ZINC AVAILABILITY FROM SOIL APPLIED ZINC SULFATE AND ZINC EDTA

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ABSTRACT

ZINC AVAILABILITY FROM SOIL APPLIED
ZINC SULFATE AND ZINC EDTA

by WILLIAM HOWARD JUDY

Liming, pH of the growth medium, and application of phosphorus are some conditions commonly associated with zinc deficient plants. Crops such as beans, corn, hops, lima beans, and flax have been treated for zinc deficiency with various carriers of zinc. Zinc from inorganic carriers is reported to be rapidly fixed in the soil. Chelated zinc carriers have been utilized with varying success to supply zinc and their effect and fate in soils and plants are not completely understood.

This research was designed to investigate the availability of soil applied zinc sulfate and zinc EDTA[1] to pea beans (Phaseolus vulgaris L.) on mineral soils. The effect of soil applied phosphorus, soil type, and time on zinc availability was also investigated.

Five field experiments were conducted in Michigan in 1963 and 1964 at 12 locations where the effect of zinc carrier, phosphorus application, and time on zinc uptake by plants and yield of dry beans was determined. Soils were included which were both calcareous and non-calcareous at the surface, high and low in available phosphorus, and variable in acid extractable zinc. Four greenhouse pot experiments were designed to investigate the

uptake and distribution of zinc in plants and yield of pods as affected by zinc carrier, soil type, phosphorus application, and time. A calcareous soil which was high in available phosphorus was incubated with each zinc carrier and with phosphorus application for 90, 180, and 270 days. The incubated soil was extracted by a fractionation procedure with water (water soluble zinc), neutral normal ammonium chloride (exchangeable zinc), and tenth normal hydrochloric acid (acid soluble zinc).

In the field experiments where zinc EDTA was applied at rates as high as 1.6 pounds of zinc per acre and zinc sulfate at 3.0 and 4.0 pounds per acre, the zinc uptake and yield of dry beans by plants were higher, more often than not, on zinc EDTA treatments. As the rate of additional applied phosphorus was increased from 0 to 696 pounds per acre, the zinc concentration in plants and bean yield were reduced less on zinc EDTA plots than on zinc sulfate plots. Zinc uptake by plants and yield of beans increased with each increment of applied zinc EDTA.

In the greenhouse experiments where zinc was applied at rates from 0.5 to 48.0 pounds per acre, more zinc was taken up and more zinc was in the youngest growth portions of plants grown on zinc EDTA treated pots than in plants on zinc sulfate treated pots. The pod yield on the chelated zinc treatments was greater except when the zinc concentration in the above-ground plant exceeded 50 parts per million.

When zinc was not applied, the yield of pods and dry beans was reduced, but the zinc concentration in plants was not materially affected as the rate of soil applied phosphorus was increased.

More water soluble and exchangeable zinc could be extracted from incubated soil which was treated with zinc EDTA than from zinc sulfate treated soil. At higher rates of applied zinc, more zinc could be recovered from zinc EDTA treated soil. When 1000 pounds of phosphorus per acre were applied, the recovery of all three forms of soil zinc was increased, except for exchangeable zinc from zinc EDTA; disproportionately more zinc from zinc sulfate than from zinc EDTA could be recovered.

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[1]Disodium zinc ethylenediamine tetraacetate dihydrate.

ZINC AVAILABILITY FROM SOIL APPLIED
ZINC SULFATE AND ZINC EDTA

By

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Description | Page number

I. INTRODUCTION

The value of zinc for growth of some plants has been recognized since 1863. The essentiality of this element for plants was not identified until the period 1914 to 1919 and not generally accepted until about 1928. Zinc was recommended for annual field crops in 1927 and for tung and fruit trees in 1932[83]. Beans, soybeans, corn, hops, lima beans, flax, and castor beans are all very sensitive to zinc deficiency[87].

Zinc deficiency of pea beans (Phaseolus vulgaris L.) when grown on mineral soils has been diagnosed in Michigan and zinc treatments were applied[27,84]. There are approximately 600,000 acres of pea beans grown annually in Michigan and a large percentage of these are planted on soils on which a response to zinc treatment has been observed.

Pea beans have responded to a wide variety of soil applied zinc carriers while foliar applications of this element have been less successful in permanently alleviating zinc deficiency. Inorganic carriers which have been investigated include the sulfate, chloride, carbonate, nitrate, oxide, oxysulfate, and phosphate compounds of zinc, and blast furnace slag, frits, and stripping acid residues containing this element. Organic carriers of zinc which have been applied include polyaminecarboxylic chelates and organic extracts such as polyflavanoids.

The purpose of this research was to investigate the uptake of zinc by pea beans from zinc sulfate and zinc EDTA*.

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*Disodium zinc ethylenediamine tetraacetate dihydrate.

II. REVIEW OF LITERATURE

The availability of micro-nutrients to plants is affected by several factors. Depending on the ionic species, availability is influenced by low net content, low exchangeable content, organic matter and calcite complexes, anion precipitation, ageing and recrystallization, and competition among species[46].

II-A. Zinc in Plants

Zinc is active in enzymatic systems in plants, primarily for some enzyme cofactors[53]. The zinc concentration in plants where deficiency symptoms occurred was usually in the range from 15 to 20 parts per million[33,62,86]. Often, deficient plants contained a concentration of zinc equal to or in excess of that in zinc sufficient plants[33,88].

Shaw et al[73] found that zinc did not readily redistribute in plants. Foliar applied zinc was intermediately mobile, but less mobile than phosphorus[16]. Seatz et al[71] analyzed parts of plants near early bloom stage and found an equivalency of bases in each part.

Beans took up less native zinc and phosphorus than other crops[87]. Nearpass[59] assumed that native soil zinc was not affected by added zinc since the plant took up the added form. Epstein and Stout[28] reported that exchangeable soil zinc was available to plants, but Boawn et al[11] proposed that plant roots obtained this element from acid soluble as well as ammonium acetate forms. The per cent utilization of soil applied zinc by plants was shown to be inversely related to the rate of application[73]. Only five per cent of applied zinc was recovered by plants in experiments conducted by Leyden and Toth[47].

Smith[74] proposed that zinc was taken up by sour orange seedling roots as a non-vital process and he likened it to that of soil absorption of zinc.

II-B. Zinc in the Soil

Inorganic zinc is rapidly fixed in the soil. Alben[1] found inorganic zinc to be readily fixed. The work of Shaw et al[73] indicated that there was no difference in plant uptake of zinc from zinc sulfate, zinc carbonate, plant residue, and residual soil zinc. Zinc sulfate did not move readily in acid sandy soils, except Lakeland fine sand, and a surface application of this form was not utilized by tung trees[3,60]. However, Stewart and Leonard[79] obtained good uptake of zinc when zinc sulfate plus calcium chloride was applied. Broadcast zinc was found to be more effective than banded zinc[67,73].

On the other hand, chelated zinc is less readily inactivated. A relatively small amount of chelated metal was needed to supply plants on some soils[1]. More zinc was taken up from zinc EDTA than from inorganic carriers[11,21,48]. Zinc65 EDTA penetrated and moved more readily in the soil than zinc65 chloride[97]. However, Stewart and Leonard[78] found zinc EDTA to have few advantages over zinc sulfate and to be effective only when mixed with zinc sulfate in piles or in soda ash under citrus trees. The work of other researchers[23] indicated that plants in solution culture took up zinc more readily as an ion than as the EDTA chelate.

Very little exchangeable or inorganic forms of zinc were found in 14 soils whose pH values ranged from 4.5 to 7.2[85]. Nelson and Melsted[64] determined that (a) in a hydrogen saturated soil, all applied zinc was recovered by ammonium acetate, (b) in a calcium saturated soil, part of the applied zinc was recovered by ammonium acetate and part by tenth normal hydrochloric acid, and (c) the acid soluble zinc increased and exchangeable zinc decreased with time in both soils. Zinc was rapidly converted to a form not extractable with hydrochloric acid[12].

Elgabaly[26] called the fraction of zinc that was non-exchangeable with ammonium acetate fixed zinc and proposed that zinc occupied aluminum- or magnesium-vacant sites in layer silicates. By infrared procedures, DeMumbrum and Jackson[24] determined that zinc reacted with the octahedral hydroxide in layer silicates but did not react with kaolinite. Jurinak and Thorne[41] proposed that the unavailability of zinc was a result of its chemical nature in that numerous chemical and strong clay absorption complexes were formed as well as zinc hydroxide. Dolomite absorbed more zinc than magnesite which absorbed more than calcite; ten per cent of the available exchange sites on calcite were occupied by zinc[40].

