention of Zn in calcareous soils (Udo, Bohn, and Tucker, 1970). These researchers found that Zn absorption and CEC were not so closely related as Matsuda and Ikuta (1969) thought as Zn^{+2} was not absorbed as a classical exchangeable ion. The cations competing with the Zn were primarily calcium and magnesium from the cation exchange complex and the dissolution of soil carbonates. These sources yielded much higher concentrations of Ca^{+2} and Mg^{+2} than those of the added Zn^{+2}.

Effect of Soil Temperatures

Of interest to workers is the effect of temperature on Zn uptake. It was noted that Zn deficiency symptoms often seen in field crops during the early spring frequently disappeared by mid-

season (Lindsay and Romsdal, 1965). Bauer and Lindsay (1965) conducted a short term growth chamber experiment to study the effects of temperature. There was some question as to this effect. They set out to determine if temperature was affecting uptake of Zn or was some other nutrient or factor of plant growth the answer. They found evidence that available Zn was in limited supply as the Zn was down in the 7 to 8 ppm range in the tops. If the incubation temperature was raised to 43°C for 1 week twice as much available Zn was present as was present in soil that had been incubated at 5°C for 6 weeks. As the incubation temperatures were raised both uptake and yield were increased. Increased uptake of Zn with increasing soil temperature was also noted by Wallace, et al., (1969) on four different crops. They also noted that other micronutrients tended to be increased in the plants by Zn.

Ellis, Davis, and Thurlow (1964) found that a decrease from 24°C to 13°C decreased yield and Zn concentrations. Total Zn was reduced from 310 to 73 μg per pot for corn grown on Wisner clay loam.

Bauer and Lindsay (1965) postulated that since the release of available quantities of Zn was found only at higher temperatures, the soil microbial population might very well be involved. Zinc is present in both organic and inorganic forms in the soil. In the organic form, Zn is likely present as a part of proteins since it is a constituent of numerous enzyme systems (Nason, 1958).

Several release mechanisms may work to free organic Zn. Mineralization of organic compounds, release of natural chelating agents during decomposition of organic residue, and also the increase in CO_2 pressure with its increase of H^+ ion activity. Both of these

processes could increase the solubility of Zn bearing minerals. In calcareous soils, Zn occluded within solid phase $CaCO_3$ could be solubilized in localized zones near sites of organic matter decomposition. Work done by Martin, McLean, and Quick (1965) showed the effect of several rates of phosphorus with and without Zn upon tomato plants. Results on soil with moderately low (0.9ppm) dithizone extractable Zn show P to induce Zn deficiency symptoms at 10°C and 16°C but not at 21°C and 27°C although some growth differences attributable to Zn occurred at the higher temperatures. On soil from an acutely Zn deficient area (0.1ppm), P induced Zn deficiency was observed at all temperatures.

Effect of Phosphorus

Phosphorus can depress corn yields when soil Zn levels are low (Adriano, 1970, Adriano and Murphy, 1970). When higher Zn levels were applied with the P, however, grain yields increased (Ganiron, et al., 1969, Adriano and Murphy, 1970). Their studies suggested that the interaction between P and Zn occurred in the plant and not in the soil.

Melton, Ellis, and Doll (1970) noted that on some Michigan soils, high P levels increased Zn response of beans and on others depressed the response. They reported that high levels of soil P are more likely to induce or increase Zn deficiency on soils testing above pH 7.0 which contain free $CaCO_3$. Martin, et al., (1965) reported that P applications were observed to reduce Zn concentrations in tomato leaves while Zn applications tended to reduce P concentrations.

Wantanbe, Lindsay, and Olsen (1965) warned that the maintenance of a proper balance of the nutrients appears to be necessary for normal plant growth. In susceptible plants, if more than one essential mineral is near the critical level of availability, the addition of any one without regard for the other may have an adverse effect on the yield. The nature of resistance to P induced Zn deficiency is still obscure, but appears to be under genetic control (Halim, Wassom, and Ellis, 1968).

METHODS AND MATERIALS

Field Experiment

In 1969 three sites that had been leveled for furrow irrigation were selected as experimental areas (Table 1). The fertilizer treatments for the first study at the Stafford county site involved comparisons of four Zn carriers (Table 2) supplied in fluid form with two methods of application. The Zn carriers included $ZnSO_4$, ZnO, each applied at rates of 4.5 and 8.9 kg/ha Zn, and two lignosulfate Zn carriers, each applied at rates of 1.1 and 2.2 kg/ha Zn. The two methods of application included knifing the Zn containing fluid fertilizer into the soil with a simultaneous application of anhydrous ammonia in close contact with the fluid material. The second method of application involved spraying the fluid on the soil and incorporating it during seedbed preparation.

The second study in Stafford county investigated the effect of coating ZnO and $ZnSO_4$ on dry macronutrient materials (Table 3). Three phosphate carriers were involved, triple superphosphate, TSP, (0-19.8-0)[4], ammonium orthophosphate, MAP, (11-21.1-0), and ammonium polyphosphate, APP, (15-26.4-0), at a rate of 39 kg/ha P. The Zn carriers in all cases were supplied as a coating on a P carrier, or as a coating on ammonium nitrate if the treatment did not involve P, and applied at the rate of 8.9 kg/ha Zn.

The materials were applied prior to seeding and incorporated during tillage. Both of these 1969 studies received 280 kg/ha N,

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[4](0-19.8-0) denotes 0% N, 19.8% P, and 0% K, by weight.

Table 1. Soil analysis of experimental sites.

County	pH	Organic Matter %	Avail. P kg/ha	Exch. K kg/ha	Avail. Zn ppm
		1969			
Pottawatomie	7.9	1.1	13.3	158	2.8
Stafford #1	6.3	0.8	12.8	381	1.3
Stafford #2	6.6	0.8	7.4	317	1.3
Wallace #1	7.8	1.2	11.8	464+	2.7
Wallace #2	7.6	1.5	18.2	464+	3.0
		1970			
Pawnee #1	7.1	1.2	7.9	325	1.7
Pawnee #2	6.5	1.3	17.8	464	7.9
Sedgwick #1	6.7	0.9	10.8	139	1.6
Sedgwick #2	6.6	0.9	11.8	148	1.3

Table 2. Treatments used in Comparisons of Liquid and Solid Sources of Zinc for Irrigated Grain Sorghum, Stafford County, 1969.

Nutrient Rates		Zinc Carrier	Form	Application Method
Zn kg/ha	P kg/ha			
0	39	-	10-34-0	Broadcast
0	39	-	10-34-0	Knifed
4.5	39	ZnO	Suspension	Knifed
8.9	39	ZnO	Suspension	Knifed
4.5	39	$ZnSO_4$	Suspension	Knifed
8.9	39	$ZnSO_4$	Suspension	Knifed
1.1	39	Reax	10-34-0-mix	Knifed
2.2	39	Reax	10-34-0-mix	Knifed
1.1	39	Key-el	10-34-0-mix	Knifed
2.2	39	Key-el	10-34-0-mix	Knifed
4.5	39	ZnO	Suspension	Broadcast
8.9	39	ZnO	Suspension	Broadcast
4.5	39	$ZnSO_4$	Suspension	Broadcast
8.9	39	$ZnSO_4$	Suspension	Broadcast
1.1	39	Reax	10-34-0-mix	Broadcast
2.2	39	Reax	10-34-0-mix	Broadcast
1.1	39	Key-el	10-34-0-mix	Broadcast
2.2	39	Key-el	10-34-0-mix	Broadcast
4.5	39	ZnO	APP-ZnO Solid	Broadcast
8.9	39	ZnO	APP-ZnO Solid	Broadcast
4.5	39	$ZnSO_4$	APP-$ZnSO_4$ Solid	Broadcast
8.9	39	$ZnSO_4$	APP-$ZnSO_4$ Solid	Broadcast

Table 3. Treatments used in Comparison of Zinc and Phosphorus Sources for Irrigated Corn (Pottawatomie Co.) and Irrigated Grain Sorghum (Stafford Co.), 1969.

Nutrient Rates		Carrier	
P kg/ha	Zn kg/ha	P	Zn
0	0	-	-
0	8.9	-	ZnO
0	8.9	-	$ZnSO_4$
39	0	AOP	-
39	0	APP	-
39	0	TSP	-
39	8.9	AOP	ZnO
39	8.9	AOP	$ZnSO_4$
39	8.9	APP	ZnO
39	8.9	APP	$ZnSO_4$
39	8.9	TSP[a/]	ZnO
39	8.9	TSP[a/]	$ZnSO_4$
39	8.9	TSP[b/]	ZnO

a/ Formulated by TVA.

b/ Formulated by American Cyanamid Co.

as anhydrous ammonia and ammonium-N supplied by P materials. All plots also received 92.9 kg/ha K. The second study was duplicated on a slightly basic (pH 7.9) soil in Pottawatomie county (Table 3).

Two other studies were under investigation in 1969 in Wallace county. The first of these concerned ZnO and $ZnSO_4$ in combination with four P carriers, (Table 4) MAP, TSP, APP, and DAP[5]. The P was applied at a rate of 39 kg/ha P and two rates of Zn, 4.5 and 8.9 kg/ha Zn were used. The Zn was coated onto the P fertilizers or on ammonium nitrate in cases where no P applications were used. These materials were applied preplant and incorporated during tillage.

The second study at the Wallace county site (Table 5) involved three Zn carriers; $ZnSO_4$, ZnEDTA[6], and an experimental Zn compound formulated by Farmland Industry which will hereafter be called "Coop" Zn. Two sources of P, solid AOP, and liquid APP were included as another variable. Both of these areas received 280 kg/ha N as anhydrous ammonia and/or with P carriers and 92.9 kg/ha K. The dry materials were broadcast and the liquids were sprayed on the soil and incorporated during seedbed preparation.

In 1970 the two Wallace county studies were duplicated at two different locations, one in Sedgwick county on a loamy sand and the other in Pawnee county on a silt loam soil.

The design of the investigations was randomized complete block with four replications at all locations except Sedgwick county

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[5]DAP - Diammonium phosphate (18-20.2-0)

[6]EDTA is Zn-ethylene diamine tetracetic acid.

Table 4. Treatments Employed in Comparisons of Zinc and Phosphorus Carriers for Irrigated Corn in Wallace (1969), Sedgwick (1970), and Pawnee Counties (1970).

Nutrient Rates		Carriers	
P kg/ha	Zn kg/ha	P	Zn
0	0	-	-
0	4.5	-	ZnO
0	8.9	-	ZnO
0	4.5	-	$ZnSO_4$
39	0	AOP	-
39	0	APP	-
39	0	TSP	-
39	4.5	AOP	ZnO
39	8.9	AOP	ZnO
39	4.5	AOP	$ZnSO_4$
39	8.9	AOP	$ZnSO_4$
39	4.5	APP	ZnO
39	8.9	APP	ZnO
39	4.5	APP	$ZnSO_4$
39	8.9	APP	$ZnSO_4$
39	4.5	TSP	ZnO
39	8.9	TSP	ZnO
39	4.5	TSP	$ZnSO_4$
39	8.9	TSP	$ZnSO_4$
39	4.5	TSP[a/]	ZnO
39	8.9	TSP[a/]	ZnO
39	4.5	DAP[a/]	ZnO
39	8.9	DAP[a/]	ZnO

a/ Materials provided by American Cyanamid, all others provided by TVA.

Table 5. Treatments Employed in Comparisons of Zinc and Phosphorus Carriers for Irrigated Corn in Wallace (1969), Sedgwick (1970), and Pawnee Counties (1970).

Nutrient Rates		Carrier	
P kg/ha	Zn kg/ha	P	Zn
0	0	-	-
59	0	APP	-
59	0	AOP	-
0	1.1	-	EDTA
0	4.5	-	$ZnSO_4$
0	4.5	-	Coop
0	2.2	-	EDTA
0	8.9	-	$ZnSO_4$
0	8.9	-	Coop
59	1.1	APP	EDTA
59	4.5	APP	$ZnSO_4$
59	4.5	APP	Coop
59	2.2	APP	EDTA
59	8.9	APP	$ZnSO_4$
59	8.9	APP	Coop
59	1.1	AOP	EDTA
59	4.5	AOP	$ZnSO_4$
59	4.5	AOP	Coop
59	2.2	AOP	EDTA
59	8.9	AOP	$ZnSO_4$
59	8.9	AOP	Coop

where three were utilized. Nine meter, four row plots were established. Crops were seeded, herbicide and insecticide applied (Table 6) and irrigation was provided as needed.

The first fully extended leaf from the top at the 7-8 leaf stage was collected to make up the early tissue sampling for both corn and grain sorghum, (date 1). Leaves directly below and immediately opposite the ears of tasseling plants comprised the second sample of corn, first fully extended leaves of grain sorghum comprised the late tissue samples, (date 2). All plant materials were randomly selected from the two center rows of each plot. The plant materials were briefly rinsed in washes of distilled water then deionized water, and then oven-dried at 60°C for at least 72 hours. The samples were ground through a Wiley mill using stainless steel knives and a stainless steel 2 mm screen.

One gram portions of the plant samples were dry ashed at 200°C for 1 hour and 550°C for 2½ hours. The ash was dissolved in 0.1N HCl and allowed to stand overnight. The mixture was filtered through Whatman 42 filter paper and made to 50 ml volume. Zinc was determined on this stock solution by atomic absorption spectrophotometry using a Perkin-Elmer model 303 instrument.

The vanadate-molybdate yellow procedure[7] of Chapman and Pratt (1961) was used for the determination of P. A 5 ml aliqout of the original sample solution was transferred to a 50 ml volumetric

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[7] Made by dissolving 22.5 g of $(NH_4)_6Mo_6O_{24}.4\ H_2O$ in 400 ml of deionized water. To this solution, 1.25 gm of NH_4VO_3 dissolved in 300 ml of boiling water, was added and cooled. This mixture was made to one liter by adding 250 ml of concentrated HNO_3 and deionized water.

Table 6. Crop, Herbicide, Insecticide, and Row Spacing for Studies, 1969-1970.

County	Crop and Variety	Herb.	Insect.	Row Spacing
Pottawatomie	White Corn (*Zea mays* L.) DeKalb X1-390	Ramrod-Atrazine	Aldrin	97 cm
Stafford	Grain Sorghum (*Sorghum Vulgare Pers*) N-K 225	Milogard	-	76 cm
Wallace	Corn DeKalb XL-347	-	Thimet 15G	76 cm
Pawnee	Corn Pioneer 3306	Atrazine	Thimet	76 cm
Sedgwick	Corn NC+ 775X	Simazine	Thimet	76 cm

flask and 10 ml of the ammonium vanadate-molybdate reagent was added. This solution was mixed, diluted to volume with deionized water and mixed again. After 30 minutes absorbance was read at 440 mu wavelength on a Beckman model DB-G spectrophotometer.

Grain yields were obtained by hand harvesting one of the two center rows of each plot. The corn was shelled with a tractor mounted sheller and grain sorghum was threshed with either a plot thresher or a modified Massey-Harris combine. Grain from each plot was weighed and a sample saved for moisture determination and chemical analysis. The sample to be analyzed was dried and ground through a Laboratory Construction Co. stainless steel burr mill, dry ashed, and analyzed using the same procedure employed for leaf tissue analysis. Analysis of variance on all data was carried out by means of the University IBM 360 computer. Grain yields were corrected to 12.5% moisture.

Growth Chamber Study

Zinc deficiency is known to be temperature sensitive (Lindsay and Romsdal, 1965) with deficiencies more evident in cool, wet springs than in warm, dry seasons. With this fact in mind, a growth chamber experiment was initiated to study the temperature effect on young corn plants. Along with temperature was the added variable of soil type. Four zinc sources were employed; ZnO, $ZnSO_4$, ZnEDTA, and a lignosulfate, Zn-Reax. Nutrients [8] were added

[8] These levels were satisfactory in growth chamber work of Dr. D. C. Adriano now of the University of California, Riverside. (private communication)

to the soil and then soil and nutrients were mixed with a twin shell dry blender (Table 7) and the pots incubated at two temperatures, one half at 30°C and one half at 5°C, for 70 days. During incubation soil moisture was kept at approximately 0.3 atmospheres. One half of each set of pots were subsequently planted to corn and subjected to 40°C day - 30°C night conditions and one half subjected to 20°C day - 10°C night (Table 8).

Containers for this experiment were purified by washing in 0.1M EDTA, distilled water, 10% (v/v) HNO_3, and deionized water. Deionized water was prepared by passing steam-distilled water through a series of mixed-bed demineralizer columns.

Soils for this experiment were collected from two sites in Pottawatomie county, one calcareous and one acid, both known to be deficient in Zn. Corn used was DeKalb hybrid variety XL-390 white corn (Zea mays L.). Acid washed white sand was placed on the soil surface to reduce water loss due to evaporation. All treatments were replicated three times and randomly distributed in their respective chambers. Day length was 16 hours, sixteen 160-watt flourescent lamps and six 300-watt incandescent lamps provided the lighting, 1500 foot-candles.

The plants were harvested 34 days after planting. Whole plants were taken. The plants were washed in deionized water, dried and ground following the procedure outlined previously. The plant materials were prepared for chemical analysis following

Table 7. Plant Nutrient Concentrations Used in Growth Chamber Study

Element	Concentration	Materials[a/]
P	80 ppm	15-26.4-0*
N	80 ppm	15-26.4-0* bal. as NH_4NO_3
K	50 ppm	K_2SO_4
B	1 ppm	$N_2B_4O_7.10H_2O$
Fe	5 ppm	FeEDTA
Mn	2.5 ppm	MnEDTA
Cu	1 ppm	CuEDTA
Zn	8 ppm	ZnO $ZnSO_4$ ZnEDTA Zn-Reax*

[a/] All materials reagent grade except (*) which are fertilizer grade products. 15-26.4-0 was supplied by the Tennessee Valley Authority, Zn-Reax by Westvaco, Inc., N. Charleston, S. C.

Table 8. Zinc and Temperature Variables Used in Growth Chamber Study.

Treatments	Incubation Temperature	Growing Temperature
Ck	5°C	20°C
ZnO	5°C	20°C
$ZnSO_4$	5°C	20°C
ZnEDTA	5°C	20°C
Zn-Reax	5°C	20°C
Ck	5°C	40°C
ZnO	5°C	40°C
$ZnSO_4$	5°C	40°C
ZnEDTA	5°C	40°C
Zn-Reax	5°C	40°C
Ck	30°C	20°C
ZnO	30°C	20°C
$ZnSO_4$	30°C	20°C
ZnEDTA	30°C	20°C
Zn-Reax	30°C	20°C
Ck	30°C	40°C
ZnO	30°C	40°C
$ZnSO_4$	30°C	40°C
ZnEDTA	30°C	40°C
Zn-Reax	30°C	40°C

the slightly modified wet oxidation procedure[9] outlined by Jackson (1965). One-quarter gram samples of the tissue were digested on a hot plate by the addition of 20 ml of a H_2O-HNO_3-$HClO_4$ mixture in a 1:1:1 ratio (v/v/v) to 200 ml tall-form beakers and covered with watchglasses. After evaporation of the HNO_3, the hot plate was shut off, the beakers cooled for about 10 minutes, and the watchglasses and beaker walls rinsed with deionized water to flush any plant material down into the acid. Digestion resumed until complete dryness. The residue was allowed to cool for a few seconds and approximately 10 ml of 0.1N HCl solution was added to bring the residue into solution. The mixture was then filtered through Whatman 42 filter paper and made to 25 ml volume with 0.1N HCl. The filtrate was then assayed for Zn, Fe, Cu, Mn, and P. Zinc, Fe, Cu, and Mn, were analyzed by atomic absorption and P by the vanadate-molybdate yellow method as described earlier.

Source of Materials

Zinc oxide and $ZnSO_4$ coated APP, AOP, TSP, and AN were obtained from TVA, Muscle Shoals, Alabama; ZnO coated TSP and DAP from the American Cyanamid Co., Princeton, N. J.; TSP from J. R. Simplot and Co., Pocatello, Ida.; liquid APP (10-34-0) from the Allied Chemical Corporation; Reax-Zn from Westvaco, Inc., N. Charleston, S. C.; Key-el from Kaiser Agricultural Chemicals, Savannah, Ga.; solid $ZnSO_4$ and ZnO suspensions from Sherwin-Williams Research Laboratories, Inc., Chicago, Ill.; $ZnSO_4$, ZnEDTA,

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[9]Adriano, D. C. 1970. Phosphorus-zinc interaction in Zea mays and Phaseolus vulgare. PH.D. Thesis. Dept. of Agronomy, Kansas State University

and Coop-Zn coated AOP plus liquid APP-$ZnSO_4$, APP-ZnEDTA, and APP-Coop-Zn formulations from Farmland Industries, Inc., Kansas City, Mo. All were fertilizer grade materials.

RESULTS and DISCUSSION

Field Experiments

Treatment means for leaf and grain analysis for P and Zn are presented in Figures 1 through 17 and Table 12. Yield data are presented in Table 9 through 11 and 13. Detailed data are presented in Appendix Tables I through IX. Information on the location of the research sites and data for each is listed in Table 1.

For the figures, "Ck" refers to the check values or no Zn application. Sampling dates are labeled as 1 or 2 and the actual date is noted in the title of each figure. Check values are presented for both sampling dates. "G" is the symbol used to denote grain values where such analyses were preformed.

Comparisons on ZnO and $ZnSO_4$ as Sources of Zn for Corn

Applications of both ZnO and $ZnSO_4$ tended to increase Zn content in the plants at all locations (Fig. 1 through 6) with the exception of the first Wallace county site (Fig. 1). There, Zn content was reduced at the first date of sampling when AOP and APP served as the transport materials for the Zn. However, this apparent difference was not statistically significant, nor was this visually apparent during the growing season. Phosphorus responses were inconsistent with ZnO, levels of P in the tissue were about the same with all P carriers. Ammonium orthophosphate and APP applications produced a slight reduction in leaf P content when compared to the check at the first sampling date. This

effect had disappeared by the second sampling date for AOP but continued with the APP and appeared on the plants that received TSP coated with ZnO. Higher amounts of $ZnSO_4$ increased P content in leaf tissue (Fig. 2) at the Wallace county #1 site. Both the AOP and TSP at the higher rates supplied more Zn to the plants than did the APP. This depressing effect of APP on Zn uptake was also noted by Adriano (1970). Yield results (Table 9) in Wallace county were not significant, due partially to heavy insect damage (Western bean cutworm) during the growing season.

At the Pawnee county #1 site (Fig. 3 and 4), applications of Zn increased Zn concentrations in corn leaves and grain but this difference could not be associated with the Zn form used. Plant P concentrations were decreased by the addition of Zn in the case of both the oxide coated APP and TSP and by sulfate coated TSP. This location showed very severe Zn deficiency throughout much of the growing season on some plots. The soil had been cut in the leveling operation and the exposed subsoil was dense and Zn-deficient. Yield data (Table 9) show little variation that could be associated with treatment.

At the Sedgwick county #1 site (Fig. 5 and 6), increased Zn concentrations in leaf tissue were recorded with the application of Zn in both forms. The higher Zn rate produced increases in the Zn levels in the plants with all materials except AOP. The coated APP and TSP materials generally increased Zn concentrations in the leaf tissue more than did the AOP. All materials provided relatively the same amount of P to the corn plants. There was little visual effect of either Zn or P carrier during the growing

season. Yields (Table 9) were not significant at this location, however, this may have been at least partially due to a severe hailstorm about the time of tasseling that destroyed much of the plants' leaf structure.

Addition of Zn increased the Zn content in the leaf tissue of corn plants in Pottawatomie county (Fig. 7). Zinc oxide produced increased Zn concentrations in the first sampling date for both AOP and APP as compared to the $ZnSO_4$ in combination with the same P carriers. Addition of Zn decreased grain Zn content for all three P carriers. Plant P concentrations were highest when TSP was the source. It is interesting to note the P concentrations trend. In the previous studies P content was usually lower at the date 2 sampling but in this study P content was higher at the date 2 sampling. Yield (Table 10) data tend to show that $ZnSO_4$ produced more grain than did ZnO but this difference was not significant at the 5% level.

Comparisons of $ZnSO_4$, ZnEDTA, and an Experimental Zn Source.

Applications of the three forms of Zn; ZnEDTA, $ZnSO_4$, and Coop-Zn[10] increased the Zn content in the plants at all three locations (Fig. 8 through 16). When Zn carriers were compared there were no significant differences between plants' Zn content.

Higher rates of Zn in the three forms increased plant Zn content more than did the lower rate at the Wallace county #2

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[10] Coop-Zn is an experimental zinc material formulated by Farmland Industries, Inc.

site (Fig. 8 through 10) with APP as the P source, but the reverse was true for AOP at the first date for EDTA and Coop-Zn. The higher rates of Zn tended to depress plant leaf P concentrations. Both of these trends were not significant, however.

The trend for higher rates of Zn to reduce leaf P concentration was also noted at the Pawnee county #2 site (Fig. 11 through 13) for the AOP materials, while the reverse was true for the APP materials. The lower rate of EDTA and Coop-Zn, at the date 2 sampling gave significant differences in plant Zn content.

The effects at the Sedgwick county #2 site (Fig. 14 through 16) were quite similar to those observed in Pawnee county. The lower rate of Zn in the EDTA and Coop forms tended to increase the Zn concentration in the leaf tissue more than did the higher rate. Rates of Zn had less effect on P than at the Pawnee county #2 site.

Yield responses (Table 11) were inconclusive at all three locations. The Pawnee county site produced the highest mean yields but differences were still not significant. Part of the poor yield at the Sedgwick county site may be blamed on a hailstorm on June 17. Most of the plants' leaves were destroyed with much stalk damage. The only yield differences that were significant occurred at the Wallace county #2 site, (Table 11). Only the solid $ZnSO_4$-coated AOP showed any effect of P carrier when compared with the Zn but no P check. This difference in yield could be attributed to the effect of P.

Comparisons of ZnO and $ZnSO_4$ for Grain Sorghum

Addition of Zn increased the Zn content in the leaf tissue of grain sorghum in Stafford county #1 site (Fig. 17). Addition of Zn decreased grain Zn content only with APP. The three forms of P (AOP, APP, TSP) produced about equal concentrations of P in the leaf tissue, with APP slightly less effective than AOP or TSP. However, this difference was not significant. Yield (Table 10) was increased by the addition of both Zn and P, but this difference was not significant at the 5% level. Observations made during the growing season offered little additional information as no marked deficiency symptoms were present.

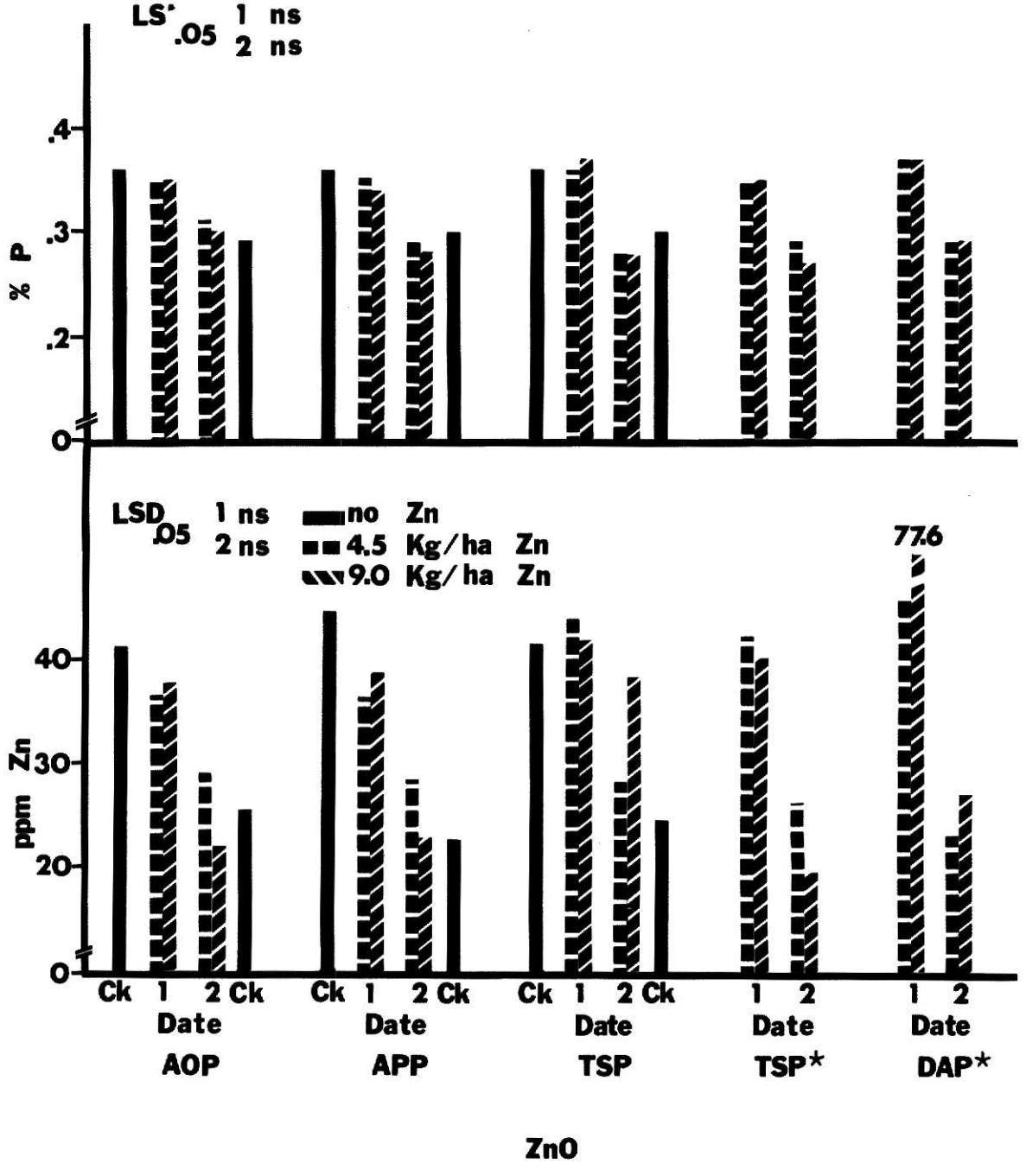
Liquid Versus Solid Sources of Zn for Grain Sorghum

The effects of Zn material and method of application on grain sorghum are presented in Table 12. Early observations indicated that the knifed applications of fluid P and Zn carriers were somewhat inferior to broadcast applications of the same materials. Date 1 tissue analysis confirmed this for plant P concentrations. The application of Zn tended to increase the plants' content of both Zn and P. Differences between Zn carriers were not clear concerning the effects of the materials upon the Zn concentrations in the plant. Yield response was quite varied. Neither Zn rate, carrier, or method of application produced a trend in yield. Additional plant tissue analyses (Appendix Table IX) offered few additional trends at this location.

Fig. 1 - Effects of two rates of Zn as ZnO and four sources of P on the P and Zn content of corn leaves. (Wallace County #1. Sampling dates, 6/25 and 7/28. Starred materials provided by American Cyanamid, others by TVA.)

THIS BOOK CONTAINS NUMEROUS PAGES WITH DIAGRAMS THAT ARE CROOKED COMPARED TO THE REST OF THE INFORMATION ON THE PAGE.

THIS IS AS RECEIVED FROM CUSTOMER.


LSD .05 1 ns
2 ns
% P
.4
.3
.2
0
LSD .05 1 ns
2 ns
no Zn
4.5 Kg/ha Zn
9.0 Kg/ha Zn
77.6
ppm Zn
40
30
20
0
Ck 1 2 Ck
Ck 1 2 Ck
Ck 1 2 Ck
1 2
1 2
Date
Date
Date
Date
Date
AOP
APP
TSP
TSP*
DAP*
ZnO

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Fig. 2 - Effects of two rates of Zn as $ZnSO_4$ and three sources of P on the P and Zn content of corn leaves. (Wallace County #1. Sampling dates, 6/25 and 7/28.)

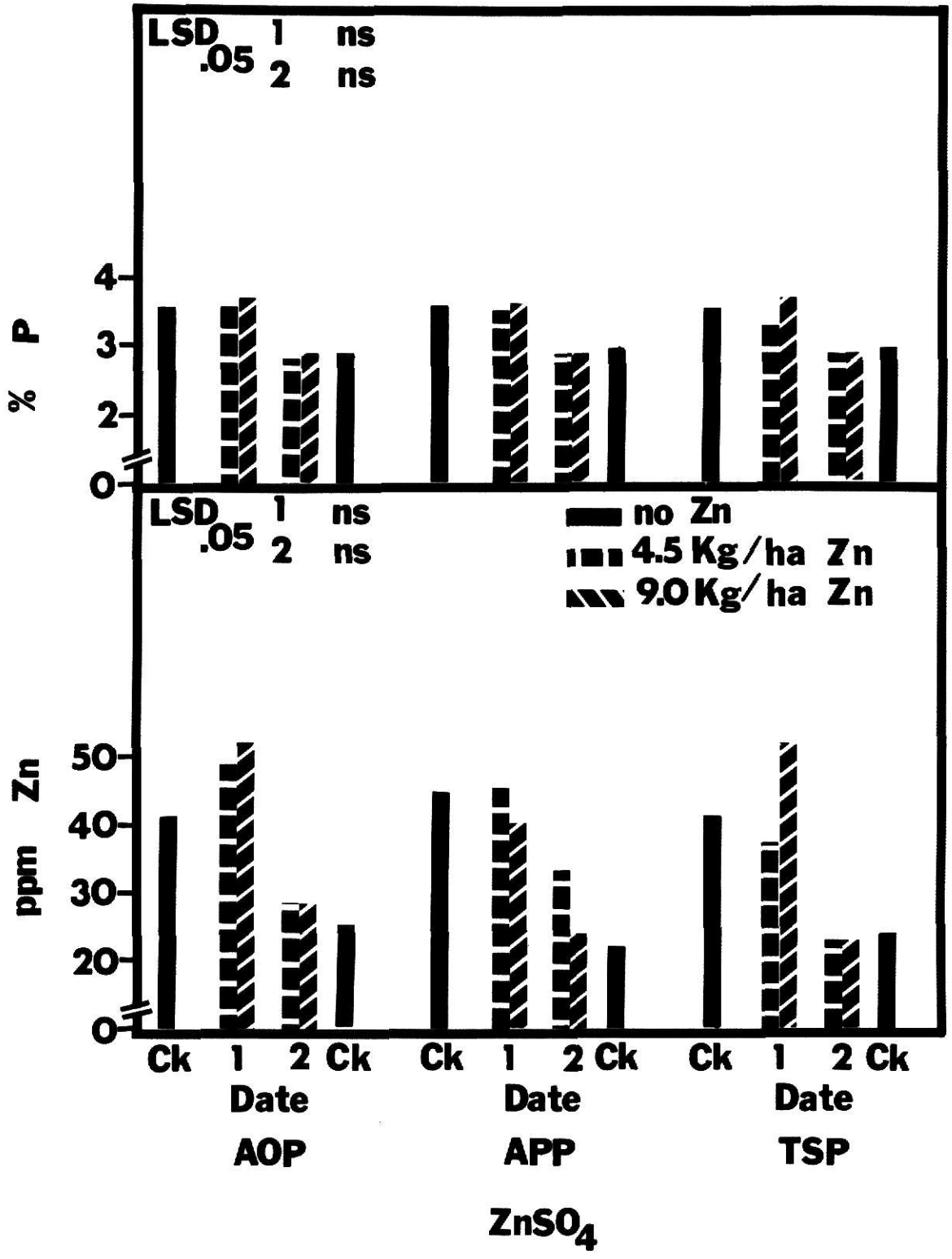

LSD .05 1 ns
2 ns
% P
4
3
2
0
LSD .05 1 ns
2 ns
no Zn
4.5 Kg/ha Zn
9.0 Kg/ha Zn
ppm Zn
50
40
30
20
0
Ck 1 2 Ck Ck 1 2 Ck Ck 1 2 Ck
Date Date Date
AOP APP TSP
ZnSO4

Fig. 3 - Effects of two rates of Zn as ZnO and four sources of P on the P and Zn content of corn leaves and grain. (Pawnee County #1. Sampling dates, 6/24 and 7/14. Starred materials provided by American Cyanamid, others by TVA.)

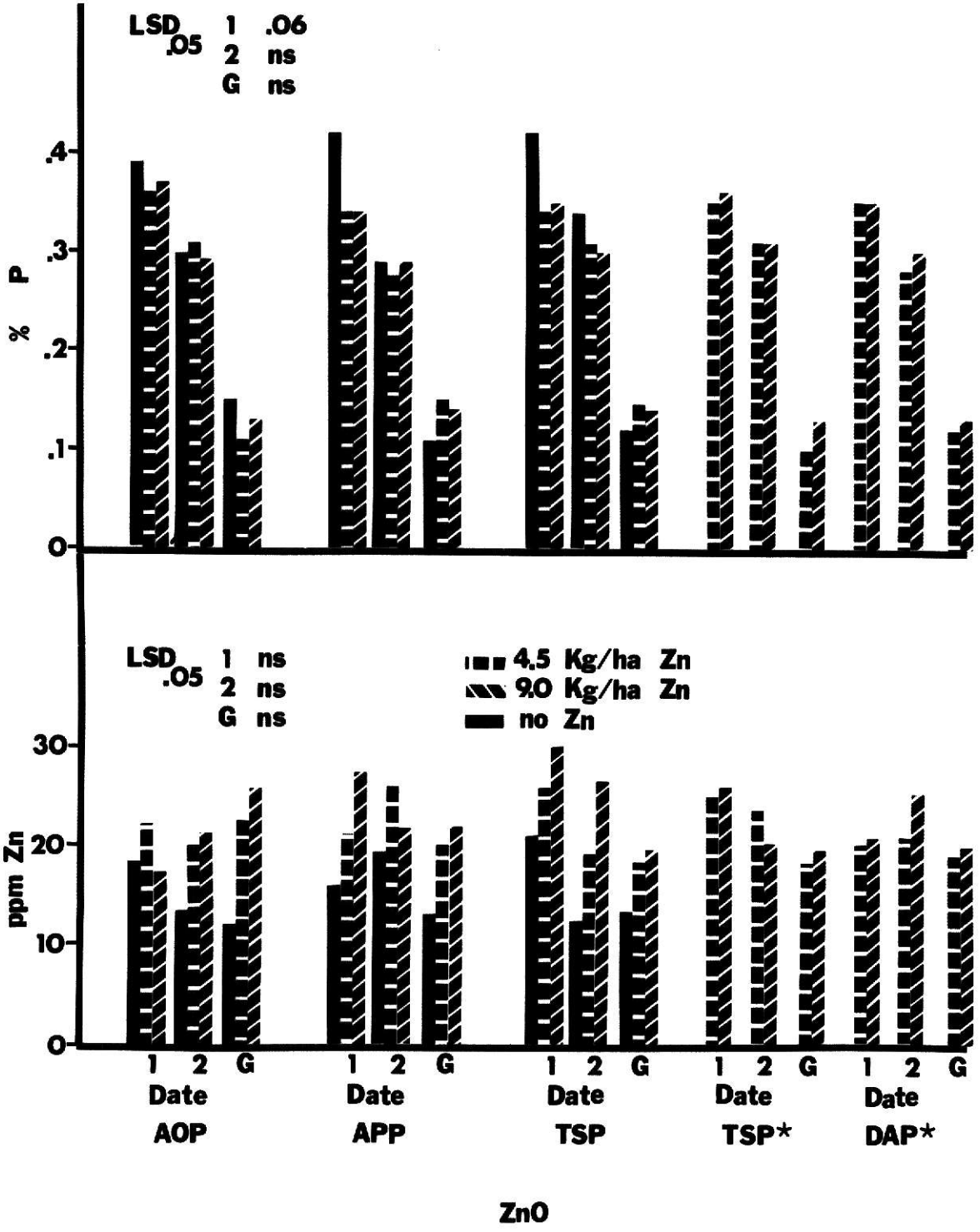

LSD .05 1 .06
2 ns
G ns
% P
.4
.3
.2
.1
0
LSD .05 1 ns
2 ns
G ns
4.5 Kg/ha Zn
9.0 Kg/ha Zn
no Zn
ppm Zn
30
20
10
0
1 2 G
Date
AOP
APP
TSP
TSP*
DAP*
ZnO

Fig. 4 - Effects of two rates of Zn as $ZnSO_4$ and three sources of P on the P and Zn content of corn leaves and grain. (Pawnee County #1. Sampling dates, 6/24 and 7/14.)