Liming and pH status are both reported to have an effect on zinc availability. The critical range for zinc availability was stated to be from pH 6.0 to 6.5[19]. Liming reduced zinc uptake by oats[68], sorghum[100], and beans[72]. Zinc deficient soils were those with the higher pH values[87]. Increased uptake was obtained when the pH was decreased[72]. Increasing the pH in New Jersey soils decreased the quantity of zinc absorbed from fertilizer zinc and increased absorption from native soil zinc with the net result that zinc uptake of tomato plants was lower[47]. More zinc could be leached from soil with a low pH value (4.0) than from a soil with a high value (7.4)[75]. Both pH value and absorption were proposed to affect zinc uptake[26]. Woltz et al[104] found more zinc fixed by limestone than phosphate. Working with sodium, potassium, and calcium hydroxides, Jurinak and Thorne[41] showed that zinc solubility increased with sodium and potassium but decreased with calcium; they theorized that these effects were because of the differential solubility of proposed metal zincates. The minimal solubility of the calcium zincate was at pH 7.6.

The effect of phosphorus on zinc availability has been debated considerably in the literature. Jamison[36] proposed that soil phosphates were not responsible for zinc fixation. Soluble phosphorus in the soil did not cause zinc deficiency[88]. Boawn et al[10] reported that twice as much phosphorus in bean tissue did not cause zinc deficiency or reduction in dry matter weight. Up to 436 pounds of phosphorus per acre were applied without effect on zinc response[72]. Soluble zinc was increased when potassium, hydrogen, ammonium, and calcium phosphates were applied at rates up to 900 pounds of phosphorus per acre[5]. Zinc uptake by citrus increased as more phosphorus was applied[4].

The association of phosphorus with zinc deficiency appeared often. The zinc concentration in oats grown on a Lakeland fine sandy loam decreased to a constant level with increasing phosphorus[68]. Zinc concentration in potato leaves and stems decreased when phosphorus was applied[8]. Seatz[70] applied up to 2180 pounds of phosphorus per acre as tri-calcium phosphate before a response to zinc was observed and proposed that the acidifying effect of monocalcium phosphate reduced response to zinc fertilizer when this form of phosphorus was applied. A large amount of phosphorus was applied before yield was reduced[6]; later experiments indicated a relationship between a particular soil and phosphorus-induced zinc deficiency[5]. Burleson et al[17] observed not only a decrease in absorption of phosphorus when zinc was applied and zinc when phosphorus was applied, but also found a mutual reduction in phosphorus and zinc uptake when both were applied to corn, tomatoes, and kidney beans. This inverse zinc-phosphorus relationship has been reported in corn, and low rates of phosphorus applied in the row aggravated zinc deficiency, especially on limed soil[45,98]. Millikan[56] proposed that the depression in plant growth was not because of low zinc concentration in the plant but of high phosphorus concentration.

Zinc seems to be essential to phosphorus utilization in the plant[56], and both were distributed similarly through pea plants[82]. The demand for zinc was shown to be dependent on the age of the plant[56]. Burleson et al[17] suggested a phosphorus-zinc antagonism in the root, but Bingham[4] concluded that a reaction outside the root contributed to this deficiency and the plant was not exclusively involved. Zinc deficiency was attributed to a nutrient imbalance in the soil[14], complexing of zinc in a water soluble form which is unavailable to the plant[4], and the presence of the mono-valent phosphate ion in the substrate[5].

Researchers agreed that generally there was a maximum cation content in the plant. Magnesium has been reported to increase the zinc uptake of bean plants[70]. Other workers[2,54] have proposed a mutual substitution effect between zinc and magnesium. Potassium and phosphorus tended to accumulate in zinc deficient corn plants[88], and applied zinc decreased the phosphorus, potassium, calcium, and magnesium content of plants[72].

Nitrogen application adversely affected zinc uptake by subterranean clover[65], which effect was attributed to zinc-protein complexing in the root. Increased uptake of native soil zinc by soybeans was obtained with applied nitrogen[61]. A favorable effect on zinc uptake was attributed to a change in the pH value of the soil caused by applied nitrogen[12].

Organic matter has been proposed as a causative factor in zinc deficiency, probably through chelation of this element[20,24,43]. Mortensen[58] concluded that soil organic matter complexed zinc by ion exchange,surface absorption, chelation, and peptidization.

II-C. Plant Available Zinc in the Soil

Determination of that quantity of zinc in the soil which is available to the plant has been attempted by chemical extraction of the soil and by measurement of biological response to available soil zinc[83]. Water, pH adjusted alkali salts, hydrochloric acid, and chelates have been utilized in soil extraction. Tucker and Kurtz[85] were able to recover about one-fifth of the total soil zinc with repeated acid extraction. The titratable alkalinity procedure was an adaptation of the acid extraction procedure[63].

Zinc deficient soils were determined to be lower in ammonium acetate, dithizone, or tenth normal hydrochloric acid extractable zinc[87]. No satisfactory correlation could be found among soil pH value, acid extractable zinc, and crop response[63]. A plant response to applied zinc was obtained when tenth normal hydrochloric acid extractable zinc was 1.6 parts per million or less in the soil[11].

II-D. Chelates in the Soil and Plant

Factors affecting the stability of the chelate and metal include the formation, dissociation, and equilibrium constants of the ligand and metal, and the solubility of metal compounds[49]. For example, the stability constants for iron^{+++} EDTA in reference to selected metals were found to be iron^{+++} >copper >zinc >iron^{++} >manganese >calcium >magnesium[50]. A comparable competetive effect among similar cations for the chelate has been determined by Brown et al[15]. Iron was removed from iron EDTA and percipitated in calcareous soils[94]. It was predicted that zinc would be displaced from zinc EDTA by iron but this does not occur, probably because iron usually exists in the soil in an insoluble form[91]. Zinc65 from zinc65 EDTA and soil zinc were found to interchange readily[93].

Metal chelates were less effective on clay or silt than on sandy loam soils[1]. Zinc was removed from zinc EDTA by clay in the soil, according to Butler and Bray[18], but zinc EDTA did not readily fix on clay[92,96]. However, calcareous soils fixed high amounts of this chelated zinc compound[77].

Chelates have been applied without the cation in an attempt to increase native cation uptake. Up to 5000 pounds per acre of the sodium salt of EDTA increased extractable iron but had no effect on the soil pH value[66]. Both stimulation and depression of growth were obtained by chelates[25], and increased translocation of zinc from root to top in beans was observed in a loam soil of pH 7.85[29]. Wallace[91] concluded that chelates applied without zinc were not effective in correcting zinc deficiency. Toxic levels of sodium EDTA ranged from 200 to 400 pounds per acre[95].

Chelate molecules are probably absorbed and translocated in plants[90,95,101]. In a split root experiment where iron was supplied to one side and EDTA to the other, Weinstein et al[102] concluded that EDTA or a decomposition product migrated from one side of the root to the other and increased iron uptake. Both metal and chelate were traced to the foliage[93], and, in later experiments, EDTA or a decomposition product was shown to move freely to all parts of bean plants[32]. Uptake of the chelate itself was dependent on the pH value and concentration of the ligand[77].

Competition between the chelate and the enzymes for metals within the plant[102] and between chelate and root for cations[77] have been cited by researchers. Martell[49] also noted competition between hydrogen and metal ions for the ligand. The ratio of zinc to chelate became wider moving from the roots to the top of the plant, and this phenomenon was attributed either to other cations replacing zinc, or to a separation of zinc from the chelate with subsequent more rapid translocation of the chelate[93].

III. STATEMENT OF HYPOTHESES

Zinc from chelated carriers was rapidly inactivated in the soil. The fate and effect of chelated zinc carriers applied to the soil are not completely understood. Zinc sulfate and zinc EDTA were selected for investigation. The effect of phosphorus, soil type and time on the availability of zinc from these two carriers was considered. The crop selected to indicate zinc availability was pea beans.

The following hypotheses were then proposed.

III-A. Hypothesis 1

Uptake of zinc and yield of beans by pea bean plants are greater when zinc is applied to the soil as zinc EDTA than when applied as zinc sulfate.

III-B. Hypothesis 2

Uptake of zinc and yield of beans by pea bean plants are reduced more by high soil phosphorus content when zinc is applied to the soil as zinc sulfate than when applied as zinc EDTA.

III-C. Hypothesis 3

More soil applied zinc remains available over a longer time when zinc is applied to the soil as zinc EDTA than when applied as zinc sulfate.

III-D. Hypothesis 4

Extractable soil zinc is reduced more by high soil phosphorus content when zinc is applied as zinc sulfate than when applied as zinc EDTA.

IV. EXPERIMENTAL PROCEDURE

Experiments were conducted in the field, greenhouse, and incubation chamber in order to test the hypotheses stated in Section III. STATEMENT OF HYPOTHESES.

Zinc sulfate and zinc EDTA were applied to a soil. Then, the relative availability of zinc from these two carriers was measured either by determining the zinc uptake by pea bean plants or by chemically extracting zinc from the soil. The variables of phosphorus, soil type, and time were introduced so that their effect on the availability of zinc from both carriers could be determined.

Selected physical and chemical characteristics of the soils were also identified.

IV-A. Description of Field Experiments

The purpose of the five field experiments was to study zinc uptake by pea bean plants and yield of dry beans as affected by:

1. soil applied zinc sulfate and zinc EDTA,
2. soil applied phosphorus in excess of planting time phosphorus.