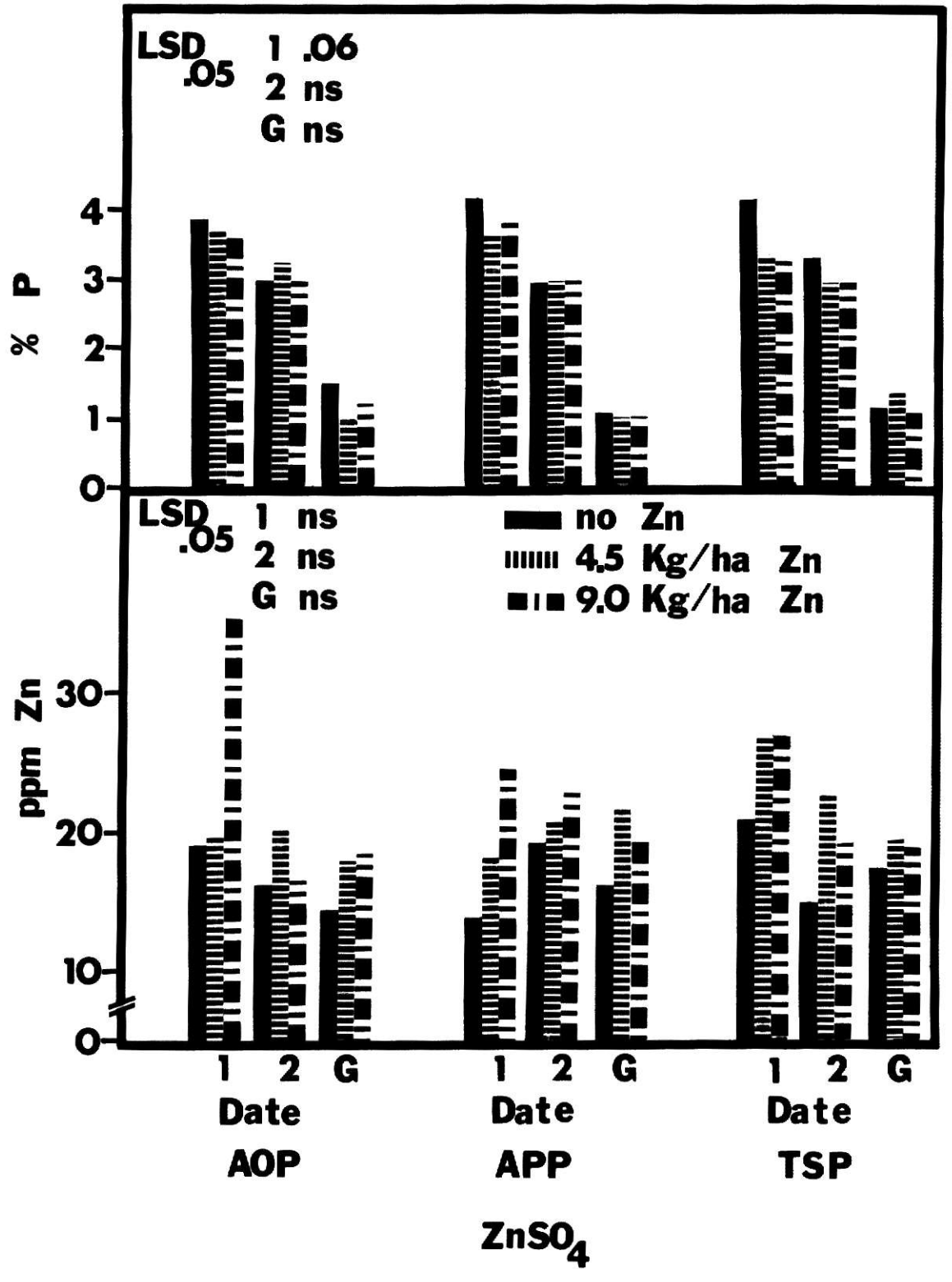

LSD .05
1 .06
2 ns
G ns
% P
4
3
2
1
0
LSD .05
1 ns
2 ns
G ns
no Zn
4.5 Kg/ha Zn
9.0 Kg/ha Zn
ppm Zn
30
20
10
0
1 2 G
Date
AOP
1 2 G
Date
APP
1 2 G
Date
TSP
ZnSO4

Fig. 5 - Effects of two rates of Zn as ZnO and four sources of P on the P and Zn content of corn leaves and grain. (Sedgwick County #1. Sampling dates, 6/10 and 7/24. Starred materials provided by American Cyanamid, others by TVA.)

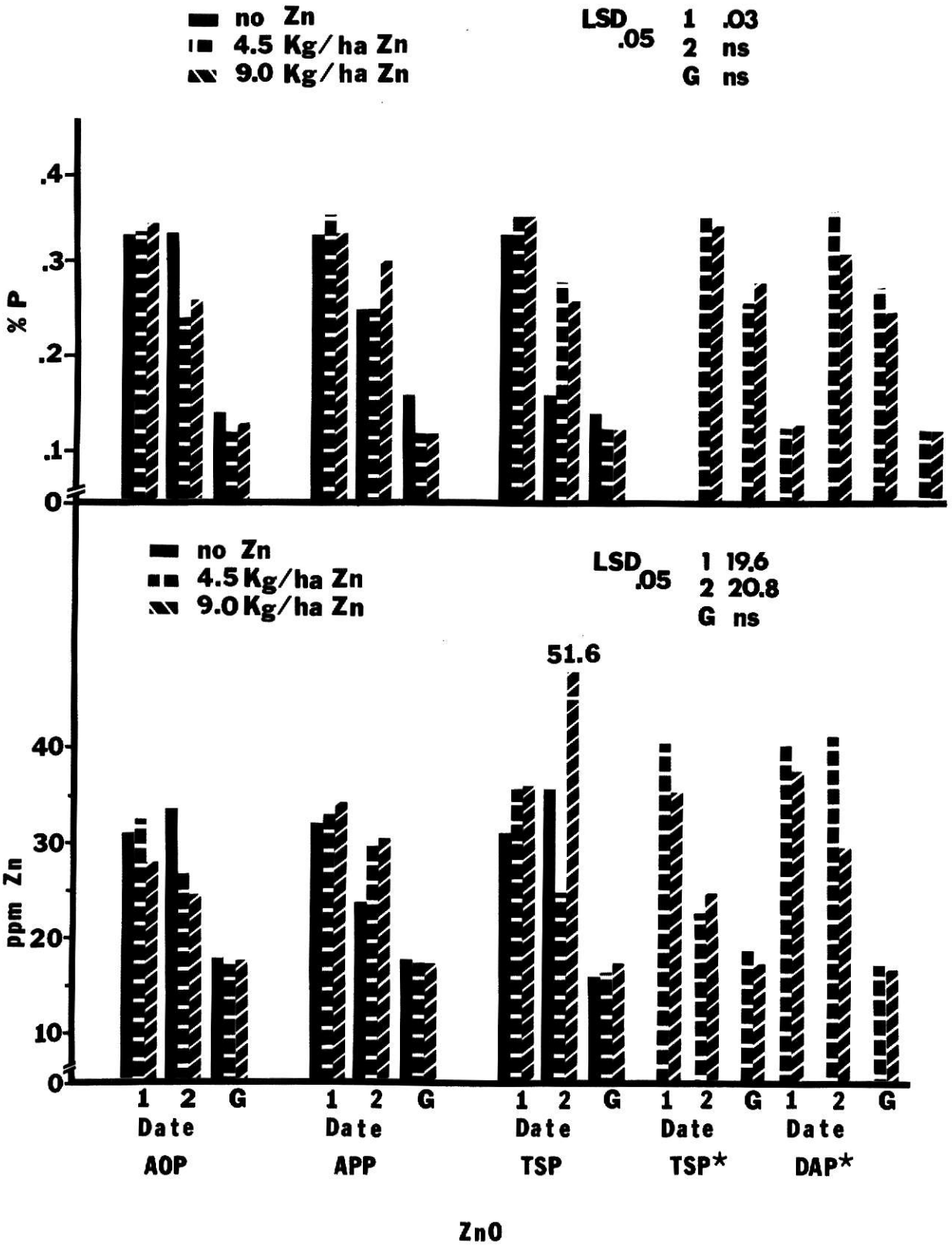

no Zn
4.5 Kg/ha Zn
9.0 Kg/ha Zn
LSD .05 1 .03
2 ns
G ns
% P
.4
.3
.2
.1
0
no Zn
4.5 Kg/ha Zn
9.0 Kg/ha Zn
LSD .05 1 19.6
2 20.8
G ns
51.6
ppm Zn
40
30
20
10
0
1 2 G
Date
AOP
APP
TSP
TSP*
DAP*
ZnO

Fig. 6 - Effects of two rates of Zn as $ZnSO_4$ and three sources of P on the P and Zn content of corn leaves and grain. (Sedgwick County #1. Sampling dates, 6/10 and 7/24.)

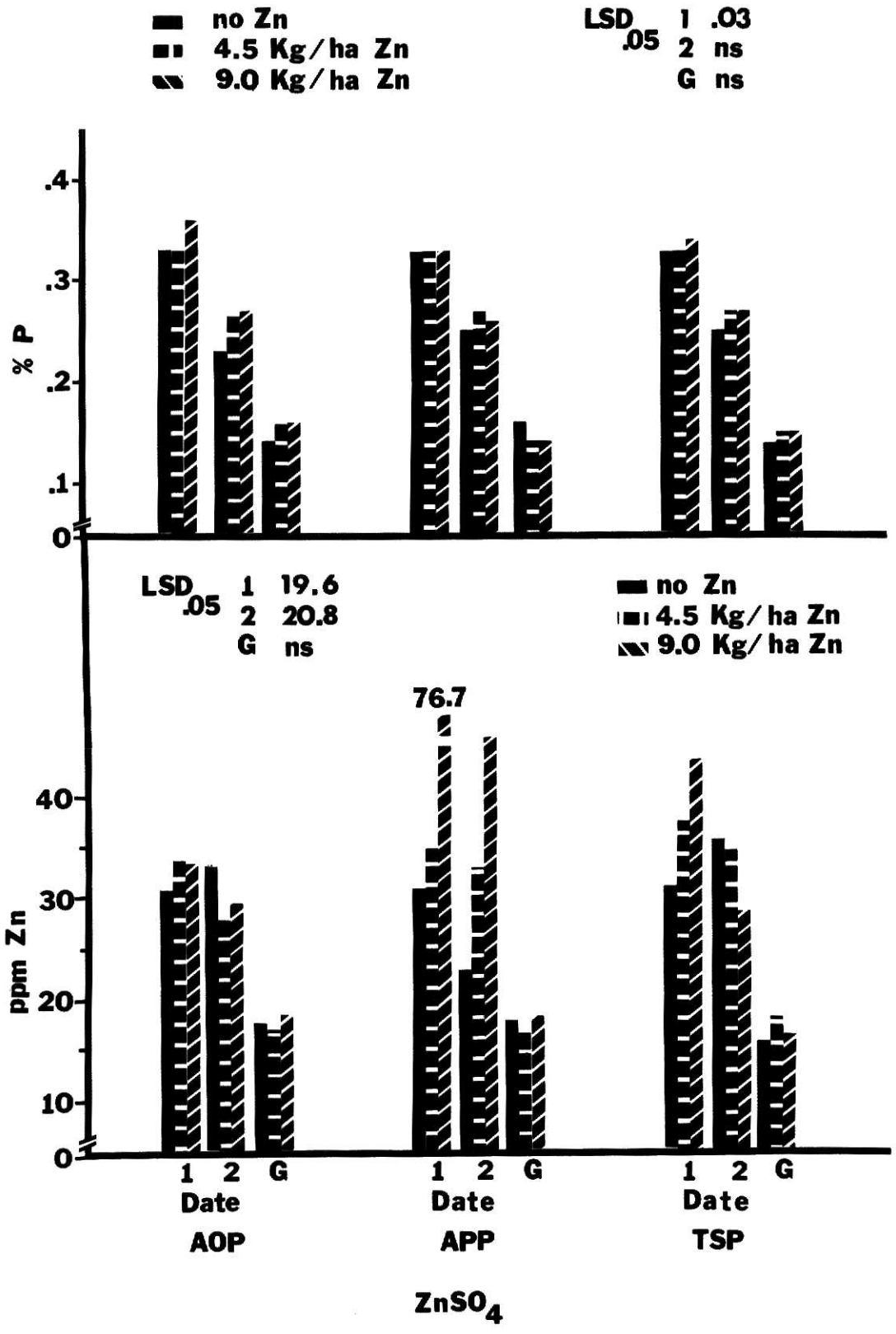

no Zn
4.5 Kg/ha Zn
9.0 Kg/ha Zn
LSD .05 1 .03
2 ns
G ns
% P
.4
.3
.2
.1
0
LSD .05 1 19.6
2 20.8
G ns
no Zn
4.5 Kg/ha Zn
9.0 Kg/ha Zn
76.7
ppm Zn
40
30
20
10
0
1 2 G
Date
AOP
1 2 G
Date
APP
1 2 G
Date
TSP
ZnSO4

Fig. 7 - Effects of two sources of Zn, ZnO and $ZnSO_4$, and three sources of P on P and Zn content of corn leaves and grain. (Pottawatomie County. Sampling dates, 7/1 and 7/29. Starred material provided by American Cyanamid, others by TVA.)

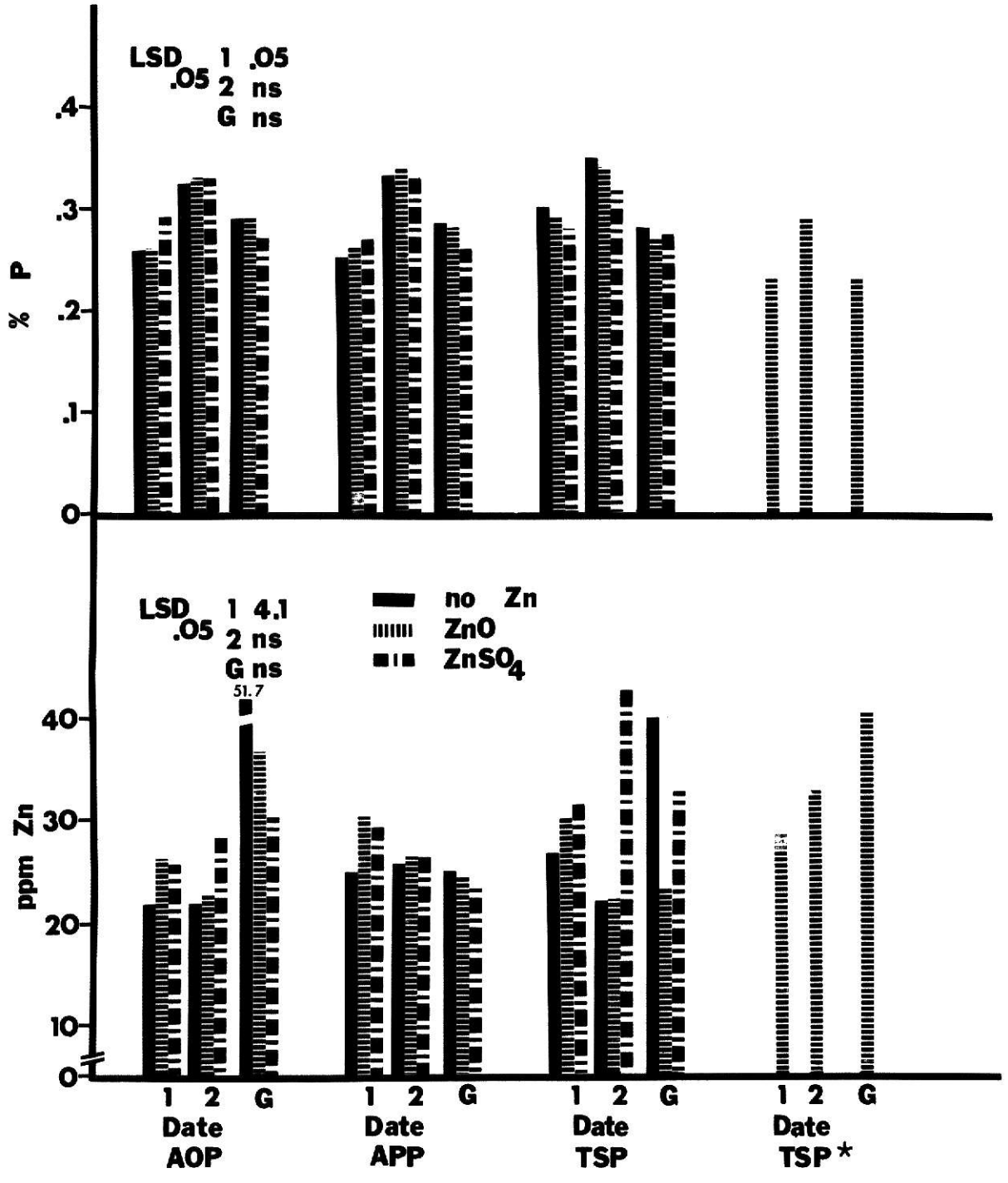

LSD .05 1 .05
2 ns
G ns
% P
.4
.3
.2
.1
0
LSD .05 1 4.1
2 ns
G ns
no Zn
ZnO
ZnSO4
51.7
ppm Zn
40
30
20
10
0
1 2 G
Date
AOP
1 2 G
Date
APP
1 2 G
Date
TSP
1 2 G
Date
TSP*

Fig. 8 - Effects of two rates of Zn as ZnEDTA and two sources of P on P and Zn content of corn leaves. (Wallace County #2. Sampling dates, 6/25 and 7/28.)

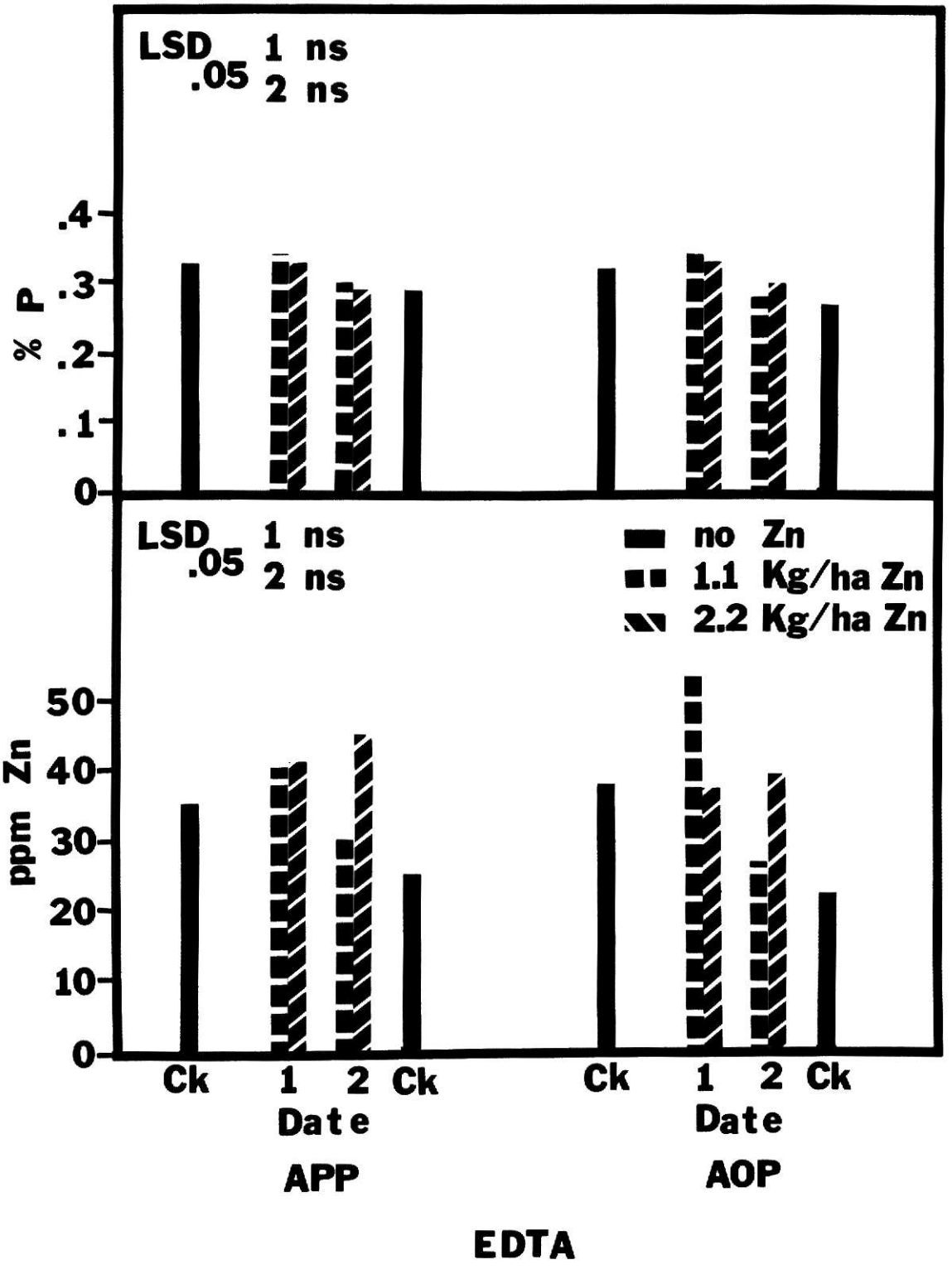

LSD .05 1 ns
2 ns
% P
.4
.3
.2
.1
0
LSD .05 1 ns
2 ns
no Zn
1.1 Kg/ha Zn
2.2 Kg/ha Zn
ppm Zn
50
40
30
20
10
0
Ck
1
2
Ck
Ck
1
2
Ck
Date
Date
APP
AOP
EDTA

Fig. 9 - Effects of two rates of Zn as $ZnSO_4$ and two sources of P on P and Zn content of corn leaves. (Wallace County #2. Sampling dates, 6/25 and 7/28.)

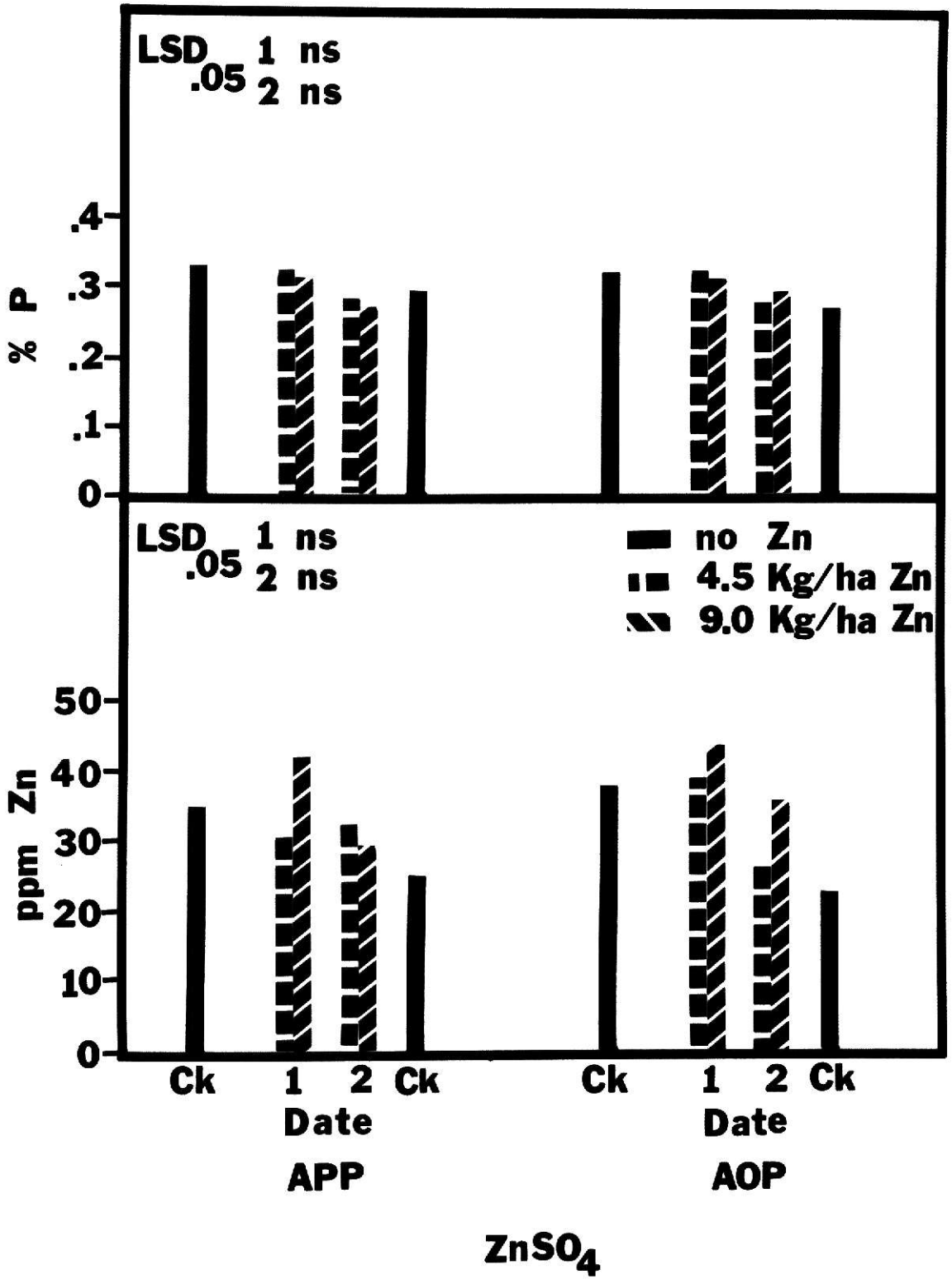

LSD .05 1 ns
2 ns
% P
.4
.3
.2
.1
0
LSD .05 1 ns
2 ns
no Zn
4.5 Kg/ha Zn
9.0 Kg/ha Zn
ppm Zn
50
40
30
20
10
0
Ck
1
2
Ck
Ck
1
2
Ck
Date
Date
APP
AOP
ZnSO4

Fig. 10 - Effects of two rates of Zn as Coop-Zn and two sources of P on P and Zn content of corn leaves. (Wallace County #2. Sampling dates, 6/25 and 7/28.)

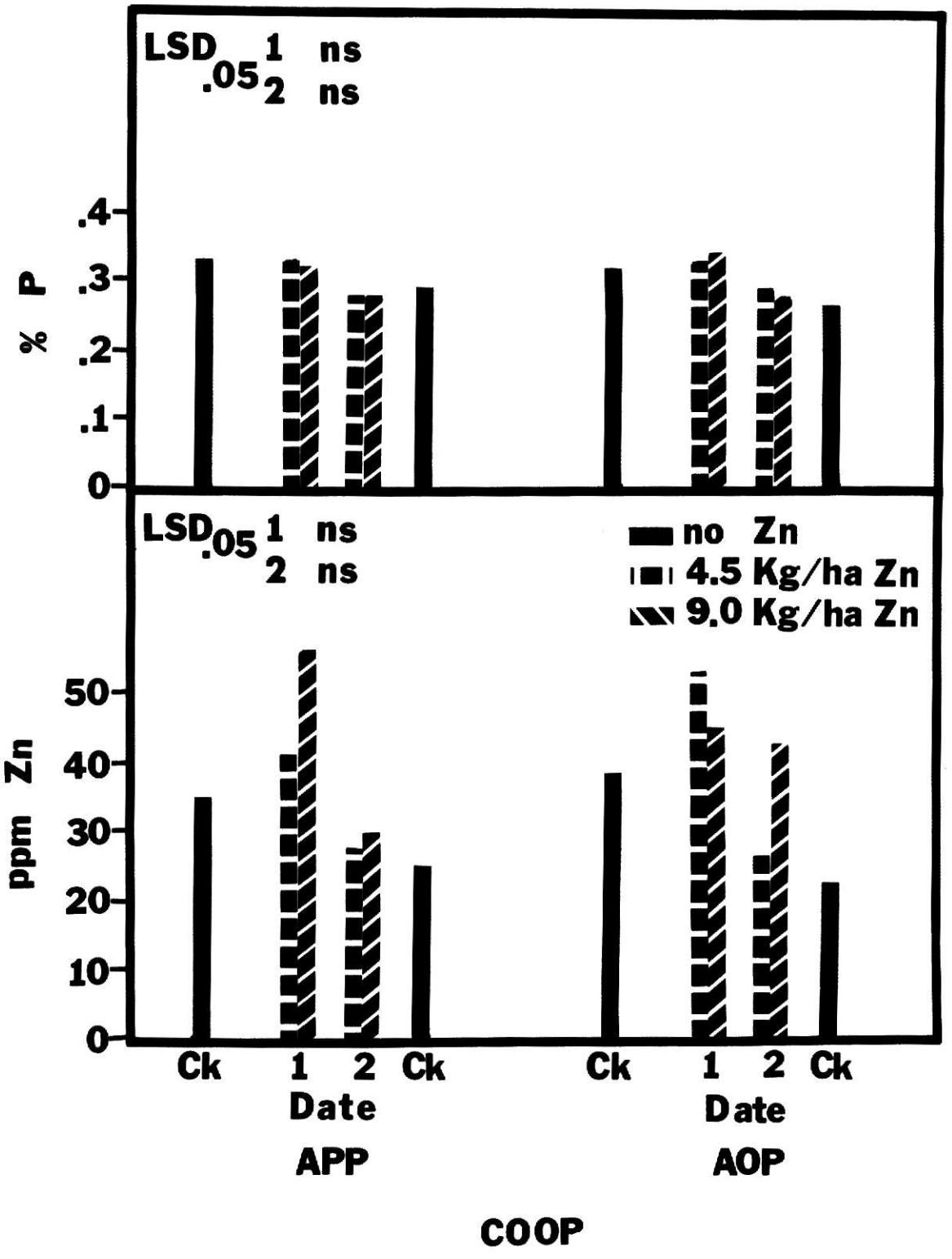

LSD .05 1 ns
2 ns
% P
.4
.3
.2
.1
0
LSD .05 1 ns
2 ns
no Zn
4.5 Kg/ha Zn
9.0 Kg/ha Zn
ppm Zn
50
40
30
20
10
0
Ck 1 2 Ck
Date
APP
Ck 1 2 Ck
Date
AOP
COOP

Fig. 11 - Effects of two rates of Zn as ZnEDTA and two sources of P on P and Zn content of corn leaves and grain. (Pawnee County #2. Sampling dates, 6/24 and 7/14.)

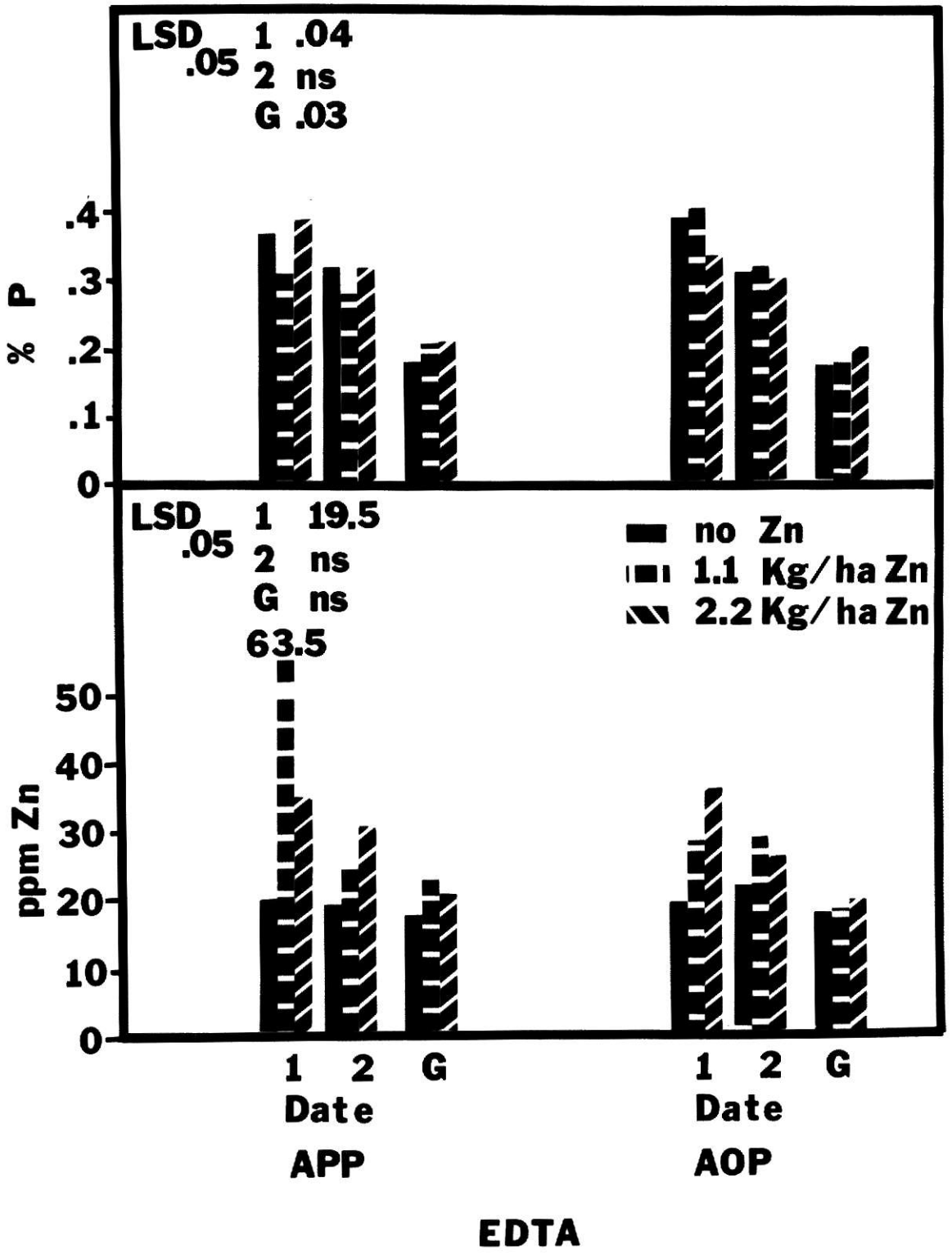

LSD .05 1 .04
2 ns
G .03
% P
.4
.3
.2
.1
0
LSD .05 1 19.5
2 ns
G ns
63.5
no Zn
1.1 Kg/ha Zn
2.2 Kg/ha Zn
ppm Zn
50
40
30
20
10
0
1 2 G
Date
APP
1 2 G
Date
AOP
EDTA

Fig. 12 - Effects of two rates of Zn as $ZnSO_4$ and two sources of P on P and Zn content of corn leaves and grain. (Pawnee County #2. Sampling dates, 6/24 and 7/14.)

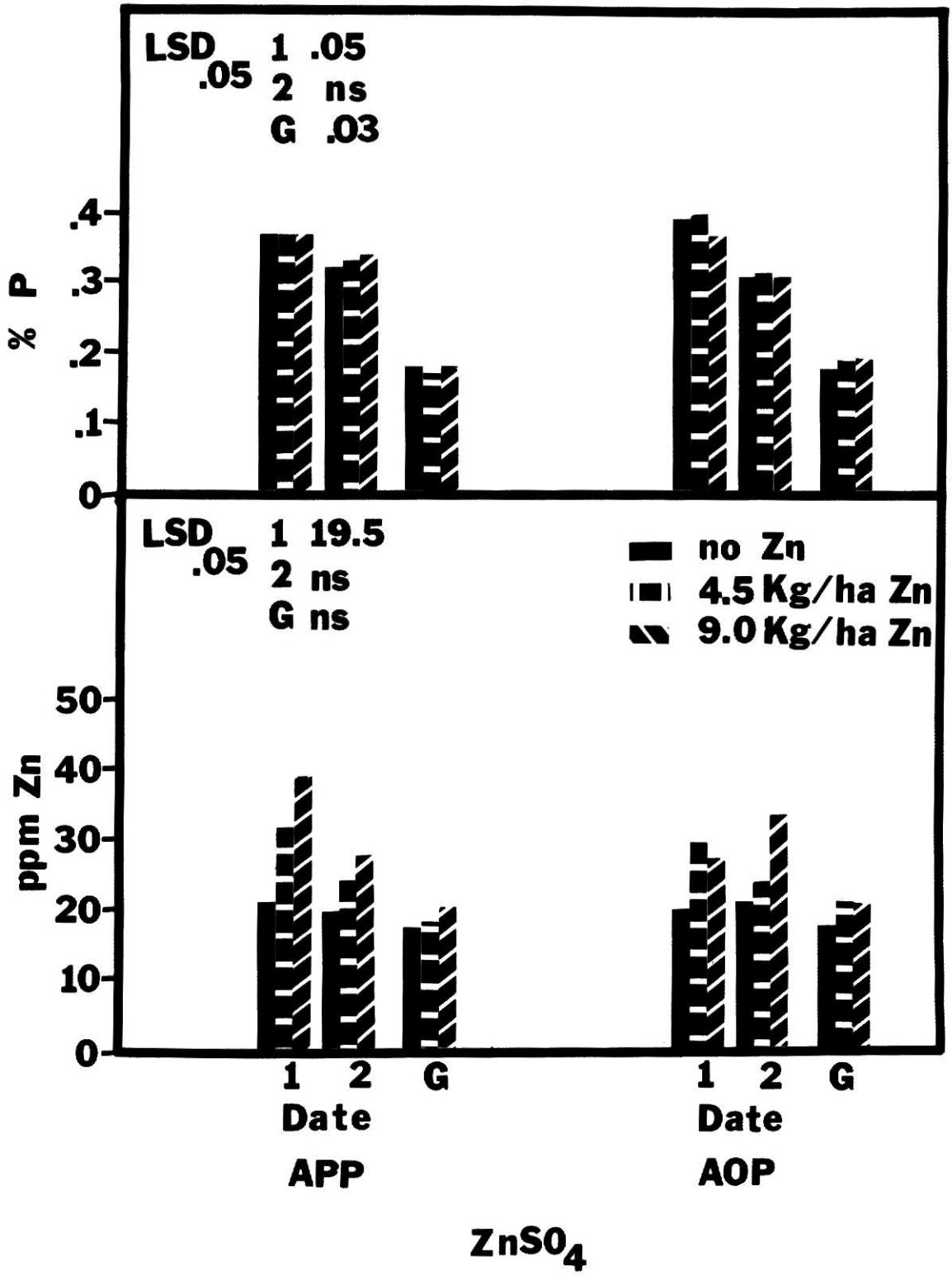

LSD .05 1 .05
2 ns
G .03
% P
.4
.3
.2
.1
0
LSD .05 1 19.5
2 ns
G ns
no Zn
4.5 Kg/ha Zn
9.0 Kg/ha Zn
ppm Zn
50
40
30
20
10
0
1 2 G
Date
APP
1 2 G
Date
AOP
ZnSO4

Fig. 13 - Effects of two rates of Zn as Coop-Zn and two sources of P on P and Zn content of corn leaves and grain. (Pawnee County #2. Sampling dates, 6/24 and 7/14.)