Experimental fields were chosen within areas where zinc deficiency had been observed in the lake plain region of East Central Michigan. These soils were deposited under a glacial lake which left the surface with a gentle slope[103]. These soils are imperfectly to poorly drained and therefore drainage tile has been installed. The soil profiles are calcareous, often to the surface. Textures of the plow layer include loams to silty clay loams. Twelve areas were selected for field experiments in 1963 and 1964 which were of minimal slope and tiled. The pH value of the plow layers ranged from 7.3 to 7.7. Four of the soils were calcareous in the plow layer. Seven different soil types were represented. Eight of the locations had had a crop of sugar beets the previous year. Extractable soil phosphorus as determined by hydrochloric acid and ammonium fluoride extraction ranged from 17 to 82 pounds of phosphorus per acre. None of the 12 areas had received any application of zinc previously, except location 7. The results from the residual zinc plot at location 7 were not included in the data reported here. The physical and chemical characteristics of the soils are given in Tables 1 and 2.

The zinc carriers for the field experiments included zinc sulfate and zinc EDTA. Zinc sulfate was a 36 per cent zinc granular or powdered material and was applied at rates of 2.0 to 8.0 pounds of zinc per acre. Zinc EDTA was applied at rates of 0.3 to 1.6 pounds of zinc per acre. The zinc EDTA used in the 1963 experiments was a 6.3 per cent zinc sequestered material; in the 1964 experiments, the sequestered material contained 14.2 per cent zinc. Both granular chelated materials were manufactured by the Geigy Chemical Corporation. The zinc materials were mixed with the planting time fertilizer and banded in the soil.

Phosphorus fertilizer above the planting time phosphorus was broadcast as a commercial 0-46-0 material and disced in or plowed down on five experimental areas. These phosphorus applications are referred to as "additional phosphorus" to differentiate them from the planting time phosphorus applications which were banded

Table 1: Previous crop grown and physical characteristics of the soils used in the field experiments.

Field experiment		Previous crop grown	Soil type[a]	Soil management group[a]
Location	Year			
1	1963	Sugar beets	Rudyard silty clay loam	1b-c
2	1963	Wheat-Rye	Sims clay loam	1.5c
3	1963	Sugar beets	Sims clay loam	1.5c
4	1963	Corn	Parkhill clay loam	2.5c
5	1963	Sugar beets	Sims clay loam	1.5c
6	1963	Corn	Sims clay loam	1.5c
7	1963	Sugar beets	Kawkawlin loam	1.5b-c
8	1964	Sugar beets	Colwood loam	2.5c
9	1964	Sugar beets	Not identified	Not identified
10	1964	Pea beans	Tappan loam	2.5b-c
11	1964	Sugar beets	Kawkawlin loam	1.5b-c
12	1964	Sugar beets	Wisner clay loam	1.5c-c

(a) Soil type and management group identified by Professor E.P. Whiteside, Soil Science Department, Michigan State University.

Table 2: Chemical analysis of the soils used for field experiments.

Field experiment		Soil chemical analysis						
Location	Year	pH[(a)]	Pounds per acre					Cation exchange capacity[(e)] (me/100g)
			Zn[(b)]	P[(c)]	K[(d)]	Ca[(d)]	Mg[(d)]	
1	1963	7.4	10.4	17	--	--	--	--
2	1963	7.3	24.8	55	--	--	--	--
3	1963	7.6	11.2	30	--	--	--	--
4	1963	7.5	24.0	30	--	--	--	--
5	1963	7.3	14.0	28	--	--	--	--
6	1963	7.3	17.0	14	--	--	--	--
7	1963	7.7	9.0	Variable	--	--	--	--
8	1964	7.7	9.5	42	128	5408	640	16.2
9	1964	7.4	10.3	82	192	5408	680	16.5
10	1964	7.7	9.4	27	208	6136	544	17.7
11	1964	7.7	1.2	57	200	6344	1000	20.1
12	1964	7.7	7.4	Variable	158	4940	400	14.1

(a) 1:2-soil:water.
(b) 0.1N HCl extractable; 1:10-soil:extractant.
(c) 0.025N HCl and 0.03N NH_4F extractable; 1:8-soil:extractant.
(d) 1N neutral CH_3COONH_4 extractable; 1:8-soil:extractant.
(e) Replaced by Na from NaCl.

with the other plant nutrients. The pea beans and fertilizer were placed in the soil with a tractor and an adapted commercial planter which was calibrated to within five per cent. The certified varieties of pea beans which were planted included Sanilac, Saginaw, Gratiot, and Mehlfeldt. One bushel of seed per acre was planted to insure an adequate plant population. The commercial macro-nutrient fertilizer, which contained two per cent manganese, was banded one inch to the side and two inches below the seed line in such quantity that zinc, when deficient, was the only known growth-limiting nutrient element for pea beans. The analysis and rate of application of fertilizer are given in Table 3.

Precautions were taken during hand-mixing of the fertilizer and zinc material and throughout the planting process to handle low zinc materials first and to clean the equipment. The commercial fertilizers were analyzed for zinc content and found to contain less than 0.02 per cent zinc. Weeds were controlled by hoeing; no chemicals were applied for any pests.

Plant tissue samples were collected at random from each plot for zinc analysis. Stainless steel collecting and grinding equipment and paper bags were utilized to minimize contamination[37]. The first tissue samples, taken three weeks after planting in 1963, consisted of 10 to 12 of the total above-ground plants per plot. The second sample that year was composed of 10 to 12 of the uppermost mature trifoliate leaves collected at pre-bloom stage. One tissue sampling was made in 1964. This sample was composed of ten total above-ground plants removed at pre-bloom stage.

Table 3: Placement, analysis, and rate of application of nitrogen, phosphorus, potassium, and manganese fertilizer used in the field experiments.

Field experiment location	Rate and placement of commercial fertilizer								
	Planting time fertilizer						Additional phosphorus		
	Placement[a]	Per cent in fertilizer				Rate (lb/acre)	Placement	Per cent P in fertilizer	Rate (lb/acre)
		N	P	K	Mn				
1	Banded	6	10.5	10.1	2	250	--	--	--
2	Banded	6	10.5	10.1	2	250	--	--	--
3	Banded	6	10.5	10.1	2	250	--	--	--
4	Banded	6	10.5	10.1	2	250	--	--	--
5	Banded	6	10.5	10.1	2	250	--	--	--
6	Banded	6	10.5	10.1	2	250	--	--	--
7	Banded	6	10.5	10.1	2	250	Broadcast	20.1	87,174,348,696
8	Banded	6	10.5	10.1	2	300	Broadcast	20.1	300
9	Banded	6	10.5	10.1	2	300	Broadcast	20.1	300
10	Banded	6	10.5	10.1	2	300	Broadcast	20.1	300
11	Banded	6	10.5	10.1	2	300	--	--	--
12	Banded	6	10.5	10.1	2	250	Broadcast	20.1	87,174,348,696

(a) Banded one inch to the side and two inches below the seed line.

Soil samples for chemical testing were composites of a minimum of 20 cores to plow depth from the sampling area. All soil samples from field experimental areas were taken before the area was planted. The non-galvanized equipment used for collecting soil samples was cleaned and used only for zinc experimental work. Except for zinc analyses, the chemical tests were performed by the University Soil Testing Laboratory.

The yield of dry beans from pea bean plants was obtained from bushes pulled by hand at maturity. After drying in a stack, the bushes were threshed in an experimental thresher. The size of yield area on each plot was at least 0.002 acre.

IV-A-1. Description of Field Experiment 1, 1963

The effect of soil applied zinc sulfate and zinc EDTA on the zinc concentration in pea bean plants and on the yield of dry beans was studied on three soil types at six field locations in Field Experiment 1 which was conducted in 1963.

The soil type on locations 2, 3, 5, and 6 is a Sims clay loam. On location 1, the soil is a calcareous Rudyard silty clay loam and on location 4, a Parkhill clay loam.

The experiment was designed as a randomized block with four replications. Zinc sulfate was applied at 4.0 pounds of zinc per acre and zinc EDTA at 0.4, 0.8, and 1.2 pounds of zinc per acre. Sanilac variety pea beans were planted on locations 1, 3, 5, and 6. Gratiot beans were planted on location 2 and Mehlfeldt beans on location 4.

IV-A-2. Description of Field Experiment 2, 1963

The effect of soil applied zinc sulfate and zinc EDTA and level of additional soil applied phosphorus on the zinc concentration in pea bean plants and on the yield of dry beans was studied in Field Experiment 2 which was conducted on location 7 in 1963.

The soil type on location 7 is a calcareous Kawkawlin loam soil complexed with some calcareous Wisner clay loam soil.

The experiment was designed as a randomized split block with three replications. The blocks were split by levels of phosphorus. In the fall of 1959, phosphorus was broadcast at the rates of 0, 87, 174, and 348 pounds of phosphorus per acre and plowed down. In the fall of 1961, a second application of phosphorus at the same rate was broadcast on half of these split plots and plowed down to give phosphorus levels of 0, 174, 348, and 696 pounds of phosphorus per acre. Zinc sulfate was applied at 4.0 pounds of zinc per acre and as zinc EDTA at 0.4, 0.8, and 1.2 pounds of zinc per acre. Sanilac variety pea beans were planted.

IV-A-3. Description of Field Experiment 3, 1964

The effect of soil applied zinc sulfate and zinc EDTA on the zinc uptake of pea bean plants and on the yield of dry beans was studied on three soil types in Field Experiment 3, which was conducted on locations 8, 9, and 10 in 1964.

The soil types on location 8 and 10 are Hettinger silty clay loam and a calcareous Tappan loam, respectively. The soil type on location 9 was not identified.

The experiment was designed as a randomized block with eight replications. Three hundred pounds of additional phosphorus per acre were broadcast and disced into the soil on each area before planting. Zinc sulfate was applied at 3.0 pounds of zinc per acre and zinc EDTA at 0.3, 0.6, 0.9, and 1.2 pounds of zinc per acre. Sanilac variety pea beans were planted on all three locations.

IV-A-4. Description of Field Experiment 4, 1964

The effect of soil applied zinc sulfate and zinc EDTA and level of additional soil applied phosphorus on the zinc uptake of pea bean plants and the yield of dry beans was studied in Field Experiment 4, which was conducted on location 11 in 1964.

The experiment was designed as a randomized split block with three replications. Location 11 is adjacent to location 7, and the soil type is the same calcareous Kawkawlin loam soil. The blocks were split exactly as described for location 7 in IV-A-2. Field Experiment 2, 1963, except that the second application of phosphorus was applied in the fall of 1962, rather than in 1961. This gave the same levels of phosphorus: 0, 87, 174, 348, and 696 pounds of phosphorus per acre. Zinc sulfate was applied at 3.0 pounds of zinc per acre and zinc EDTA at 0.3, 0.6, 0.9, and 1.2 pounds of zinc per acre. Sanilac variety pea beans were planted.

IV-A-5. Description of Field Experiment 5, 1964

The effect of soil applied zinc sulfate and zinc EDTA on the zinc concentration in pea bean plants and the yield of dry beans was studied in Field Experiment 5, which was conducted at location 12 in 1964.

The soil type at location 12 is a calcareous Wisner clay loam. Severe zinc deficiency on pea beans had been observed in this field the past four years.

The experiment was designed as a randomized block design with four replications. Zinc sulfate was applied at 2.0 , 4.0, and 8.0 pounds of zinc per acre and zinc EDTA at 0.4, 0.8, and 1.6 pounds of zinc per acre. Sanilac variety pea beans were planted.

IV-B. Description of Greenhouse Experiments

The purpose of the four greenhouse pot experiments was to study zinc uptake, dry matter weight, and pod yield of pea bean plants as affected by:

1. soil applied zinc sulfate and zinc EDTA,
2. level of soil applied phosphorus,
3. soil type.

Three soil types were chosen from locations where zinc deficiency had been observed during field experiments. The Wisner clay loam soil utilized in all four greenhouse experiments was collected from the area of Field Experiment 5 at location 12. The Kawkawlin loam soil used in Greenhouse Experiment 4 came from the area of Field Experiment 2 at location 7. The Bach silt loam soil used in Greenhouse Experiment 1 came from Lessman's field experiment at location H[38]. These soils, which came from plots which had not received any zinc, were collected with nongalvanized equipment, air dried, sieved through a stainless steel screen, and stored in covered bins. The physical and chemical characteristics of the soils are reported in Table 4.

Both zinc carriers were banded in the soil with the other plant nutrients at levels from 0.5 to 48.0 pounds of zinc per acre. The zinc sulfate source was a chemically pure grade zinc sulfate with seven water molecules of hydration. The zinc EDTA material was the 14.2 per cent sequestered product described under IV-A., Description of Field Experiments.

All nutrients were placed in a ring one-half inch to the side and one inch below the seed ring. The sources of these elements were chemically pure grade materials which were analyzed for zinc content. Plant nutrients were supplied in such quantity that zinc, when deficient, was the only known growth-limiting nutrient for pea beans. Calculation of the rate of nutrients was based on the soil weight, using the value of 2,000,000 pounds of soil per acre. Thirty-six hundred grams of soil were potted in double plastic lined cans. The analysis, rate, and method of application of all elements except zinc are reported in Table 5.

A common source of Sanilac variety pea bean seed was used in all experiments. Fifty per cent more seeds were planted than the population desired and the excess plants were removed. The vines were staked and tied for coherence.

The pots were randomized on greenhouse benches. Artificial light was provided to lengthen the day to 14 hours. Deionized water was used for all watering. Pots were maintained at the 20

Table 4: Chemical and physical analyses of the soils used in the greenhouse and incubation experiments.

Experiment		Soil chemical analysis									Organic matter content[g] (per cent)	Mechanical analysis[h] (per cent)			Soil type[i]
Kind	Number	pH[a]	Pounds per acre						Cation exchange capacity[f] (me/100g)			Sand	Silt	Clay	
			Extractable Zn[b]	Total Zn[c]	P[d]	K[e]	Ca[e]	Mg[e]							
Greenhouse	1,2,3,and 4	7.7	1.2	85.6	55	208	6344	1000	20.1		2.4	25	43	32	Wisner clay loam
Greenhouse	1	7.7	9.2	69.6	16	--	--	--	--		--	--	--	--	Bach silt loam
Greenhouse	4	7.8	7.4	56.0	18	184	5824	352	13.7		1.9	46	32	22	Kawkawlin loam
Incubation	--	7.8	1.2	85.6	55	208	6344	1000	20.1		2.4	25	43	32	Wisner clay loam

(a) 1:2-soil:water.
(b) 0.1N HCl extractable; 1:10-soil:extractant.
(c) Concentrated HCl.
(d) 0.025N HCl and 0.03N NH_4F extractable; 1:8-soil:extractant.
(e) 1N neutral CH_3COONH_4 extractable; 1:8-soil:extractant.
(f) Replaced by Na from NaCl.
(g) Wet digestion, method of Walkley and Black (1934).
(h) Hydrometer method of Kilmer and Alexander (1949).
(i) Identified by Professor E.P. Whiteside, Soil Science Department, Michigan State University.

Table 5: Source and rate of nutrients (except zinc) applied to the soils used in the greenhouse experiments.

Greenhouse experiment number	Source, rate, and method of application of nutrients				
	Nutrient	Nutrient source	Mixed in soil (lb/acre)	Banded in soil (lb/acre)	Added in solution (lb/acre)
1	N[a]	$NH_4H_2PO_4$	0 or 452.0	467.4 or 15.4	--
	P		1000.0	34.0	--
	N	NH_4NO_3	--	--	122.0
	K	KCl	--	25.0	202.0
	Mn	$MnSO_4 \cdot H_2O$	--	20.0	--
2 and 3	N	$NH_4H_2PO_4$	--	28.4	--
	P		--	62.8	--
	N	NH_4NO_3	--	7.6	--
	K	KCl	--	60.0	--
	Mn	$MnSO_4 \cdot H_2O$	--	20.0	--
4	N	$NH_4H_2PO_4$	--	28.4	--
	P		--	62.8	--
	N	NH_4NO_3	--	77.1	--
	K	KCl	--	120.0	--
	Mn	$MnSO_4 \cdot H_2O$	--	20.0	--

(a) Rate of N mixed or banded is dependent on N in P fertilizer mixed in soil.

per cent moisture level by periodic weighing.

Plant tissue samples were collected by cutting off the plant near the soil surface with a stainless steel knife. Tissue samples were placed in paper bags, dried, weighed, ground, and analyzed for zinc concentration. The yield of pods was obtained by removing the complete pod. The pods were then dried, weighed, ground, and analyzed for zinc concentration.

IV-B-1. Description of Greenhouse Experiment 1

The effects of two levels each of soil applied zinc sulfate and additional phosphorus and two soil types on the dry matter weight and zinc concentration in pea bean plants were studied in Greenhouse Experiment 1.

Wisner clay loam and Bach silt loam soils, both calcareous, were utilized in this experiment.

The experiment was designed as a 2^3 factorial, completely randomized. One thousand pounds of additional phosphorus per acre as monammonium phosphate were mixed in half of both soils before potting. Zinc sulfate at 8.0 pounds of zinc per acre was applied in half of the pots. Sanilac variety pea beans were planted and thinned to four plants per pot.

The plants were sampled 97 days after planting which was near maturity but before any leaves fell. The pods were removed, and the balance of the above-ground plant constituted the leaf and stem sample. These two portions were weighed and then combined for zinc analysis.

IV-B-2. Description of Greenhouse Experiment 2

The effect of soil applied zinc sulfate and zinc EDTA on the dry matter weight and on the uptake and distribution of zinc in pea bean plants was studied in Greenhouse Experiment 2.

The Wisner clay loam soil was used in this experiment.

The experiment was designed to include five treatments, completely randomized, and had four replications. Zinc sulfate and zinc EDTA were applied at levels of 4.0 and 20.0 pounds of zinc per acre. The control did not receive any zinc treatment. Sanilac variety pea beans were planted and thinned to four plants per pot.