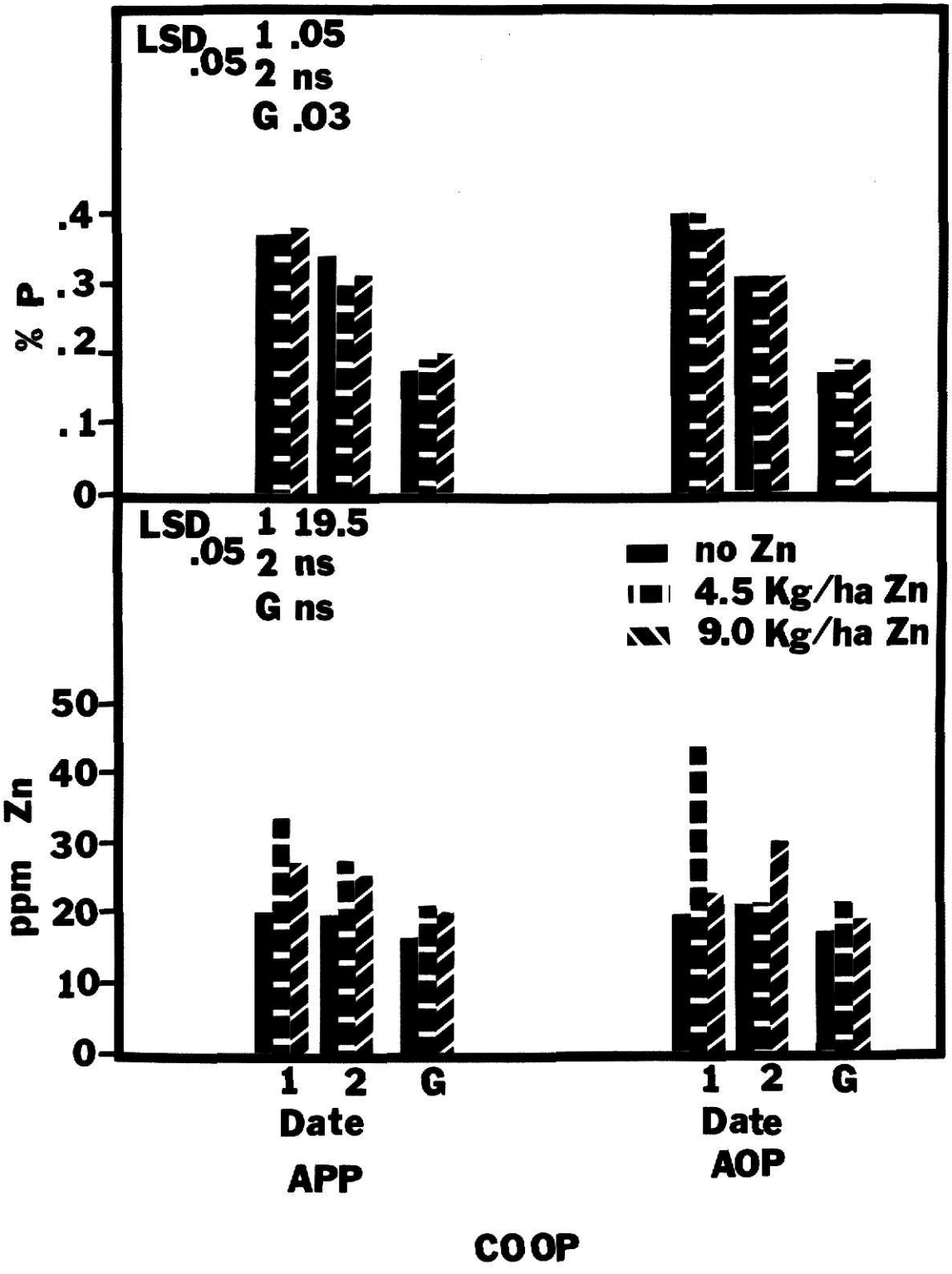

LSD.05 1 .05
2 ns
G .03
% P
.4
.3
.2
.1
0
LSD.05 1 19.5
2 ns
G ns
no Zn
4.5 Kg/ha Zn
9.0 Kg/ha Zn
ppm Zn
50
40
30
20
10
0
1 2 G
Date
APP
1 2 G
Date
AOP
COOP

Fig. 14 - Effect of two rates of Zn as ZnEDTA and two sources of P on P and Zn content of corn leaves and grain. (Sedgwick County #2. Sampling dates, 6/10 and 7/24.)

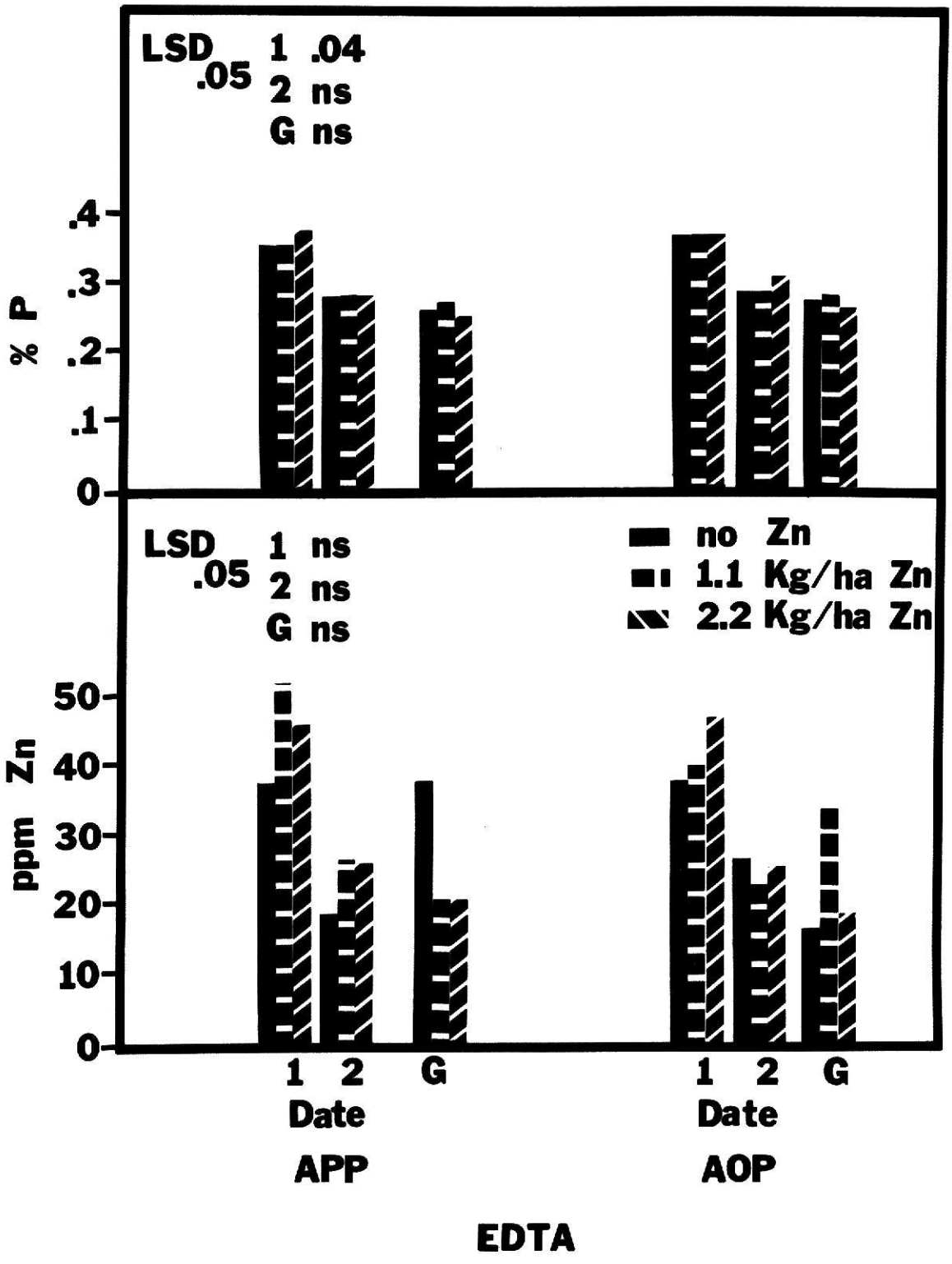

LSD .05
1 .04
2 ns
G ns
% P
.4
.3
.2
.1
0
LSD .05
1 ns
2 ns
G ns
no Zn
1.1 Kg/ha Zn
2.2 Kg/ha Zn
ppm Zn
50
40
30
20
10
0
1 2 G
Date
APP
1 2 G
Date
AOP
EDTA

Fig. 15 - Effect of two rates of Zn as $ZnSO_4$ and two sources of P on P and Zn content of corn leaves and grain. (Sedgwick County #2. Sampling dates, 6/10 and 7/24.)

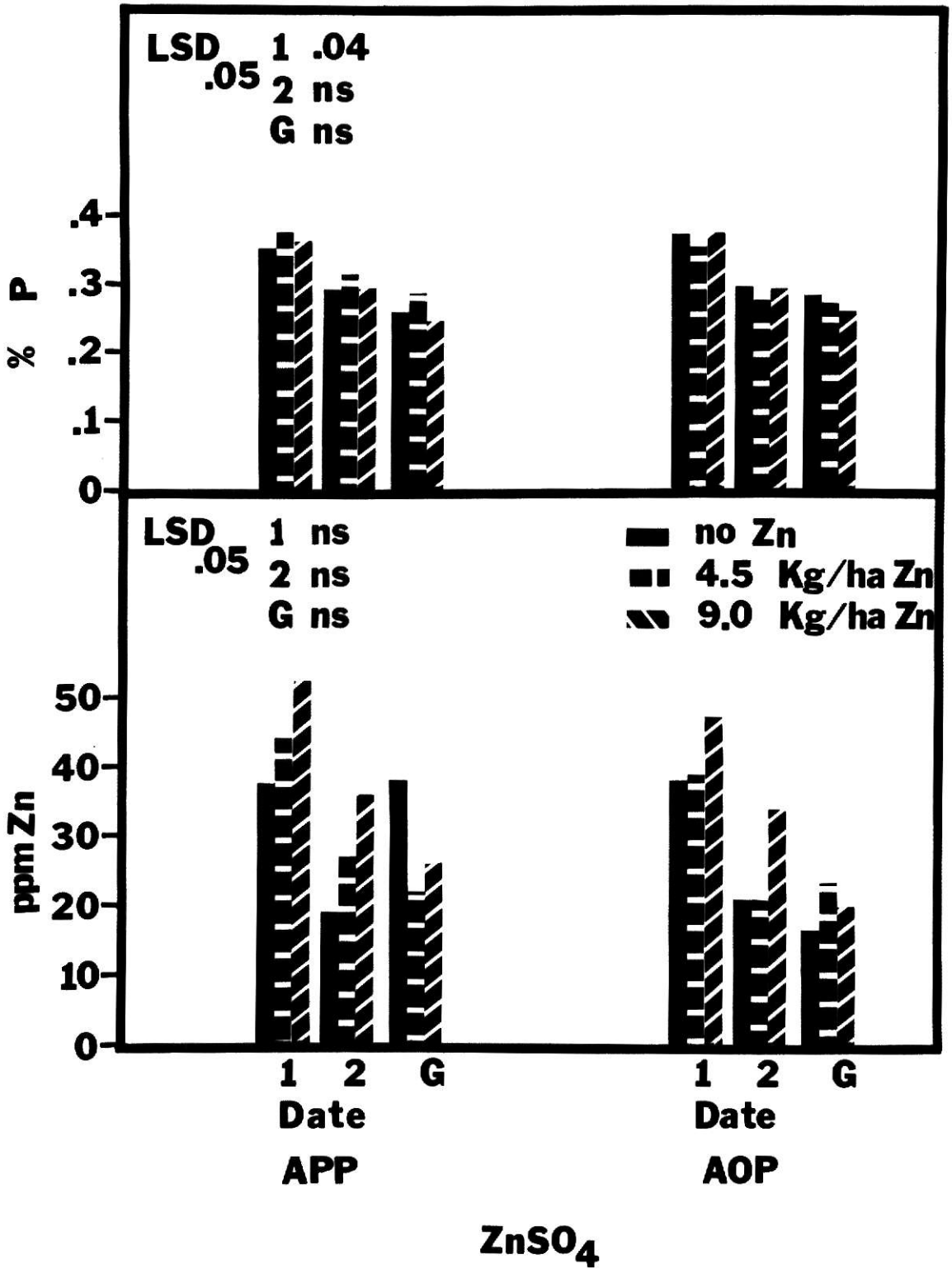

LSD .05
1 .04
2 ns
G ns
% P
.4
.3
.2
.1
0
LSD .05
1 ns
2 ns
G ns
no Zn
4.5 Kg/ha Zn
9.0 Kg/ha Zn
ppm Zn
50
40
30
20
10
0
1 2 G
Date
APP
1 2 G
Date
AOP
ZnSO4

Fig. 16 - Effect of two rates of Zn as Coop-Zn and two sources of P on P and Zn content of corn leaves and grain. (Sedgwick County #2. Sampling dates, 6/10 and 7/24.)

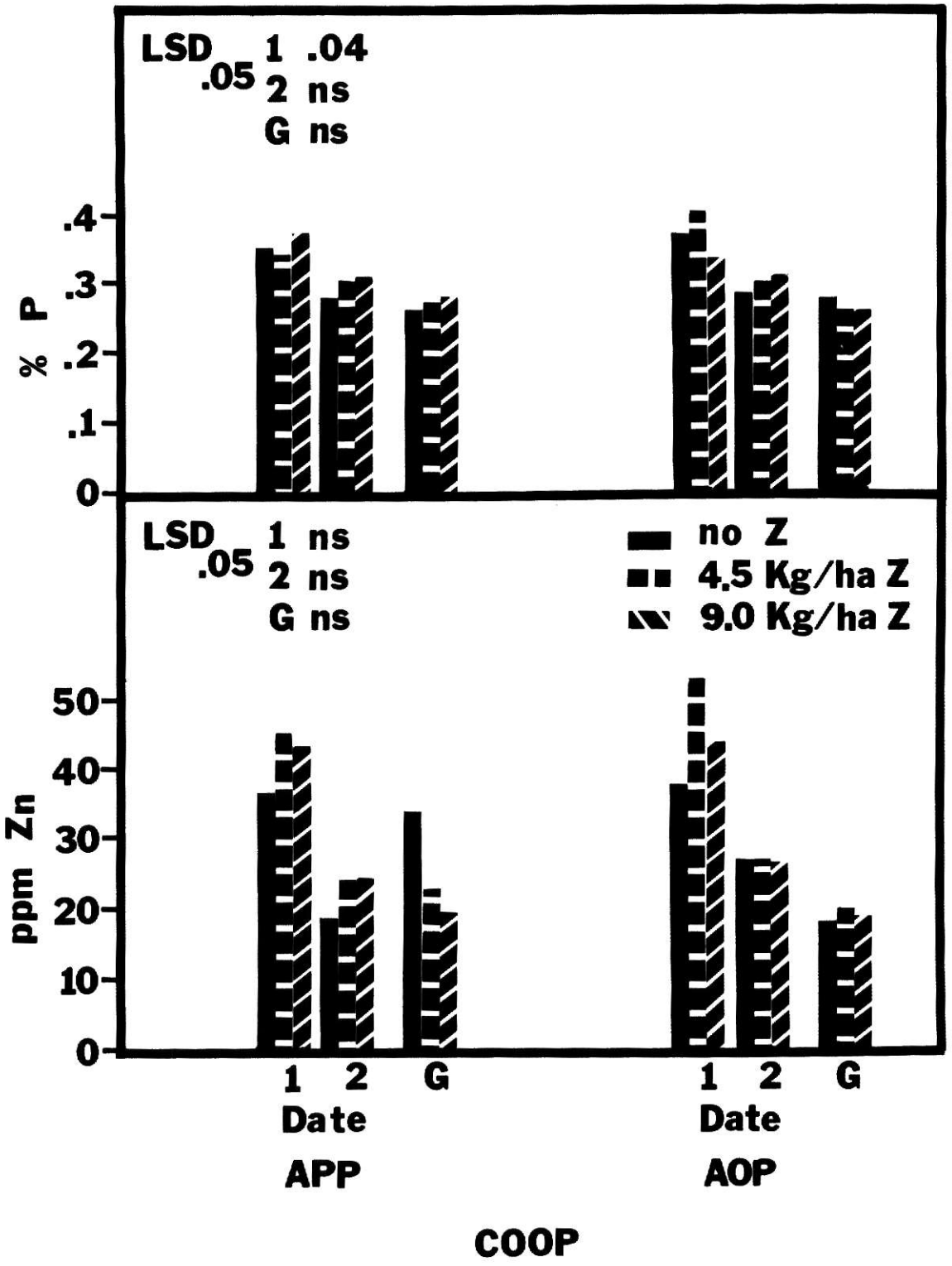

LSD .05 1 .04
2 ns
G ns
% P
.4
.3
.2
.1
0
LSD .05 1 ns
2 ns
G ns
no Z
4.5 Kg/ha Z
9.0 Kg/ha Z
ppm Zn
50
40
30
20
10
0
1 2 G
Date
APP
1 2 G
Date
AOP
COOP

Fig. 17 - Effects of two sources of Zn as ZnO and $ZnSO_4$ and three sources of P on P and Zn content of grain sorghum leaves and grain. (Stafford County #2. Sampling dates, 6/10 and 7/13. Starred material provided by American Cyanamid, others by TVA.)

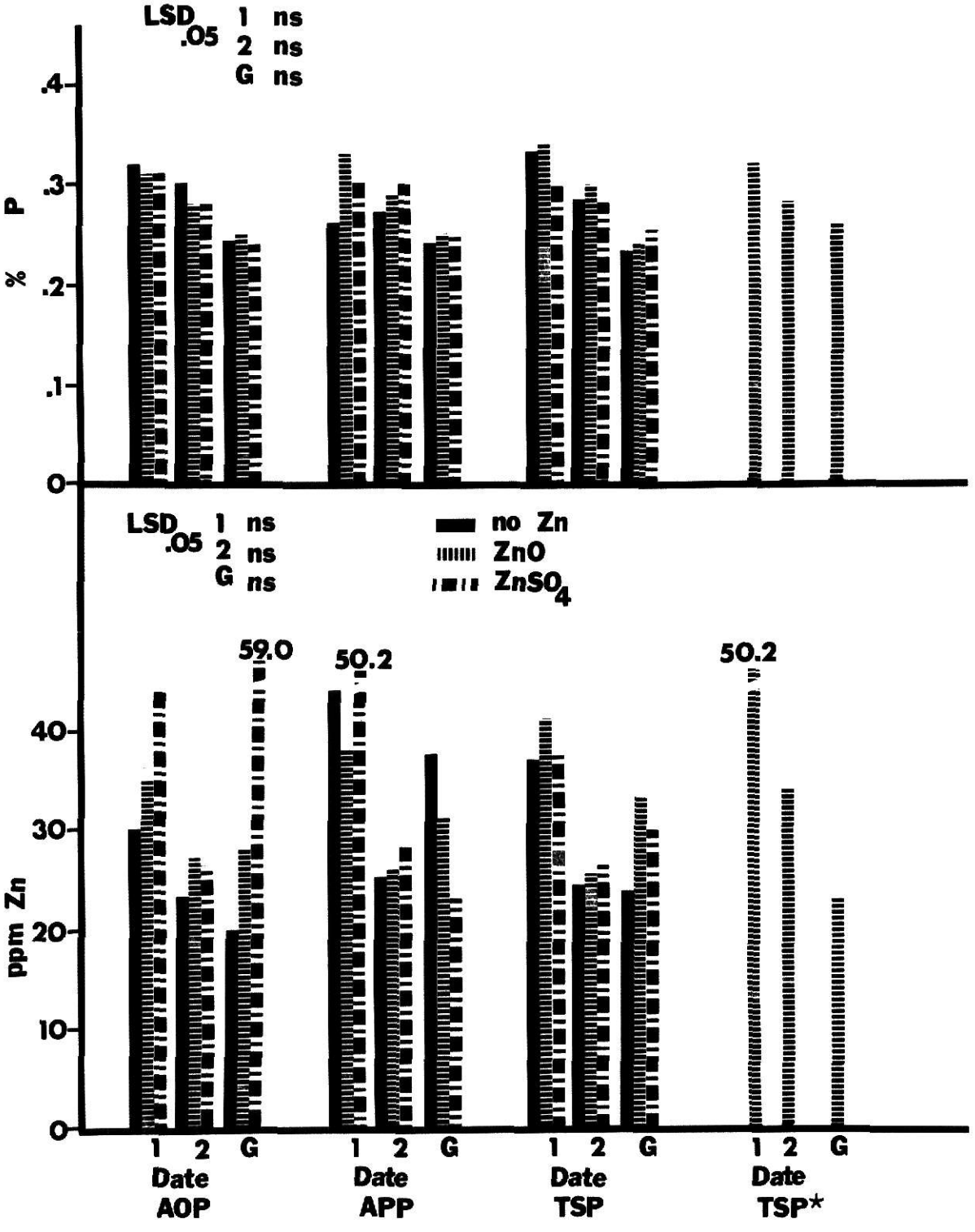

LSD .05 1 ns
2 ns
G ns
% P
.4
.3
.2
.1
0
LSD .05 1 ns
2 ns
G ns
no Zn
ZnO
ZnSO4
ppm Zn
40
30
20
10
0
59.0
50.2
50.2
1 2 G
Date
AOP
1 2 G
Date
APP
1 2 G
Date
TSP
1 2 G
Date
TSP*

Table 9. Yield of Irrigated Corn on Three Experimental Sites in Kansas. Yield in kg/ha. Comparisons of Zn sources and P sources.