The plants were sampled at early bloom stage 29 days after planting. Plants were separated into leaf, stem, and vine portions for weighing and zinc analysis. The leaf portion included the petiole. The vine portion included all of the stem and leaves above the axil of the uppermost mature trifoliate.

IV-B-3. Description of Greenhouse Experiment 3

The effect of soil applied EDTA and nitrogen-phosphorus-potassium-manganese on the dry matter weight and on the uptake and distribution of zinc in pea bean plants was investigated in Greenhouse Experiment 3, which was conducted concurrently with Greenhouse Experiment 2.

The Wisner clay loam soil was used in this experiment.

The experiment included three treatments completely randomized with four replications. One set of pots did not receive any treatment. The second treatment was the same rate of nitrogen-phosphorus-potassium-manganese nutrients as was applied in the control for Greenhouse Experiment 2. The third treatment was 100 pounds of 99 per cent pure EDTA (manufactured by the Geigy Chemical Corporation) banded alone. Sanilac variety pea beans were planted and thinned to four plants per pot.

The plants were sampled at early bloom stage 29 days after planting and separated into plant parts for zinc analysis as described in IV-B-2. Description of Greenhouse Experiment 2.

IV-B-4. Description of Greenhouse Experiment 4

The effect of soil applied zinc sulfate and zinc EDTA and of soil type on the dry matter weight and on the uptake and distribution of zinc in pea bean plants was studied in Greenhouse Experiment 4.

The Wisner clay loam soil and the Kawkawlin loam soil were utilized in this experiment.

The experiment was designed to include 15 treatments and completely randomized with four replications. Six hundred pounds of phosphorus as dicalcium phosphate were mixed into all of the soil before potting. Zinc sulfate and zinc EDTA were applied on each soil type at rates of 0.5, 1.0, 2.0, 4.0, 8.0, 16.0, and 48.0 pounds of zinc per acre. The control did not receive any zinc treatment. Sanilac variety pea beans were planted and thinned to six plants per pot.

Four plants were removed near the soil surface 28 days after planting and dried, weighed and analyzed for zinc concentration.

The second sampling was made 56 days after planting, near maturity, but before any leaves fell. The remaining two plants per pot were separated into leaves, stems, and pods, and then dried, weighed, and analyzed for zinc concentration. The leaf portion included the petiole.

IV-C. Description of Incubation Experiment

The purpose of the incubation experiment was to study soil zinc as affected by:

1. soil applied zinc sulfate and zinc EDTA,
2. level of soil applied phosphorus,
3. length of incubation.

The Wisner clay loam soil was collected from the area of Field Experiment 5 at location 12. The soil was air dried and sieved through a 5/16 inch stainless steel screen.

Maximum water holding capacity was determined with disturbed soil cores. The soil cores were prepared with filter paper and cheesecloth on the bottom. They were water saturated for 12 hours and drained for 30 minutes on a paper towel; this condition was considered to be water saturation. The soil cores were placed on a tension table at 60 centimeters of tension for 24 hours; this condition was considered to be the maximum water holding capacity of the soil. The amount of water added to the soil during incubation was 70 per cent of the maximum water holding capacity. For the Wisner clay loam soil used in this experiment, this value was 15 per cent water.

The experiment was designed to include 11 treatments and completely randomized with two replications. One thousand pounds of phosphorus per acre as monocalcium phosphate with one water molecule of hydration were mixed into half of the soil Zinc sulfate as the chemically pure grade of zinc sulfate with seven water molecules of hydration and zinc EDTA as the 14.2 per cent sequestered material were each applied to the soil at levels of 2.0, 6.0, 18.0, 54.0, and 162.0 pounds of zinc per acre. The control did not receive any zinc treatment.

The zinc treatments were sprayed on the soil. The appropriate quantity of zinc stock solution was mixed into part of the deionized water and sprayed over 200 grams of soil which was agitated in a large beaker. Washings from this beaker subsequent to zinc treatments indicated that less than 0.5 per cent of the amount of zinc applied was retained on the beaker. The treated soil was placed into 250 milliliter griffin beakers and the balance of the water was added by weight to bring the soil to 70 per cent maximum water holding capacity. Any addition of water was trickled down the side of the beaker to avoid puddling and crusting of the soil surface.

The beakers were covered with a single sheet of 0.001 millimeter thick polyethylene which was secured by a rubber band. Each soil treatment was brought to weight at three week intervals by adding deionized water. The usual water deficit was ten to twenty per cent per beaker.

Three separate samples of each treatment were prepared for incubation at 90, 180, and 270 days at 30 degrees centigrade in a controlled environment incubation chamber.

When incubation was complete, the plastic was removed from the beakers, and the samples were covered loosely with paper and air dried at room temperature. Each soil sample was crushed by a glass roller on an individual paper sheet, handling the lowest zinc treated samples first.

The incubated soil samples were extracted with deionized water (water soluble zinc), neutral normal ammonium chloride (exchangeable zinc), tenth normal hydrochloric acid (acid soluble zinc), and normal hydrochloric acid. All four soil extracts were analyzed for zinc concentration. The pH value was determined for all soil extracts, except the normal hydrochloric acid extracts.

IV-D. Methods of Chemical Analysis

Chemical analyses were performed on soil and plant samples. The available phosphorus, potassium, calcium, and magnesium, and the cation exchange capacity were obtained for soils used in all experiments. Acid extractable zinc, total zinc, organic matter content, and mechanical analysis were obtained for selected soils. Total zinc was determined in plant samples.

Precautions were taken in the laboratory during zinc analyses to avoid contamination[37]. The weighing and handling equipment were composed of stainless steel or glass. Glass containers were utilized for extracting soil and ashing tissue. All laboratory handling, storage, and dispensing equipment was made of glass or plastic.

Equipment was cleansed by washing two times in two normal hydrochloric acid and rinsing three times in deionized water. The deionized water was prepared by filtering distilled water through cation exchange resin which was periodically cleaned by hydrochloric acid.

Standard plant tissue and soil samples were periodically analyzed as checks during analyses for zinc content.

IV-D-1. Chemical and Physical Analyses of Soils

Soil samples were stored until air dry in loosely covered paper boxes and then crushed with a glass or wooden roller on paper sheets.

Acid extractable zinc was determined by a modified procedure of Tucker and Kurtz[85]. Duplicate five gram ($\pm$ 0.01 gram) samples were weighed into erhlenmeyer flasks. Fifty milliliters of tenth normal hydrochloric acid were added and the sample was shaken for one hour on a rotary shaker. After the sample was filtered through number 2 Whatman filter paper, the zinc concentration in the extract was determined by atomic absorption spectrophotometry*. A blank sample of the extractant was carried through the procedure concurrently with each lot of soil samples.

The analysis of the soil samples from the incubation experiment was carried out using a fractionation procedure. Duplicate

*Perkin Elmer 303 Atomic Absorption Spectrophotometer.

samples were run for each replicate. Five grams (± 0.01 gram) of soil were weighed into a 100 milliliter centrifuge tube. Fifty milliliters of deionized water were added and the sample was agitated on a reciprocating shaker at 290 cycles per minute for one hour. The sample was centrifuged for 15 minutes and filtered. The centrifugate was resuspended in 50 milliliters of neutral normal ammonium chloride (modified procedure of Bingham et al[7]), shaken for one hour, centrifuged for 12 minutes, and filtered. The centrifugate was resuspended in 50 milliliters of tenth normal hydrochloric acid (modified procedure of Tucker and Kurtz[85]), shaken for one hour, centrifuged for 12 minutes, and filtered. The centrifugate was resuspended in normal hydrochloric acid, shaken for one hour, centrifuged for 12 minutes, and filtered. All extracts were analyzed for zinc content with the atomic absorption unit. The speed of the centrifuge was 3300 revolutions per minute. Number 2 Whatman filter paper was used for all separations. The pH values of all except the normal hydrochloric acid soil extracts were measured to within ± 0.02 of a pH unit. Check samples consisting of the extractants only were run with each lot of 25 soil extracts.

Various extraction sequences for several zinc rates and both zinc carriers indicated that the amount of zinc extractable by normal hydrochloric acid from a soil sample could be considered essentially equivalent to that amount of zinc obtained by the fractionation procedure using water plus neutral normal ammonium chloride plus tenth normal hydrochloric acid plus normal hydrochloric acid; also tenth normal hydrochloric acid extractable zinc could be considered equivalent to water plus neutral normal ammonium chloride plus tenth normal hydrochloric acid extractable zinc; and, neutral normal ammonium chloride extractable zinc, equivalent to water plus neutral normal ammonium chloride extractable zinc. The normal hydrochloric acid extraction was employed in an attempt to recover all of the zinc which had been applied to a soil sample. The sum of the zinc extracted by water plus neutral normal ammonium chloride plus tenth normal hydrochloric acid plus normal hydrochloric acid was equivalent to 95 to 100 per cent of the zinc applied.