Nutrient Rate		Carrier		Wallace Co.	Pawnee Co.	Sedgwick Co.
P kg/ha	Zn kg/ha	P	Zn	1969 kg/ha	1970 kg/ha	1970 kg/ha
0	0	-	-	5762	7211	6333
0	4.5	-	ZnO	6000	6521	5518
0	9.0	-	ZnO	4866	6834	5706
0	4.5	-	$ZnSO_4$	4232	7712	5204
0	9.0	-	$ZnSO_4$	6402	7649	4828
0	0	AOP	-	4445	6458	4703
0	0	APP	-	4972	7609	5079
0	0	TSP	-	4239	6834	4891
39	4.5	AOP	ZnO	7104	7524	6145
39	9.0	AOP	ZnO	5656	6834	6145
39	4.5	AOP	$ZnSO_4$	4126	8589	5706
39	9.0	AOP	$ZnSO_4$	6477	7775	4953
39	4.5	APP	ZnO	5362	7399	5382
39	9.0	APP	ZnO	4163	7211	5894
39	4.5	APP	$ZnSO_4$	3693	7022	6207
39	9.0	APP	$ZnSO_4$	5248	8151	4640
39	4.5	TSP[a]	ZnO	3938	6521	5455
39	9.0	TSP	ZnO	6477	7774	5329
39	4.5	TSP	$ZnSO_4$	5906	8214	5141
39	9.0	TSP	$ZnSO_4$	4471	7148	5455
39	4.5	TSP[b]	ZnO	5179	8590	5079
39	9.0	TSP	ZnO	5116	7587	6019
39	4.5	DAP[b]	ZnO	5091	6395	6019
39	9.0	DAP	ZnO	6013	7524	5894
$LSD_{.05}$				ns	ns	ns

a/ TVA formulated b/ American Cyanamid formulated

Table 10. Effects of ZnO and $ZnSO_4$ and three sources of P on the yield of irrigated grain sorghum and corn.

Nutrient Rate		Carrier		Stafford Co. 1969 Grain Sorghum	Pottawatomie Co. 1969 Corn
P kg/ha	Zn kg/ha	P	Zn	kg/ha	kg/ha
0	0	-	-	4765	6646
0	9	-	ZnO	5831	6019
0	9	-	$ZnSO_4$	6333	6207
39	0	AOP	-	6834	7336
39	0	APP	-	6333	6646
39	0	TSP	-	6458	7399
39	9	AOP	ZnO	6834	6270
39	9	AOP	$ZnSO_4$	6082	6646
39	9	APP	ZnO	6207	6333
39	9	APP	$ZnSO_4$	6270	6521
39	9	TSP[a/]	ZnO	5894	7022
39	9	TSP	$ZnSO_4$	6584	7022
39	9	TSP[b/]	ZnO	6019	7022
$LSD_{.05}$				ns	ns

a/ TVA Formulated

b/ American Cyanamid Formulated

Table 11. Effect of three sources of Zn and two sources of P on the yield of irrigated corn.

Nutrient Rate P kg/ha	Nutrient Rate Zn kg/ha	Carrier P	Carrier Zn	Wallace Co. 1969 kg/ha	Pawnee Co. 1970 kg/ha	Sedgwick Co. 1970 kg/ha
0	-	-	-	4076	6959	4326
59	-	APP	-	2822	7399	5392
59	-	AOP	-	3699	8151	4336
0	1.1	-	EDTA	4703	8151	4452
0	4.5	-	$ZnSO_4$	4389	7587	4765
0	4.5	-	Coop	3574	7273	5330
0	2.2	-	EDTA	5392	7587	4891
0	8.9	-	$ZnSO_4$	3825	7085	4828
0	8.9	-	Coop	5267	6897	4389
59	1.1	APP	EDTA	5392	6772	4703
59	4.5	APP	$ZnSO_4$	4013	8151	4953
59	4.5	APP	Coop	4204	7461	5267
59	2.2	APP	EDTA	5016	6584	4515
59	8.9	APP	$ZnSO_4$	6458	7399	5580
59	8.9	APP	Coop	5580	6709	5392
59	1.1	AOP	EDTA	5267	7399	4765
59	4.5	AOP	$ZnSO_4$	5392	8088	4264
59	4.5	AOP	Coop	5016	8088	4640
59	2.2	AOP	EDTA	4765	6960	5455
59	8.9	AOP	$ZnSO_4$	6834	7273	5518
59	8.9	AOP	Coop	6082	8465	4389
$LSD_{.05}$				2069	ns	ns

Table 12. Nutrient content of leaves and grain of irrigated grain sorghum as affected by source, form, and method of application. Stafford Co., 1969.

Zn kg/ha	Zn Carrier	Form	Application Method	Leaf				Grain	
				Zn		P			
				Date 1	Date 2	Date 1	Date 2	Zn	P
				ppm	ppm	%	%	ppm	%
0	-	10-34-0	Knifed	27.7	32.9	.26	.25	16.3	.24
0	-	10-34-0	Broadcast	20.8	20.3	.26	.25	22.2	.21
4.5	ZnO	Suspension	Knifed	29.6	30.2	.31	.29	16.6	.25
8.9	ZnO	Suspension	Knifed	40.1	27.5	.28	.27	44.6	.23
4.5	$ZnSO_4$	Suspension	Knifed	38.7	30.9	.32	.28	43.2	.21
8.9	$ZnSO_4$	Suspension	Knifed	48.3	27.1	.28	.30	27.0	.22
1.1	Reax	10-34-0-mix	Knifed	29.2	22.7	.33	.31	31.6	.23
2.2	Reax	10-34-0-mix	Knifed	28.3	30.4	.35	.28	34.4	.23
1.1	Key-el	10-34-0-mix	Knifed	28.8	24.3	.29	.27	48.0	.22
2.2	Key-el	10-34-0-mix	Knifed	30.8	22.9	.30	.27	26.7	.23
4.5	ZnO	Suspension	Broadcast	41.7	26.9	.22	.24	18.9	.21
8.9	ZnO	Suspension	Broadcast	39.9	35.2	.25	.24	40.0	.21
4.5	$ZnSO_4$	Suspension	Broadcast	36.7	45.4	.27	.19	20.7	.22
8.9	$ZnSO_4$	Suspension	Broadcast	38.2	30.6	.27	.30	38.4	.24
1.1	Reax	10-34-0-mix	Broadcast	32.2	25.2	.25	.26	34.5	.21
2.2	Reax	10-34-0-mix	Broadcast	35.0	29.9	.26	.25	39.8	.20
1.1	Key-el	10-34-0-mix	Broadcast	21.6	24.4	.28	.27	22.9	.27
2.2	Key-el	10-34-0-mix	Broadcast	29.3	32.2	.28	.28	38.5	.21
4.5	ZnO	APP-ZnO-Solid	Broadcast	32.7	37.6	.26	.29	42.0	.23
8.9	ZnO	APP-ZnO-Solid	Broadcast	37.3	40.2	.27	.28	19.7	.23
4.5	$ZnSO_4$	APP-$ZnSO_4$-Solid	Broadcast	31.6	44.9	.26	.28	17.7	.20
8.9	$ZnSO_4$	APP-$ZnSO_4$-Solid	Broadcast	33.4	31.4	.28	.28	45.6	.26
$LSD_{.05}$				11.6	ns	.05	ns	ns	ns

Table 13. Yield of irrigated grain sorghum as affected by source, form, and method of Zn application. Stafford Co., 1969.

Zn kg/ha	Zn Carrier	Form	Application Method	Yield kg/ha
0	-	10-34-0	Knifed	7399
0	-	10-34-0	Broadcast	8966
4.5	ZnO	Suspension	Knifed	8778
8.9	ZnO	Suspension	Knifed	8715
4.5	$ZnSO_4$	Suspension	Knifed	8214
8.9	$ZnSO_4$	Suspension	Knifed	8151
1.1	Reax	10-34-0-mix	Knifed	9781
2.2	Reax	10-34-0-mix	Knifed	8151
1.1	Key-el	10-34-0-mix	Knifed	8778
2.2	Key-el	10-34-0-mix	Knifed	8339
4.5	ZnO	Suspension	Broadcast	8633
8.9	ZnO	Suspension	Broadcast	7838
4.5	$ZnSO_4$	Suspension	Broadcast	8026
8.9	$ZnSO_4$	Suspension	Broadcast	8699
1.1	Reax	10-34-0-mix	Broadcast	7775
2.2	Reax	10-34-0-mix	Broadcast	8527
1.1	Key-el	10-34-0-mix	Broadcast	8402
2.2	Key-el	10-34-0-mix	Broadcast	8151
4.5	ZnO	APP-ZnO-Solid	Broadcast	9468
8.9	ZnO	APP-ZnO-Solid	Broadcast	8841
4.5	$ZnSO_4$	APP-$ZnSO_4$-Solid	Broadcast	8715
8.9	$ZnSO_4$	APP-$ZnSO_4$-Solid	Broadcast	8778
$LSD_{.05}$				ns

Growth Chamber Experiments

Corn plants were grown on two soil types that had been incubated at two different temperatures. Two growing temperatures were superimposed on the two incubation temperatures. Zinc and P contents of the shoots are presented in Figures 18 and 19, dry weights of the plants in Figure 20.

The most striking visual effects were the differences in plant growth caused by growing temperature. At the end of the growing period the plants grown at the lower temperature were about 20 cm tall while those grown at the higher temperature were over 60 cm in height. The shorter plants exhibited a yellowing of the leaves and the plants were generally abnormal. The leaves were twisted, the internodal length shortened and the entire plant stunted. Those plants grown at the higher temperature appeared normal with only a slight yellowing at harvest that could be attributed to iron becoming slightly deficient.

Plants grown on soil incubated at $5^{o}C$ (Fig. 18) were found to be quite high in Zn, particulary when grown at the lower temperature. Under these conditions Zn-Reax, ZnEDTA, and ZnO seemed to be able to supply more Zn to the plants than did the $ZnSO_4$. Zinc materials appeared to have little effect on P concentrations. It is interesting to note that at the lower growing temperature there was more total P in the plants grown on the calcareous soil while at the higher growing temperature the opposite is true.

In the case of the soil incubated at $30^{o}C$, Figure 19 shows that $ZnSO_4$ seemed to be less able to supply Zn than did the other

materials. Differences in P concentrations were not so marked in plants grown at the higher soil incubation temperature.

Dry weights (Fig. 20) reflected the effect of growing temperature more than any other treatment. The inorganic Zn sources seemed to favor plant growth at the higher growing temperature on the acid soil while on the calcareous soil the organic materials produced the highest mean dry weights.

Uptake of P and Zn are presented in Table 14. Plants grown on the acid soil exhibited a greater uptake of Zn-Reax and ZnO than ZnEDTA and $ZnSO_4$ with $ZnSO_4$ uptake the least. On the calcareous soil, however, the $ZnSO_4$ was equal to Zn-Reax and uptake of both of these Zn sources were less ZnO and ZnEDTA. With both soil types, the higher growing temperature produced the greatest Zn uptake. On the acid soil P uptake was affected only by temperature and in both cases the higher growing temperature produced the greatest P uptake.

The low incubation temperature favored the organics from the standpoint of plant appearance while the high incubation temperature favored the inorganics. These observations agree with the work of Bauer and Lindsay (1965). The organics needed little bacterial action to make them available for plant growth. The author feels that the organics were easily water soluble and the plant could absorb them easily. However, the oxide and the sulfate may need soil microbial action to make them available. The high temperature would make more indigenous soil Zn available for plant utilization. Another factor is plant growth. At the higher temperature the roots are growing rapidly and coming in

contact with a greater volume of the soil particles and soil solution.

Fig. 18 - Effects of 5°C incubation temperature, 4 sources of Zn, 2 soil types, and 2 growing temperatures on the Zn and P content of corn plants grown in a growth chamber.

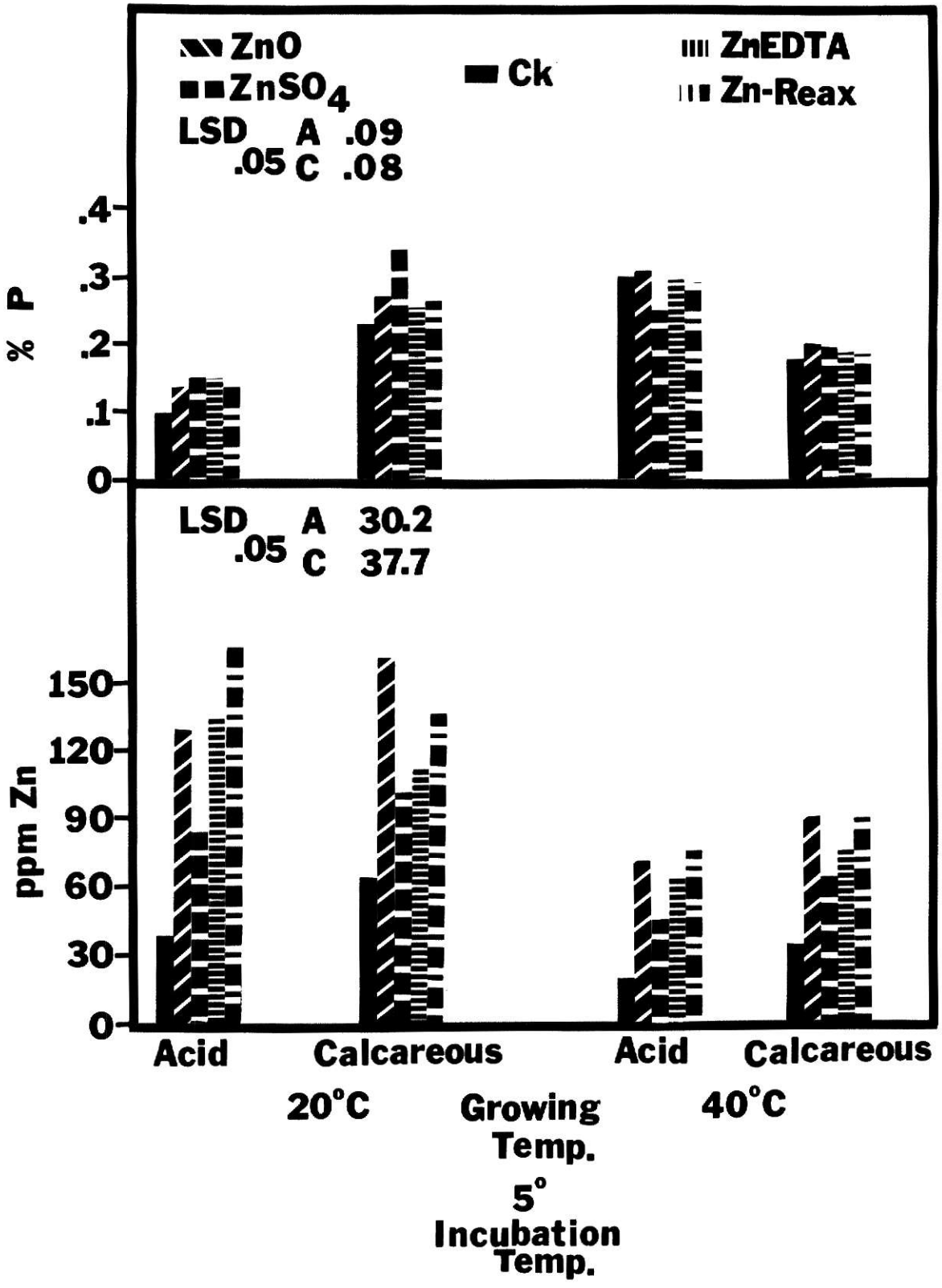

ZnO
ZnSO4
Ck
ZnEDTA
Zn-Reax
LSD .05 A .09
C .08
% P
.4
.3
.2
.1
0
LSD .05 A 30.2
C 37.7
ppm Zn
150
120
90
60
30
0
Acid
Calcareous
Acid
Calcareous
20°C
Growing Temp.
40°C
5°
Incubation Temp.

Fig. 19 - Effects of 30°C incubation temperature, 4 sources of Zn, 2 soil types, and 2 growing temperatures on the Zn and P content of corn plants grown in a growth chamber.

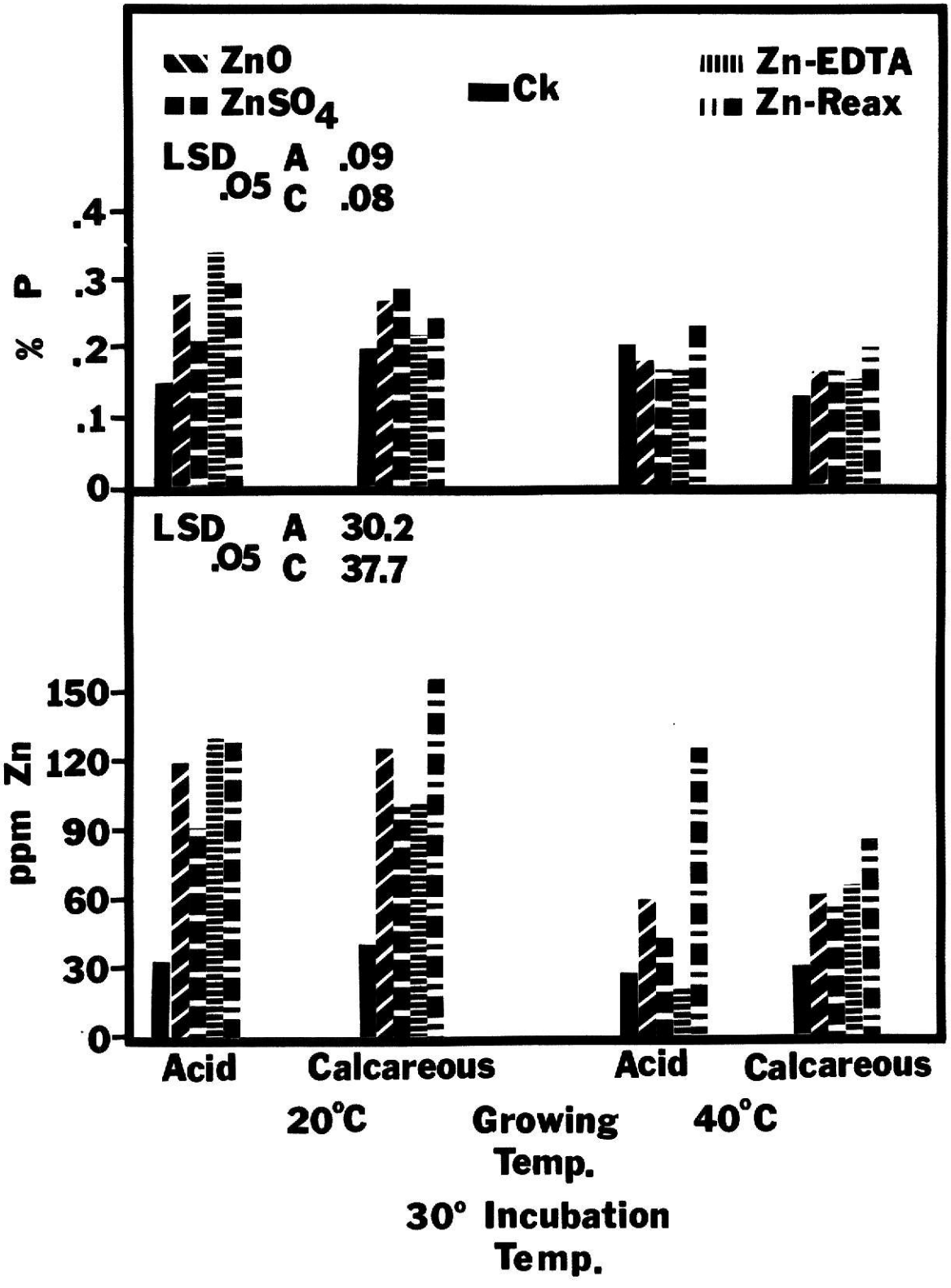

ZnO
ZnSO4
Ck
Zn-EDTA
Zn-Reax
LSD .05 A .09
C .08
% P
.4
.3
.2
.1
0
LSD .05 A 30.2
C 37.7
ppm Zn
150
120
90
60
30
0
Acid
Calcareous
Acid
Calcareous
20°C
Growing Temp.
40°C
30° Incubation Temp.

Fig. 20 - Effects of 4 sources of Zn, 2 soil types, 2 incubation temperatures, and 2 growing temperatures on the dry weight of corn plants grown in a growth chamber.

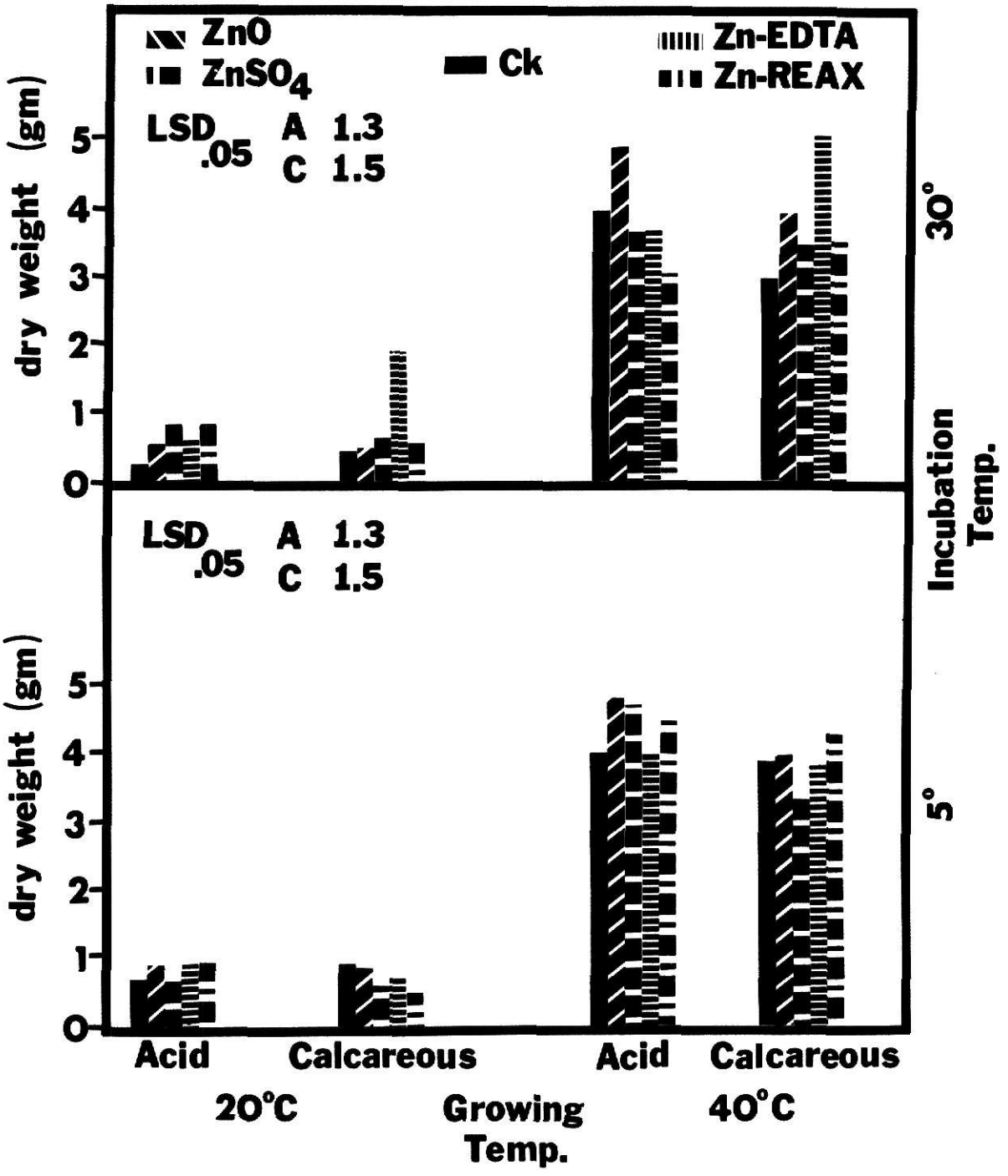

ZnO
ZnSO4
Ck
Zn-EDTA
Zn-REAX
LSD.05 A 1.3
C 1.5
dry weight (gm)
0
1
2
3
4
5
30°
Incubation Temp.
LSD.05 A 1.3
C 1.5
dry weight (gm)
5°
Acid
Calcareous
Acid
Calcareous
20°C
Growing Temp.
40°C

Table 14 Uptake of P and Zn by corn plants grown 34 days in growth chambers at two different growing temperatures and two soil types.

Treatment	Temperature		Acid soil		Cal. soil	
	Incubation	Growing	P mg/pot	Zn ug/pot	P mg/pot	Zn ug/pot
Ck	5°C	20°C	2.4	28.7	1.9	58.0
ZnO	5°C	20°C	2.9	112.3	2.0	135.4
$ZnSO_4$	5°C	20°C	1.7	61.2	1.9	60.2
ZnEDTA	5°C	20°C	2.8	112.3	2.7	107.2
Zn-Reax	5°C	20°C	3.3	156.1	1.4	72.3
Ck	5°C	40°C	8.8	79.1	7.0	130.8
ZnO	5°C	40°C	9.4	339.2	8.1	364.7
$ZnSO_4$	5°C	40°C	9.0	214.6	6.4	200.7
ZnEDTA	5°C	40°C	7.8	252.4	7.1	292.2
Zn-Reax	5°C	40°C	9.4	349.4	8.0	301.5
Ck	30°C	20°C	0.6	9.3	1.1	22.0
ZnO	30°C	20°C	1.5	65.3	1.5	71.9
$ZnSO_4$	30°C	20°C	1.7	74.8	1.8	64.2
ZnEDTA	30°C	20°C	2.1	87.4	3.7	164.8
Zn-Reax	30°C	20°C	2.4	107.6	1.6	99.3
Ck	30°C	40°C	7.8	105.4	4.0	101.5
ZnO	30°C	40°C	8.7	292.3	6.9	251.6
$ZnSO_4$	30°C	40°C	5.8	163.5	6.0	192.7
ZnEDTA	30°C	40°C	6.2	230.2	7.5	329.6
Zn-Reax	30°C	40°C	6.3	322.0	6.4	315.6
$LSD_{.05}$			2.6	110.5	2.6	128.4

CONCLUSIONS

Field Studies

Results of these investigations indicate that the various sources of Zn did have similar effects on Zn concentrations in corn and grain sorghum plants. The P sources (AOP, APP, TSP) were similar in their general effects on plant P content and yield. The differences in Zn uptake that did appear were possibly related to the pH characteristics of the P sources. Triple superphosphate, for example, had a pH of around 3.0 in solution, contact of this solution with the ZnO would have tended to make the oxide more available than contact with a solution of higher pH due to higher solubility of ZnO in an acid solution. This relationship is a possible reason why the TSP-ZnO combination produced the highest mean plant Zn content at the three field locations.

Growth Chamber Study

Under low soil incubation temperatures and low growth temperatures the organic Zn materials tended to supply more Zn to the plants. Higher growth temperature lessened this effect. In the case of the acid soil, the inorganic Zn sources were more effective at the higher growing temperature. The organic Zn sources, however, were slightly more effective on the calcareous soil, under the same growing conditions.

These results suggest that the organic sources, especially Zn-Reax should be more effective than the inorganic materials if both classes of carriers were applied early in the spring where

much cool weather growth of the crop was anticipated. As the soil temperature increased, organic and inorganic carriers might be equally effective. Soil pH could conceivably have an effect on the efficiency of the Zn carriers. Results of this investigation suggested some differences between materials according to the pH of the soil.

These studies, both field and growth chamber, indicate that performance of the inorganic Zn sources generally equaled that of the organic materials. These results suggest that selection of a Zn carrier from among the four used in the investigation should be based primarily on cost of the metal.

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VITA

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APPENDIX

Table I. Effects of P carriers, Zn carriers, and rates of Zn application of the yield and composition of irrigated corn, Wallace county, 1969.

Nutrient Rate kg/ha		Carriers		June 25-leaf		July 28-leaf		Yield
				Zn	P	Zn	P	
P	Zn	P	Zn	ppm	%	ppm	%	kg/ha
0	0	-	-	51.6	.36	25.3	.30	5762
0	4.5	-	ZnO	40.8	.36	31.3	.30	6000
0	8.9	-	ZnO	39.5	.36	24.1	.29	4866
0	4.5	-	$ZnSO_4$	51.4	.36	29.0	.29	4232
0	8.9	-	$ZnSO_4$	40.7	.36	32.7	.28	6402
39	0	AOP	-	41.2	.36	25.1	.29	4445
39	0	APP	-	44.5	.36	22.5	.30	4972
39	0	TSP	-	41.6	.36	24.3	.30	4239
39	4.5	AOP	ZnO	36.4	.35	29.0	.31	7104
39	8.9	AOP	ZnO	37.8	.35	22.0	.30	5656
39	4.5	AOP	$ZnSO_4$	48.4	.36	28.0	.28	4126
39	8.9	AOP	$ZnSO_4$	52.6	.37	28.7	.29	6477
39	4.5	APP	ZnO	36.3	.36	28.5	.29	5392
39	8.9	APP	ZnO	38.8	.35	22.8	.28	4163
39	4.5	APP	$ZnSO_4$	45.6	.35	33.2	.29	3693
39	8.9	APP	$ZnSO_4$	39.9	.36	24.9	.29	5248
39	4.5	TSP[a/]	ZnO	43.8	.36	28.4	.28	3938
39	8.9	TSP	ZnO	41.8	.37	38.2	.28	6477
39	4.5	TSP	$ZnSO_4$	37.8	.33	23.5	.29	5906
39	8.9	TSP	$ZnSO_4$	52.7	.37	23.2	.29	4471
39	4.5	TSP[b/]	ZnO	40.6	.35	26.0	.29	5179
39	8.9	TSP	ZnO	42.0	.35	16.5	.27	5116
39	4.5	DAP[b/]	ZnO	77.7	.37	23.7	.29	5091
39	8.9	DAP	ZnO	45.9	.37	27.2	.29	6013
$LSD_{.05}$				ns	ns	ns	ns	ns

a/ TVA formulated
b/ American Cyanamid formulated

Table II. Effects of P carriers, Zn carriers and rates of Zn application on the yield and composition of irrigated corn. Pawnee county, 1970.

Nutrient Rate kg/ha		Carriers		June 24-leaf		July 14-leaf		Grain		Yield
				Zn	P	Zn	P	Zn	P	
P	Zn	P	Zn	ppm	%	ppm	%	ppm	%	kg/ha
0	-	-	-	19.1	.30	15.6	.29	16.8	.13	7211
0	4.5	-	ZnO	24.1	.29	20.5	.28	22.9	.13	6521
0	8.9	-	ZnO	26.8	.28	26.5	.27	19.5	.12	6834
0	4.5	-	$ZnSO_4$	25.6	.27	17.3	.28	16.4	.13	7712
0	8.9	-	$ZnSO_4$	30.0	.31	21.9	.27	24.5	.14	7649
39	-	AOP	-	18.7	.39	16.4	.30	14.2	.15	6458
39	-	APP	-	13.5	.42	19.3	.29	16.0	.11	6709
39	-	TSP	-	21.0	.42	15.0	.34	17.4	.12	6834
39	4.5	AOP	ZnO	21.9	.36	20.4	.31	22.7	.11	7524
39	8.9	AOP	ZnO	17.6	.37	21.4	.29	25.8	.13	6834
39	4.5	AOP	$ZnSO_4$	19.6	.37	20.0	.32	17.8	.10	8589
39	8.9	AOP	$ZnSO_4$	35.7	.36	16.5	.30	18.4	.12	7757
39	4.5	APP	ZnO	25.8	.34	26.0	.28	20.2	.14	7399
39	8.9	APP	ZnO	27.5	.34	21.5	.29	22.1	.13	7211
39	4.5	APP	$ZnSO_4$	18.2	.33	21.0	.30	21.9	.10	7022
39	8.9	APP	$ZnSO_4$	24.5	.35	23.3	.30	19.3	.10	8151
39	4.5	TSP[a]	ZnO	25.8	.34	19.1	.31	18.6	.14	6521
39	8.9	TSP	ZnO	29.9	.35	26.4	.30	19.7	.13	7774
39	4.5	TSP	$ZnSO_4$	27.7	.36	22.8	.30	19.5	.13	8214
39	8.9	TSP	$ZnSO_4$	27.8	.34	19.0	.30	19.2	.11	7148
39	4.5	TSP[b]	ZnO	25.3	.35	23.8	.31	18.4	.10	8590
39	8.9	TSP	ZnO	25.9	.36	20.4	.31	19.8	.13	7587
39	4.5	DAP[b]	ZnO	20.6	.35	20.8	.28	19.1	.12	6395
39	8.9	DAP	ZnO	20.7	.35	25.6	.30	21.0	.13	7524
$LSD_{.05}$	Treatment			ns	.06	ns	ns	ns	ns	ns
	Zn Rate				ns					
	Zn Carrier				ns					
	P Carrier				ns					
	Zn rate X Zn carrier				ns					
	Zn rate X P carrier				ns					
	P X Zn carrier				ns					
	3 way interaction				ns					

[a] TVA formulated [b] American Cyanamid formulated

Table III. Effects of P carriers, Zn carriers and rates of Zn application on the yield and composition of irrigated corn, Sedgwick county, 1970.

Nutrient Rate kg/ha		Carriers		June 10-leaf		July 16-leaf		Grain		Yield
				Zn	P	Zn	P	Zn	P	
P	Zn	P	Zn	ppm	%	ppm	%	ppm	%	kg/ha
0	0	-	-	44.6	.31	41.3	.25	20.2	.17	6333
0	4.5	-	ZnO	38.8	.30	35.8	.24	17.8	.14	5518
0	9	-	ZnO	38.9	.31	60.0	.22	19.2	.15	5706
0	4.5	-	$ZnSO_4$	26.7	.30	48.3	.25	19.6	.14	5204
0	9	-	$ZnSO_4$	34.5	.32	41.5	.25	20.2	.14	4828
39	0	AOP	-	31.0	.33	33.5	.23	17.7	.14	4703
39	0	APP	-	32.4	.33	22.8	.25	17.9	.16	5079
39	0	TSP	-	31.2	.33	35.8	.25	15.8	.14	4891
39	4.5	AOP	ZnO	32.3	.33	26.9	.24	17.2	.14	6145
39	9	AOP	ZnO	27.8	.34	24.4	.26	14.4	.16	6145
39	4.5	AOP	$ZnSO_4$	33.7	.33	27.7	.27	17.0	.16	5706
39	9	AOP	$ZnSO_4$	33.3	.36	29.6	.27	18.3	.16	4953
39	4.5	APP	ZnO	32.9	.35	30.0	.25	17.4	.14	5392
39	9	APP	ZnO	34.2	.33	30.4	.30	17.4	.14	5894
39	4.5	APP	$ZnSO_4$	34.8	.33	32.9	.27	16.7	.14	6207
39	9	APP	$ZnSO_4$	76.7	.33	46.3	.26	18.2	.14	4640
39	4.5	TSP[a/]	ZnO	35.7	.35	24.8	.28	16.4	.15	5455
39	9	TSP	ZnO	36.0	.35	51.6	.26	17.6	.15	5329
39	4.5	TSP	$ZnSO_4$	37.6	.33	34.9	.27	18.2	.15	5141
39	9	TSP	$ZnSO_4$	43.7	.34	28.7	.27	16.3	.15	5455
39	4.5	TSP[b/]	ZnO	40.4	.35	22.3	.26	18.7	.15	5079
39	9	TSP	ZnO	35.3	.34	24.7	.27	17.2	.16	6019
39	4.5	DAP[b/]	ZnO	40.1	.35	41.3	.27	17.3	.15	6019
39	9	DAP	ZnO	37.8	.32	29.5	.25	16.8	.15	5894
$LSD_{.05}$	Treatment			19.6	.02	20.8	ns	ns	ns	ns
	Zn Rate			ns	ns	ns				
	Zn Carrier			ns	ns	ns				
	P Carrier			ns	ns	ns				
	Zn rate X Zn carrier			ns	ns	ns				
	Zn rate X P carrier			ns	ns	ns				
	P X Zn carrier			ns	ns	ns				
	3 way interaction			ns	ns	sig				

[a/] TVA formulated [b/] American Cyanamid formulated

Table IV. Comparisons of three forms of Zn, and two forms of P on the yield and composition of irrigated corn, Wallace County, 1969.

Nutrient Rate kg/ha		Carriers		June 25-leaf		July 28-leaf		Yield
				Zn	P	Zn	P	
P	Zn	P	Zn	ppm	%	ppm	%	kg/ha
0	0	-	-	38.6	.31	30.2	.27	4076
59	0	APP	-	35.3	.33	25.4	.29	2822
59	0	AOP	-	38.2	.32	22.8	.27	3699
0	1.1	-	EDTA	35.9	.32	23.9	.28	4703
0	4.5	-	$ZnSO_4$	37.9	.32	31.4	.30	4389
0	4.5	-	Coop	57.4	.33	32.0	.28	3574
0	2.2	-	EDTA	30.4	.26	30.7	.29	5392
0	9	-	$ZnSO_4$	35.7	.33	44.6	.28	3825
0	9	-	Coop	38.0	.33	27.3	.27	5267
59	1.1	APP	EDTA	40.7	.34	30.1	.30	5392
59	4.5	APP	$ZnSO_4$	30.6	.32	33.1	.28	4013
59	4.5	APP	Coop	41.3	.33	27.2	.28	4201
59	2.2	APP	EDTA	41.3	.33	45.6	.29	5016
59	9	APP	$ZnSO_4$	42.5	.31	27.8	.27	6458
59	9	APP	Coop	56.6	.32	30.4	.28	5580
59	1.1	AOP	EDTA	53.2	.34	27.6	.28	5267
59	4.5	AOP	$ZnSO_4$	41.5	.33	27.0	.28	5392
59	4.5	AOP	Coop	53.3	.33	26.5	.29	5016
59	2.2	AOP	EDTA	37.1	.33	39.2	.30	4765
59	9	AOP	$ZnSO_4$	46.1	.31	35.9	.29	6834
59	9	AOP	Coop	44.6	.34	42.8	.28	6082
$LSD_{.05}$				ns	ns	ns	ns	2069

Table V. Comparison of three forms of Zn, and two forms of P on the yield and composition of irrigated corn, Pawnee county, 1970.

Nutrient Rate kg/ha		Carriers		June 24-leaf		July 14-leaf		Grain		Yield
				Zn	P	Zn	P	Zn	P	
P	Zn	P	Zn	ppm	%	ppm	%	ppm	%	kg/ha
0	0	-	-	32.6	.31	23.0	.29	19.1	.19	6959
59	0	APP	-	19.7	.37	19.6	.32	16.7	.18	7399
59	0	AOP	-	19.8	.39	21.8	.31	16.8	.17	8151
0	1.1	-	EDTA	26.9	.32	26.5	.31	20.4	.18	8151
0	4.5	-	$ZnSO_4$	34.1	.36	26.6	.30	20.6	.18	7587
0	4.5	-	Coop	34.7	.32	27.3	.31	22.9	.17	7273
0	2.2	-	EDTA	32.6	.26	27.9	.28	23.5	.17	7587
0	9	-	$ZnSO_4$	40.8	.33	29.0	.30	21.0	.19	7085
0	9	-	Coop	32.5	.33	25.8	.29	20.6	.17	6897
59	1.1	APP	EDTA	63.5	.32	25.3	.28	22.8	.21	6772
59	4.5	APP	$ZnSO_4$	31.8	.37	23.9	.31	18.3	.17	8151
59	4.5	APP	Coop	33.0	.37	27.3	.30	21.1	.19	7461
59	2.2	APP	EDTA	35.0	.39	31.4	.31	21.4	.21	6584
59	9	APP	$ZnSO_4$	38.8	.37	27.6	.32	20.3	.18	7399
59	9	APP	Coop	26.3	.38	24.9	.31	20.2	.20	6709
59	1.1	AOP	EDTA	28.8	.40	28.8	.32	18.2	.18	7399
59	4.5	AOP	$ZnSO_4$	29.2	.40	24.3	.31	19.0	.19	8088
59	4.5	AOP	Coop	43.7	.40	21.4	.31	21.3	.19	8088
59	2.2	AOP	EDTA	36.3	.34	26.7	.30	20.6	.20	6960
59	9	AOP	$ZnSO_4$	27.0	.37	32.9	.31	19.0	.19	7273
59	9	AOP	Coop	22.5	.38	30.9	.31	19.7	.19	8465
$LSD_{.05}$	Treatment			19.5	.05	ns	ns	ns	.02	ns
	P carrier			ns	ns				ns	
	Zn carrier			ns	ns				ns	
	P X Zn carrier			ns	ns				ns	

Table VI. Comparisons of three forms of Zn and two forms of P on the yield and composition of irrigated corn, Sedgwick County, 1970.