Total zinc in selected soils was determined by boiling the soil sample in concentrated hydrochloric acid for eight hours.*

The soil pH was determined using a soil to water ratio of 1:2. For available phosphorus, the soil was agitated one minute with twenty-five thousandth normal hydrochloric acid and three hundredth normal ammonium fluoride using a soil to extractant ratio of 1:8. Available potassium, calcium, and magnesium were determined by agitating the soil one minute with neutral normal ammonium acetate, using a soil to extractant ratio of 1:8. The exchange capacity was determined by displacement of cations with sodium chloride and subsequent measurement of displaced sodium.

Soil organic matter and mechanical analysis were determined on the Wisner clay loam and Kawkawlin loam soils only. Organic matter was determined according to the method of Walkley and

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* Unpublished procedure and data by James R. Melton, Soil Science Department, Michigan State University.

Black[89]. Mechanical analysis was performed according to Kilmer and Alexander[44].

The type of the soils at each of the field experimental areas was identified by on-site investigation. The soil management group identification is defined according to soil characteristics.*

The physical and chemical characteristics of the soils are reported in Tables 1, 2, and 4.

IV-D-2. Chemical Analysis of Plant Tissue Samples

All plant tissue samples were analyzed for total zinc concentration. For the samples which were weighed, the total zinc content has been calculated.

Plant tissue samples were placed in paper bags and dried at 70 degrees centrigrade in a forced air oven, weighed, and ground in a zinc-free Wiley mill. Duplicate one gram ($\pm$ 0.001 gram) samples were ashed for four hours at 500 degrees centrigrade in an electric oven, taken up in ten milliliters of normal hydrochloric acid, filtered through a number two Whatman filter, brought to volume by deionized water, and analyzed for zinc content. One blank sample of the normal hydrochloric acid solvent was included with each group of fifty tissue samples. Also, standard pea bean tissue samples were run periodically as checks.

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* Soil type and soil management group identified by Professor E. P. Whiteside, Soil Science Department, Michigan State University.

Zinc concentration in tissue samples is reported in parts per million of zinc by dry matter weight. Zinc content is reported in milligrams of zinc which was calculated for each replicate by multiplying the dry matter weight of the tissue sample by the zinc concentration.

V. RESULTS AND DISCUSSION

The objective of the field, greenhouse and incubation chamber experiments was to examine the relative availability of zinc from soil applied zinc sulfate and zinc EDTA by determining the zinc uptake and bean yield of pea bean plants and by chemically extracting the soil. The effect of the variables of soil applied phosphorus, soil type, and time on zinc availability was also studied.

Extensive field and greenhouse work had indicated that correction of the abnormal growth described on pea beans planted on inorganic soils in Michigan could be accomplished by application of zinc to the soil[27]. The plants grown in the field and greenhouse experiments conducted in this research exhibited zinc deficiency symptoms. When zinc was applied to the soil in sufficient quantity, the uptake of zinc by the plant increased and symptoms of zinc deficiency were not observed on plants.

Zinc deficiency symptoms on pea bean plants varied in intensity, but were alike on both field and greenhouse plants and were similar to those described by Thorne[83]. Pale green plants in the early stages of growth were evidence of mild zinc deficiency; plants subsequently recovered and often yielded a normal harvest of beans. More severe symptoms included small and deformed leaves with chlorotic areas. More drastically affected plants had shortened petioles and stems and necrotic areas appeared on the leaf, usually beginning with those leaves at the lower part of the plant and progressing up the stem affecting more and more leaves. The most severe symptoms appeared on plants during early growth, usually within 10 to 25 days after emergence; these plants rarely grew taller than six inches and many died without blossoming or fruiting. On plants with moderate to severe deficiency, the date of blossoming was frequently delayed. Pods would form but drop off or not develop fully. Maturity was delayed and frost or early mandatory harvest further depressed yields. A few severely affected plants would suddenly recover and produce a near normal yield.

The data were analyzed according to analysis of variance techniques[30,76].

V-A. Field Experiment Results

The purpose of the field experiments was to study zinc uptake by pea bean plants and yield of dry beans as affected by soil applied zinc sulfate and zinc EDTA and additional soil applied phosphorus. In all of the field experiments except Field Experiment 5, zinc treatments other than zinc sulfate and zinc EDTA were included. The results of these other treatments are reported elsewhere[38,39].

V-A-1. Results of Field Experiment 1, 1963

The effect of soil applied zinc sulfate and zinc EDTA on the zinc concentration in pea bean plants and on the yield of dry beans is reported for locations 1 through 6 in Tables 6 through 11. The data from these six locations are summarized in Table 12.

On the 1.2 pound zinc EDTA treatment, the plant population

Table 6 : Zinc concentration in pea bean plants (var. Sanilac) and yield of dry beans as affected by carrier and rate of zinc application. (Field Experiment 1, location 1, 1963)

Treatment		Zinc concentration and yield of beans[a]		
Zinc applied (lb/acre)	Zinc carrier	Zinc concentration (ppm)		Yield[d] (bu/acre)
		1st sampling[b]	2nd sampling[c]	
0	--	19.0	16.0	28.2
4.0	$ZnSO_4$	56.0	34.0	28.0
0.4	ZnEDTA	23.0	16.0	32.7
0.8	ZnEDTA	50.0	24.0	32.7
1.2	ZnEDTA	54.0	26.0	29.4
LSD, P=.05[e]				
Zinc treatment				4.1

(a) Average of four replications.
(b) Sampled 24 days after planting.
(c) Sampled 42 days after planting.
(d) Harvested 98 days after planting.
(e) Analysis of 12 treatments.

Table 7 : Zinc concentration in pea bean plants (var. Gratiot) and yield of dry beans as affected by carrier and rate of zinc application. (Field Experiment 1, location 2, 1963)

Treatment		Zinc concentration and yield of beans[a]		
Zinc applied (lb/acre)	Zinc carrier	Zinc concentration (ppm)		Yield[d] (bu/acre)
		1st sampling[b]	2nd sampling[c]	
0	--	15.0	22.0	30.9
4.0	$ZnSO_4$	26.0	26.0	33.0
0.4	ZnEDTA	30.0	28.0	34.9
0.8	ZnEDTA	28.0	27.0	38.1
1.2	ZnEDTA	24.0	24.0	35.8
LSD, P=.05[e]				
Zinc treatment				4.4

(a) Average of four replications.
(b) Sampled 27 days after planting.
(c) Sampled 43 days after planting.
(d) Harvested 98 to 100 days after planting.
(e) Analysis of 12 treatments.

Table 8: Zinc concentration in pea bean plants (var. Sanilac) and yield of dry beans as affected by carrier and rate of zinc application. (Field Experiment 1, location 3, 1963)

Treatment		Zinc concentration and yield of beans[a]		
Zinc applied (lb/acre)	Zinc carrier	Zinc concentration (ppm)		Yield[d] (bu/acre)
		1st sampling[b]	2nd sampling[c]	
0	--	15.0	12.0	25.8
4.0	$ZnSO_4$	40.0	22.0	26.3
0.4	ZnEDTA	28.0	12.0	29.9
0.8	ZnEDTA	36.0	15.0	38.6
1.2	ZnEDTA	48.0	16.0	27.3
LSD, P=.05[e] Zinc treatment				8.6

(a) Average of four replications.
(b) Sampled 27 days after planting.
(c) Sampled 43 days after planting.
(d) Harvested 90 days after planting.
(e) Analysis of 12 treatments.

Table 9: Zinc concentration in pea bean plants (var. Sanilac) and yield of dry beans as affected by carrier and rate of zinc application. (Field Experiment 1, location 4, 1963)

Treatment		Zinc concentration and yield of beans[a]		
Zinc applied (lb/acre)	Zinc carrier	Zinc concentration (ppm)		Yield[d] (bu/acre)
		1st sampling[b]	2nd sampling[c]	
0	--	14.0	15.0	31.6
4.0	$ZnSO_4$	50.0	31.0	32.1
0.4	ZnEDTA	20.0	20.0	31.8
0.8	ZnEDTA	32.0	24.0	32.4
1.2	ZnEDTA	36.0	26.0	31.3
LSD, P=.05[e]				
Zinc treatment				3.9

(a) Average of four replications.
(b) Sampled 36 days after planting.
(c) Sampled 50 days after planting.
(d) Harvested 93 to 102 days after planting.
(e) Analysis of 12 treatments.

Table 10: Zinc concentration in pea bean plants (var. Mehlfeldt) and yield of dry beans as affected by carrier and rate of zinc application. (Field Experiment 1, location 5, 1963)

Treatment		Zinc concentration and yield of beans[a]		
Zinc applied (lb/acre)	Zinc carrier	Zinc concentration (ppm)		Yield[d] (bu/acre)
		1st sampling[b]	2nd sampling[c]	
0	--	20.0	13.0	20.5
4.0	$ZnSO_4$	74.0	26.0	27.4
0.4	ZnEDTA	26.0	16.0	24.9
0.8	ZnEDTA	39.0	14.0	25.7
1.2	ZnEDTA	45.0	17.0	25.9
LSD, P=.05[e]				
Zinc treatment				2.3

(a) Average of four replications.
(b) Sampled 22 days after planting.
(c) Sampled 40 days after planting.
(d) Harvested 83 to 89 days after planting.
(e) Analysis of 12 treatments.

Table 11: Zinc concentration in pea bean plants (var. Sanilac) and yield of dry beans as affected by carrier and rate of zinc application. (Field Experiment 1, location 6, 1963)

Treatment		Zinc concentration and yield of beans[a]		
Zinc applied (lb/acre)	Zinc carrier	Zinc concentration (ppm)		Yield[d] (bu/acre)
		1st sampling[b]	2nd sampling[c]	
0	--	24.0	17.0	46.7
4.0	$ZnSO_4$	48.0	40.0	45.3
0.4	ZnEDTA	30.0	26.0	41.7
0.8	ZnEDTA	28.0	21.0	42.2
1.2	ZnEDTA	38.0	24.0	46.7
LSD, P=.05[e] Zinc treatment				ns

(a) Average of four replications.
(b) Sampled 23 days after planting.
(c) Sampled 48 days after planting.
(d) Harvested 94 to 104 days after planting.
(e) Analysis of 12 treatments.

Table 12: Zinc concentration in pea bean plants and yield of dry beans as affected by carrier and rate of zinc application. (Field Experiment 1, combination of locations 1 through 6, 1963)

Treatment		Zinc concentration and yield of beans[a]		
Zinc applied (lb/acre)	Zinc carrier	Zinc concentration (ppm)		Yield (bu/acre)
		1st sampling	2nd sampling	
0	--	17.8	15.8	30.6
4.0	$ZnSO_4$	49.0	29.8	32.0
0.4	ZnEDTA	26.2	19.7	32.7
0.8	ZnEDTA	35.5	20.8	35.0
1.2	ZnEDTA	40.8	22.2	32.7

(a) Averages from six locations.

was reduced about 25 per cent and some leaf damage was observed soon after emergence; however,the yield level was maintained at or exceeded the yield level of beans on plots which did not receive zinc.

Zinc deficiency symptoms appeared and persisted until harvest on pea bean plants grown on plots which did not receive zinc on locations 1, 2, 3, and 5. On location 6, symptoms appeared early but disappeared after about two weeks.

On all locations except 6, the yield of dry beans was lower from plants grown on plots which did not receive zinc.

The zinc concentration in plants was higher at both sampling times when zinc was applied as either carrier (Table 12). The yield of dry beans was also higher.

When 4.0 pounds of zinc per acre as zinc sulfate were applied, the zinc concentration in plants was increased from 17.8 to 49.0 parts per million at the three week sampling and from 15.8 to 29.8 parts per million at the pre-bloom sampling (Table 12). The yield of dry beans was increased from 30.6 to 32.0 bushels per acre when the sulfate zinc carrier was applied.

When 1.2 pounds per acre of zinc as zinc EDTA were applied, the zinc concentration in plants was increased to 40.8 parts per million at the first sampling and to 22.2 parts per million at the pre-bloom sampling (Table 12). The yield of beans with this chelate treatment was 32.7 bushels per acre. Zinc concentration in plants increased with each increment of zinc EDTA but the yield of beans increased only from the 0.4 to the 0.8 zinc EDTA treatment.

The zinc concentration in plants was lower at the second sampling. Plants grown on the zinc sulfate plots decreased 39.2 per cent in concentration between samplings and the plants on the 1.2 pound zinc EDTA plots decreased 45.6 per cent (Table 12).

V-A-2. Results of Field Experiment 2, 1963

The effect of soil applied zinc sulfate and zinc EDTA and of additional soil applied phosphorus on the zinc concentration in pea bean plants and on the yield of dry beans is reported in Tables 13 and 14. The data from the plots which received 87 pounds of additional phosphorus in both 1959 and 1961 were compared with the data from the plots which received 174 pounds of additional phosphorus in 1961; comparison was also made for data from the plots which received 174 pounds of additional phosphorus in both 1959 and 1961 and from those which received 348 pounds of additional phosphorus in 1959. Since there was no difference in data from the plots which received the same total amount of additional phosphorus, the results were combined and are reported according to additional phosphorus levels of 0, 87, 174, 348, and 696 pounds per acre.

Zinc deficiency symptoms appeared on plants soon after emergence and persisted until harvest on plots which did not receive zinc. As the level of applied phosphorus increased, the deficiency symptoms became more severe and, on the 348 and 696 pound phosphorus plots, some symptoms also appeared on plants grown on low levels of applied zinc.

On plots which did not receive zinc or phosphorus, the concentration of zinc in plants was 20.0 parts per million (Table 13).

Table 13: Zinc concentration in pea bean plants (var. Sanilac) as affected by carrier and rate of zinc application and rate of phosphorus application. (Field Experiment 2, location 7, 1963)

Treatment		Zinc concentration in bean plants[a] (ppm)				
Zinc applied (lb/acre)	Zinc carrier	No additional P (b)(d)	87 additional lb P/acre (c)(d)	174 additional lb P/acre (b)(d)	348 additional lb P/acre (b)(d)	696 additional lb P/acre (c)(d)
0	--	20.0	14.0	14.0	15.0	14.0
4.0	$ZnSO_4$	37.0	39.0	35.0	31.0	39.0
0.4	ZnEDTA	26.0	18.0	27.0	25.0	28.0
0.8	ZnEDTA	36.0	24.0	30.0	27.0	26.0
1.2	ZnEDTA	38.0	39.0	40.0	39.0	39.0

(a) Sampled 41 days after planting.
(b) Average of six replications.
(c) Average of three replications.
(d) 87 lb P plots and half of 174 and 348 lb P plots received all of P in fall of 1959. Balance of 174 and 348 lb P plots and 696 lb P plots received half of P in fall of 1959 and remainder in fall of 1961.

Table 14: Yield of dry beans from pea bean plants (var. Sanilac) as affected by carrier and rate of zinc application and rate of phosphorus application. (Field Experiment 2, location 7, 1963)

Treatment		Yield of dry beans[a] (bu/acre)				
Zinc applied (lb/acre)	Zinc carrier	No additional P (b)(d)	87 additional lb P/acre (c)(d)	174 additional lb P/acre (b)(d)	348 additional lb P/acre (b)(d)	696 additional lb P/acre (c)(d)
0	--	30.8	24.1	20.0	16.7	8.8
4.0	$ZnSO_4$	39.1	40.7	39.8	33.1	34.6
0.4	ZnEDTA	33.1	27.5	29.8	34.0	25.9
0.8	ZnEDTA	34.0	26.6	29.9	24.6	31.5
1.2	ZnEDTA	30.3	24.0	29.4	27.8	25.6

(a) Harvested 96 to 97 days after planting.
(b) Average of six replications.
(c) Average of three replications.
(d) 87 lb P plots and half of 174 and 348 lb P plots received all of P in fall of 1959. Balance of 174 and 348 lb P plots and 696 lb P plots received half of P in fall of 1959 and remainder in fall of 1961.

With the first increment of phosphorus, the concentration decreased to 14 parts per million, but remained constant for all other phosphorus treatments. However, the yield of beans decreased from 30.8 to 8.8 bushels per acre as the rate of applied phosphorus increased from 0 to 696 pounds per acre (Table 14).

When zinc was applied with either carrier on any phosphorus plot,the concentration of this element in plants and the yield of beans both increased.

On the 4.0 pound zinc sulfate treatment, the zinc concentration in plants increased from 15 to 36 parts per million and the yield from 20.1 to 37.5 bushels per acre over all phosphorus treatments. The concentration in plants was constant except for a 10 per cent decrease on the 174 and 348 pound plots (Table 13). The yield decreased from 40.7 to 34.6 bushels of beans as the level of applied phosphorus increased from 87 to 696 pounds per acre (Table 14).

When zinc EDTA was applied at 1.2 pounds of zinc per acre, the zinc concentration in plants was the same or higher than in plants from the zinc sulfate plots (Table 13). Over all phosphorus treatments, the yield was 27.4 bushels per acre. There was a decrease in yield from 29.4 to 25.6 bushels per acre with this chelate treatment, as the rate of applied phosphorus increased from 174 to 696 pounds per acre (Table 14).

V-A-3. Results of Field Experiment 3, 1964

The effect of soil applied zinc sulfate and zinc EDTA on the zinc uptake of pea bean plants and on the yield of dry beans is reported for locations 8 through 10 in Tables 15 through 17. The data from these three locations are summarized in Table 18.

All three locations were affected at blossoming time by hot, dry weather which affected pod set and thus reduced yield of beans[22]. The yield on location 9 was also reduced by late maturity and frost damage.

Zinc deficiency symptoms appeared and persisted until harvest on plants grown on plots which did not receive zinc.

Application of zinc with either carrier tended to decrease the dry matter weight of plants, to increase zinc concentration and zinc content in plants, and to increase yield of beans (Table 18).

When 3.0 pounds of zinc as zinc sulfate were applied, the zinc concentration in plants increased from 24.8 to 39.8 parts per million and the bean yield from 19.0 to 20.5 bushels per acre (Table 18).

When 1.2 pounds of zinc as zinc EDTA were applied, the plants increased in zinc concentration to 45.7 parts per million and the yield of beans was 23.6 bushels per acre (Table 18). Zinc uptake by plants and bushels of beans harvested increased with each increment of zinc applied in the chelated form.