Nutrient Rate kg/ha		Carriers		June 10-leaf		July 16-leaf		Grain		Yield
				Zn	P	Zn	P	Zn	P	
P	Zn	P	Zn	ppm	%	ppm	%	ppm	%	kg/ha
0	0	-	-	41.1	.34	26.7	.27	20.4	.26	4326
59	0	APP	-	47.0	.35	19.0	.28	34.8	.26	5392
59	0	AOP	-	38.0	.37	27.1	.29	17.2	.28	4326
0	1.1	-	EDTA	48.0	.35	30.1	.27	21.7	.25	4452
0	4.5	-	$ZnSO_4$	51.5	.33	25.1	.24	21.0	.24	4765
0	4.5	-	Coop	42.4	.31	31.4	.27	40.1	.24	5330
0	2.2	-	EDTA	45.9	.33	36.4	.27	24.0	.25	4891
0	9	-	$ZnSO_4$	46.7	.32	30.9	.27	28.2	.24	4828
0	9	-	Coop	50.6	.33	33.0	.27	24.4	.25	4389
59	1.1	APP	EDTA	51.7	.35	26.5	.28	20.5	.27	4703
59	4.5	APP	$ZnSO_4$	43.7	.37	26.9	.31	22.3	.27	4953
59	4.5	APP	Coop	45.6	.34	24.0	.30	23.8	.27	5267
59	2.2	APP	EDTA	46.1	.37	26.2	.28	20.5	.25	4514
59	9	APP	$ZnSO_4$	51.8	.36	36.3	.29	26.3	.24	5580
59	9	APP	Coop	42.7	.37	24.2	.31	19.9	.28	5392
59	1.1	AOP	EDTA	39.9	.37	22.8	.29	34.7	.28	4765
59	4.5	AOP	$ZnSO_4$	39.7	.35	20.9	.27	22.5	.27	4264
59	4.5	AOP	Coop	52.8	.40	26.9	.30	20.3	.26	4640
59	2.2	AOP	EDTA	47.1	.37	25.9	.31	18.7	.26	5455
59	9	AOP	$ZnSO_4$	47.5	.37	34.4	.29	20.0	.26	5518
59	9	AOP	Coop	43.9	.33	26.4	.31	18.6	.26	4389
$LSD_{.05}$		Treatment		ns	.04	ns	ns	ns	ns	ns
		P Carrier			ns					
		Zn Carrier			ns					
		P X Zn Carrier			ns					

Table VII. Comparisons of two forms of Zn and two forms of P on the yield and composition of irrigated corn, Pottawatomie county, 1969.

Nutrient Rate kg/ha		Carriers		July 1-leaf		July 29-leaf		Grain		Yield
				Zn	P	Zn	P	Zn	P	
P	Zn	P	Zn	ppm	%	ppm	%	ppm	%	kg/ha
0	0	-	-	26.4	.21	30.8	.29	30.8	.25	6646
0	9	-	ZnO	30.8	.19	34.7	.27	30.4	.27	6019
0	9	-	$ZnSO_4$	31.8	.22	28.8	.28	32.7	.26	6207
39	0	AOP	-	22.0	.25	21.6	.32	51.7	.29	7336
39	0	APP	-	24.8	.25	25.8	.32	24.8	.27	6646
39	0	TSP	-	26.7	.30	22.0	.35	40.2	.28	7399
39	9	AOP	ZnO	27.4	.26	22.7	.33	36.7	.29	6270
39	9	AOP	$ZnSO_4$	26.8	.29	28.6	.33	31.6	.27	6646
39	9	APP	ZnO	30.3	.26	26.3	.34	24.3	.28	6333
39	9	APP	$ZnSO_4$	29.5	.27	26.8	.33	23.7	.26	6521
39	9	TSP[a/]	ZnO	30.4	.29	22.2	.34	23.0	.27	7022
39	9	TSP[a/]	$ZnSO_4$	31.7	.28	43.1	.32	32.9	.28	7022
39	9	TSP[b/]	ZnO	28.5	.23	33.0	.29	40.9	.23	7022
$LSD_{.05}$	Treatment			4.1	.05	ns	ns	ns	ns	ns
	P Carrier			ns	.03					
	Zn Carrier			ns	ns					
	P X Zn Carrier			ns	ns					

a/ TVA formulated
b/ American Cyanamid formulated

Table VIII. Comparisons of two forms of Zn and two forms of P on the yield and composition of irrigated grain sorghum, Stafford county, 1969.

Nutrient Rate kg/ha		Carriers		July 7-leaf		Aug. 13-leaf		Grain		Yield
				Zn	P	Zn	P	Zn	P	
P	Zn	P	Zn	ppm	%	ppm	%	ppm	%	kg/ha
0	0	-	-	36.9	.25	28.5	.25	27.1	.22	4765
0	9	-	ZnO	40.2	.30	25.7	.26	29.9	.24	5831
0	9	-	$ZnSO_4$	37.6	.27	30.2	.25	29.8	.23	6333
39	0	AOP	-	30.1	.32	22.6	.30	19.3	.24	6834
39	0	APP	-	44.0	.26	24.1	.27	37.5	.24	6333
39	0	TSP	-	35.6	.33	23.9	.28	23.0	.23	6458
39	9	AOP	ZnO	35.1	.31	27.0	.28	28.4	.25	6834
39	9	AOP	$ZnSO_4$	43.8	.31	26.1	.28	59.0	.24	6082
39	9	APP	ZnO	38.2	.33	26.0	.29	31.3	.25	6207
39	9	APP	$ZnSO_4$	50.2	.30	28.4	.30	21.8	.25	6270
39	9	TSP[a/]	ZnO	41.0	.34	25.6	.30	33.1	.24	5894
39	9	TSP[a/]	$ZnSO_4$	38.0	.30	26.5	.28	30.2	.25	6584
39	9	TSP[b/]	ZnO	50.2	.32	32.4	.28	22.9	.26	6019
$LSD_{.05}$				ns	ns	ns	ns	ns	ns	ns

a/ TVA Formulated
b/ American Cyanamid formulated

Table IX. Effects of P form, zn carriers, and rates of Zn application on the yield and composition of irrigated grain sorghum, Stafford county, 1969.

Zn Rate	Carrier	Form	Method	July 7-leaf					Aug. 13-leaf	
				Zn ppm	Fe ppm	Cu ppm	Mn ppm	P %	Zn ppm	P %
0	-	-	Knifed	27.7	139.8	30.8	132.1	.26	33.0	.25
0	-	-	Broadcast	20.7	45.1	10.4	32.7	.26	20.3	.25
4.5	ZnO	Suspension	Knifed	29.6	123.5	36.9	155.8	.31	30.2	.29
9	ZnO	Suspension	Knifed	40.1	38.7	8.1	32.2	.28	27.5	.28
4.5	$ZnSO_4$	Suspension	Knifed	38.7	197.4	41.5	174.8	.32	31.0	.28
9	$ZnSO_4$	Suspension	Knifed	48.3	41.3	8.8	35.6	.28	27.1	.30
1.1	Reax	10-34-0-mix	Knifed	29.2	41.9	9.0	41.3	.33	22.7	.31
2.2	Reax	10-34-0-mix	Knifed	28.3	140.5	30.7	146.7	.34	30.4	.28
1.1	Key-el	10-34-0-mix	Knifed	28.8	233.0	52.9	187.1	.29	24.3	.27
2.2	Key-el	10-34-0-mix	Knifed	30.8	208.0	43.9	117.6	.30	22.9	.27
4.5	ZnO	Suspension	Broadcast	41.7	136.2	25.0	95.5	.22	27.0	.24
9	ZnO	Suspension	Broadcast	39.9	269.5	74.3	253.1	.25	35.2	.24
4.5	$ZnSO_4$	Suspension	Broadcast	36.7	96.4	32.0	96.4	.27	45.4	.19
9	$ZnSO_4$	Suspension	Broadcast	38.2	39.1	8.7	34.5	.27	30.6	.30
1.1	Reax	10-34-0-mix	Broadcast	38.2	294.4	68.5	246.8	.25	25.1	.26
2.2	Reax	10-34-0-mix	Broadcast	35.0	295.5	72.9	252.3	.26	29.9	.25
1.1	Key-el	10-34-0-mix	Broadcast	21.6	157.0	35.7	144.1	.28	24.4	.27
2.2	Key-el	10-34-0-mix	Broadcast	29.4	41.1	10.5	40.4	.28	32.2	.28
4.5	ZnO	APP-ZnO[a/]	Broadcast	32.7	141.8	37.3	143.3	.27	37.6	.29
9	ZnO	APP-ZnO[a/]	Broadcast	37.3	146.1	40.3	145.8	.27	40.2	.28
4.5	$ZnSO_4$	APP-$ZnSO_4$[a/]	Broadcast	31.6	184.2	40.3	187.5	.26	44.9	.29
9	$ZnSO_4$	APP-$ZnSO_4$[a/]	Broadcast	33.4	94.2	29.5	99.5	.28	31.4	.29
$LSD_{.05}$				11.6	ns	ns	ns	.05	ns	ns
	Zn Carrier			ns				ns		
	Zn Form			4.3				ns		
	Application Method			ns				.02		
	Zn Carrier X Zn Form			ns				sig		
	Zn Carrier X Method			ns				ns		
	3 way interaction			ns				ns		

[a/] TVA Formulated

Table IX. (Continued)

Zn Rate	Carrier	Form	Method	Zn ppm	P %	Yield kg/ha
0	-	-	Knifed	16.3	.24	7399
0	-	-	Broadcast	22.2	.21	8966
4.5	ZnO	Suspension	Knifed	16.6	.25	8778
9	ZnO	Suspension	Knifed	44.6	.23	8715
4.5	$ZnSO_4$	Suspension	Knifed	43.2	.21	8214
9	$ZnSO_4$	Suspension	Knifed	27.0	.22	8151
1.1	Reax	10-34-0-mix	Knifed	31.7	.23	9781
2.2	Reax	10-34-0-mix	Knifed	34.4	.23	8151
1.1	Key-el	10-34-0-mix	Knifed	48.0	.22	8778
2.2	Key-el	10-34-0-mix	Knifed	26.7	.23	8339
4.5	ZnO	Suspension	Broadcast	18.9	.21	8653
9	ZnO	Suspension	Broadcast	40.1	.21	7838
4.5	$ZnSO_4$	Suspension	Broadcast	20.7	.22	8026
9	$ZnSO_4$	Suspension	Broadcast	38.4	.24	8966
1.1	Reax	10-34-0-mix	Broadcast	34.6	.21	7775
2.2	Reax	10-34-0-mix	Broadcast	39.8	.20	8527
1.1	Key-el	10-34-0-mix	Broadcast	23.0	.27	8402
2.2	Key-el	10-34-0-mix	Broadcast	38.5	.21	8151
4.5	ZnO	APP-ZnO[a/]	Broadcast	42.0	.23	9468
9	ZnO	APP-ZnO[a/]	Broadcast	19.7	.23	8841
4.5	$ZnSO_4$	APP-$ZnSO_4$[a/]	Broadcast	17.7	.20	8715
9	$ZnSO_4$	APP-$ZnSO_4$[a/]	Broadcast	45.6	.26	8778
				ns	ns	ns

[a/] TVA Formulated

Table X. Nutrient content of corn plants grown 34 days in growth chambers at 2 different growing temperatures and on an acid soil type.

TrT	Temp. Inc.	Temp. Grow.	Zn ppm	Fe ppm	Cu ppm	Mn ppm	P %	Dry wt (gm)	Uptake Zn ugm/pot	Uptake P mg/pot
Ck	5°C	20°C	38.0	84.3	11.6	69.2	.33	.7	28.7	2.4
ZnO	5°C	20°C	128.2	72.3	8.8	62.8	.33	.9	112.3	2.9
$ZnSO_4$	5°C	20°C	85.6	62.3	9.1	54.4	.26	.7	61.2	1.7
EDTA	5°C	20°C	136.8	71.8	11.1	54.7	.31	.9	112.3	2.8
Reax	5°C	20°C	169.1	83.4	10.9	66.3	.36	.9	156.1	3.3
Ck	5°C	40°C	19.3	63.1	9.0	51.0	.21	4.2	79.1	8.8
ZnO	5°C	40°C	71.3	114.0	6.9	50.5	.20	4.8	339.2	9.4
$ZnSO_4$	5°C	40°C	46.6	83.3	6.3	46.4	.20	4.7	214.6	9.0
EDTA	5°C	40°C	62.2	66.9	5.4	39.2	.19	4.0	252.4	7.8
Reax	5°C	40°C	77.6	68.4	8.4	39.5	.21	4.5	349.4	9.4
Ck	30°C	20°C	33.1	49.5	6.0	33.5	.15	.3	9.3	0.6
ZnO	30°C	20°C	119.8	101.4	8.9	60.6	.28	.5	65.3	1.5
$ZnSO_4$	30°C	20°C	92.7	69.0	8.5	61.3	.22	.8	74.8	1.7
EDTA	30°C	20°C	137.9	72.7	8.7	52.0	.34	.6	87.4	2.1
Reax	30°C	20°C	130.6	72.1	9.2	56.6	.30	.8	107.6	2.4
Ck	30°C	40°C	25.6	68.2	6.6	47.0	.21	3.9	105.4	7.8
ZnO	30°C	40°C	60.3	60.6	5.2	37.4	.18	4.9	292.3	8.7
$ZnSO_4$	30°C	40°C	42.4	54.1	6.8	58.1	.17	3.7	162.5	5.8
EDTA	30°C	40°C	60.2	64.1	8.2	41.6	.17	3.7	230.2	6.2
Reax	30°C	40°C	126.2	65.6	7.1	58.1	.24	3.0	322.0	6.3
$LSD_{.05}$			30.2	ns	ns	20.6	.08	1.3	110.5	2.6
Zn Carrier			15.9			ns	.05	ns	61.0	ns
Incubation Temp			ns			ns	ns	ns	ns	.9
Growing Temp			11.2			5.9	.03	0.5	43.1	.9
Zn X Inc. Temp			ns			ns	ns	ns	ns	ns
Zn X Grow. Temp			ns			ns	ns	ns	ns	ns
Inc. X Grow. Temp			ns			ns	ns	ns	ns	ns
3 way interaction			sig			ns	ns	ns	ns	ns

Table XI. Nutrient content of corn plants grown 34 days in growth chambers at 2 different growing temperatures and on a calcareous soil.

TrT	Temp. Inc.	Temp. Grow.	Zn ppm	Fe ppm	Cu ppm	Mn ppm	P %	Dry wt (gm)	Uptake Zn ugm/pot	Uptake P mg/pot
Ck	5°C	20°C	64.3	85.1	8.8	54.5	.23	.9	58.0	1.9
ZnO	5°C	20°C	159.6	83.6	11.2	61.5	.28	.8	135.4	2.0
$ZnSO_4$	5°C	20°C	105.9	82.9	15.2	61.6	.34	.6	60.2	1.9
EDTA	5°C	20°C	112.0	67.1	11.8	53.9	.25	.8	107.2	2.7
Reax	5°C	20°C	134.2	73.0	11.8	43.4	.27	.5	72.3	1.4
Ck	5°C	40°C	35.1	66.4	9.4	68.0	.19	3.9	130.8	7.0
ZnO	5°C	40°C	91.1	62.1	8.7	63.4	.20	4.0	364.7	8.1
$ZnSO_4$	5°C	40°C	61.4	57.3	10.4	53.6	.20	3.3	200.7	6.4
EDTA	5°C	40°C	77.3	63.3	9.4	53.7	.19	3.8	292.2	7.1
Reax	5°C	40°C	92.0	56.7	7.1	43.2	.18	4.3	301.5	8.0
Ck	30°C	20°C	39.5	57.9	9.1	60.4	.20	.6	22.0	1.1
ZnO	30°C	20°C	126.9	80.8	11.1	66.1	.27	.6	71.9	1.5
$ZnSO_4$	30°C	20°C	100.2	78.6	12.0	66.7	.30	.6	64.2	1.8
EDTA	30°C	20°C	109.3	74.7	10.1	54.7	.22	1.9	164.8	3.7
Reax	30°C	20°C	157.1	76.3	12.5	65.5	.25	.6	9.93	1.6
Ck	30°C	40°C	33.5	70.4	7.3	50.2	.13	3.0	101.5	4.0
ZnO	30°C	40°C	61.8	57.1	8.5	45.9	.17	4.0	251.6	6.9
$ZnSO_4$	30°C	40°C	57.8	55.6	8.4	53.7	.18	3.5	192.7	6.0
EDTA	30°C	40°C	66.2	46.4	6.1	34.4	.15	5.1	329.6	7.5
Reax	30°C	40°C	86.2	44.8	6.9	58.8	.18	3.6	315.6	6.4
$LSD_{.05}$			37.7	21.0	4.3	ns	.09	1.5	128.4	2.6
Zn Carrier			20.3	ns	ns		ns	0.6	69.6	ns
Incubation Temp			ns	ns	ns		ns	ns	ns	ns
Growing Temp			14.4	6.3	1.6		.03	0.4	49.2	0.8
Zn Carrier X Inc. Temp			ns	ns	ns		ns	ns	ns	ns
Zn Carrier X Grow. Temp			ns	ns	ns		ns	ns	ns	ns
Grow. X Inc.			ns	ns	ns		ns	ns	ns	ns
3 way interaction			ns	ns	ns		ns	ns	ns	ns

ZINC OXIDE AND ZINC SULFATE AS ZINC SOURCES FOR *ZEA MAYS* AND *SORGHUM VULGARE*

by

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AN ABSTRACT OF A MASTER'S THESIS

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Zinc was applied in several forms either coated on the surface of a P carrier or in solution or suspension with a P carrier. These materials were applied preplant to either corn (Zea mays L.) or grain sorghum (Sorghum vulgare Pers.).

Application of 4.5 and 8.9 kg Zn/ha tended to increase Zn content in corn plants at all field locations in 1969 and 1970. Response to Zn coated on either triple superphosphate (TSP), ammonium orthophosphate (AOP), or ammonium polyphosphate (APP) was inconsistent from location to location. Some depression of Zn uptake was noted with APP at two locations.

Addition of $ZnSO_4$, ZnEDTA, and an experimental Zn source increased plant Zn concentrations at three field locations in central and western Kansas, when applied as a liquid or coated onto APP or AOP. There were no significant differences among Zn carriers as affected by plant Zn concentration. Higher rates of Zn depressed leaf P content at one location.

Sorghum grain Zn content was decreased with the addition of Zn coated on APP. Knifed applications of fluid P and Zn carriers were somewhat inferior to broadcast applications of the same materials on leaf P content of grain sorghum.

Corn plants were also grown in a growth chamber on two soil types that had been treated with one of four Zn forms and incubated at two different temperatures. Two growing temperatures were superimposed on the two incubation temperatures.

Under low soil incubation temperatures and low growth temperatures the organic Zn materials tended to supply more Zn to the plants. Higher growth temperatures lessened this effect. In the

case of an acid soil, the inorganic Zn sources were more effective at the higher growing temperature. The organic Zn sources, however, were slightly more effective on calcareous soil, under the same growing conditions.

Results of these investigations indicate that the various sources of Zn did have similar effects on Zn concentrations in corn and grain sorghum plants, and P sources were similar in their effects on plant P content.