V-A-4. Results of Field Experiment 4, 1964

The effect of soil applied zinc sulfate and zinc EDTA and of additional soil applied phosphorus on the zinc uptake of pea bean

Table 15: Weight, zinc concentration, and zinc content of pea bean plants (var. Sanilac) and yield of dry beans as affected by carrier and rate of zinc application. (Field Experiment 3, location 8, 1964)

Treatment		Weight, zinc uptake, and yield of beans[a]			
Zinc applied (lb/acre)	Zinc carrier	Weight per ten plants[b] (g)	Zinc concentration[b] (ppm)	Zinc content per ten plants[b] (mgm)	Yield[c] (bu/acre)
0	--	45.1	22.9	1.03	29.3
3.0	$ZnSO_4$	39.3	22.9	0.89	33.9
0.3	ZnEDTA	43.8	23.3	1.03	34.7
0.6	ZnEDTA	38.9	29.5	1.16	36.7
0.9	ZnEDTA	42.3	27.4	1.15	35.8
1.2	ZnEDTA	39.6	24.5	0.98	36.4
LSD, P=.05[d] Zinc treatment		4.3	4.6	0.22	ns

(a) Average of eight replications.
(b) Sampled at pre-bloom stage.
(c) Harvested at 94 days.
(d) Analysis of 18 treatments.

Table 16: Weight, zinc concentration, and zinc content of pea bean plants (var. Sanilac) and yield of dry beans as affected by carrier and rate of zinc application. (Field Experiment 3, location 9, 1964)

Treatment		Weight, zinc uptake, and yield of beans[a]			
Zinc applied (lb/acre)	Zinc carrier	Weight per ten plants[b] (g)	Zinc concentration[b] (ppm)	Zinc content per ten plants[b] (mgm)	Yield[c] (bu/acre)
0	--	21.7	24.5	0.53	12.3
3.0	$ZnSO_4$	21.6	46.7	1.01	16.7
0.3	ZnEDTA	21.1	34.9	0.74	15.8
0.6	ZnEDTA	21.2	33.8	0.71	14.8
0.9	ZnEDTA	20.3	43.2	0.88	15.7
1.2	ZnEDTA	19.9	58.4	1.16	16.3
LSD, P=.05[d]					
Zinc treatment		1.5	9.2	0.20	ns

(a) Average of eight replications.
(b) Sampled at pre-bloom stage.
(c) Harvested at 104 days.
(d) Analysis of 18 treatments.

Table 17: Weight, zinc concentration, and zinc content of pea bean plants (var. Sanilac) and yield of dry beans as affected by carrier and rate of zinc application. (Field Experiment 3, location 10, 1964)

Treatment		Weight, zinc uptake, and yield of beans[a]			
Zinc applied (lb/acre)	Zinc carrier	Weight per ten plants[b] (g)	Zinc concentration[b] (ppm)	Zinc content per ten plants[b] (mgm)	Yield[c] (bu/acre)
0	--	28.3	27.0	0.77	15.3
3.0	$ZnSO_4$	28.5	49.8	1.41	14.2
0.3	ZnEDTA	29.0	38.3	1.11	17.6
0.6	ZnEDTA	31.9	42.3	1.35	17.5
0.9	ZnEDTA	28.7	46.1	1.34	15.2
1.2	ZnEDTA	26.4	54.2	1.42	18.0
LSD, P=.05[d] Zinc treatment		2.7	8.6	0.28	ns

(a) Average of eight replications.
(b) Sampled at pre-bloom stage.
(c) Harvested at 105 days.
(d) Analysis of 18 treatments.

Table 18: Weight, zinc concentration, and zinc content of pea bean plants and yield of dry beans as affected by carrier and rate of zinc application. (Field Experiment 3, combination of locations 8 through 10, 1964)

Treatment		Weight, zinc uptake, and yield of beans[a]			
Zinc applied (lb/acre)	Zinc carrier	Weight per ten plants[b] (g)	Zinc concentration[b] (ppm)	Zinc content per ten plants[b] (mgm)	Yield (bu/acre)
0	--	31.7	24.8	0.78	19.0
3.0	$ZnSO_4$	29.8	39.8	1.10	20.5
0.3	ZnEDTA	31.3	32.2	0.96	22.7
0.6	ZnEDTA	30.7	35.2	1.07	23.0
0.9	ZnEDTA	30.4	38.9	1.12	22.2
1.2	ZnEDTA	28.6	45.7	1.19	23.6

(a) Averages from three locations.
(b) Sampled at pre-bloom stage.

plants and on the yield of dry beans is reported in Tables 19 through 22. The data from plots which received the same total amount of phosphorus between 1959 and 1962 were compared as in V-A-2. Results of Field Experiment 2, 1963. Since there was no difference in data from comparable phosphorus plots, the results were combined and reported according to additional phosphorus levels of 0, 87, 174, 348, and 696 pounds per acre.

Zinc deficiency symptoms appeared on plants soon after emergence and persisted until harvest on plots which did not receive zinc. The symptoms became more severe as the level of applied phosphorus increased and, on the 348 and 696 pound plots, some symptoms appeared on plants receiving low levels of applied zinc.

On the plots which did not receive zinc, there were 19.4 parts per million of zinc in the plant at the pre-bloom sampling (Table 20) and 27.7 bushels of beans were harvested (Table 22). As the rate of applied phosphorus increased from 87 to 696 pounds per acre, the plant weight, zinc concentration in plants, and zinc content of plants tended to increase; however, the yield of beans decreased from 30.9 to 10.2 bushels per acre (Table 22).

When 1.2 pounds of zinc as zinc EDTA were applied, there was a higher concentration of zinc in plants (Table 20) and more beans were harvested (Table 22) than when 3.0 pounds of zinc as zinc sulfate were applied. However, the dry matter weight of plants on the zinc sulfate plots was higher (Table 19) and thus the zinc content in plants from these two treatments was comparable (Table 21).

Table 19: Weight of ten pea bean plants (var. Sanilac) as affected by carrier and rate of zinc application and rate of phosphorus application. (Field Experiment 4, location 11, 1964)

Treatment		Weight of ten bean plants[a] (g)				
Zinc applied (lb/acre)	Zinc carrier	No additional P (b)(d)	87 additional lb P/acre (c)(d)	174 additional lb P/acre (b)(d)	348 additional lb P/acre (b)(d)	696 additional lb P/acre (c)(d)
0	--	27.3	23.7	25.7	26.8	31.6
3.0	$ZnSO_4$	33.3	31.4	31.5	36.3	37.1
0.3	ZnEDTA	28.0	28.0	30.0	33.1	33.6
0.6	ZnEDTA	32.9	31.0	30.0	31.2	34.4
0.9	ZnEDTA	30.6	28.1	29.3	34.8	36.9
1.2	ZnEDTA	26.5	27.3	29.4	32.0	37.2
LSD, P=.05[e]						
Zinc treatment (Z)				0.6		
Phosphorus treatment (P)				ns		
Z x P				ns		

(a) Sampled at pre-bloom stage.
(b) Average of six replications.
(c) Average of three replications.
(d) 87 lb P plots and half of 174 and 348 lb P plots received all of P in fall of 1959. Balance of 174 and 348 lb P plots and 696 lb P plots received half of P in fall of 1959 and remainder in fall of 1962.
(e) Analysis of 22 treatments.

Table 20: Zinc concentration in pea bean plants (var. Sanilac) as affected by carrier and rate of zinc application and rate of phosphorus application. (Field Experiment 4, location 11, 1964)

Treatment		Zinc concentration in bean plants[a] (ppm)				
Zinc applied (lb/acre)	Zinc carrier	No additional P (b)(d)	87 additional lb P/acre (c)(d)	174 additional lb P/acre (b)(d)	348 additional lb P/acre (b)(d)	696 additional lb P/acre (c)(d)
0	--	19.4	17.3	17.5	18.2	18.7
3.0	$ZnSO_4$	36.0	34.9	30.0	29.8	25.3
0.3	ZnEDTA	32.3	26.9	28.5	25.8	28.2
0.6	ZnEDTA	29.1	29.2	31.2	29.9	28.8
0.9	ZnEDTA	36.7	32.8	31.2	29.5	31.9
1.2	ZnEDTA	39.6	34.5	32.0	31.9	29.5

LSD, P=.05[e]	
Zinc treatment (Z)	2.9
Phosphorus treatment (P)	ns
Z x P	ns

(a) Sampled at pre-bloom stage.
(b) Average of six replications.
(c) Average of three replications.
(d) 87 lb P plots and half of 174 and 348 lb P plots received all of P in fall of 1959. Balance of 174 and 348 lb P plots and 696 lb P plots received half of P in fall of 1959 and remainder in fall of 1962.
(e) Analysis of 22 treatments.

Table 21: Zinc content of ten pea bean plants (var. Sanilac) as affected by carrier and rate of zinc application and rate of phosphorus application. (Field Experiment 4, location 11, 1964)

Treatment		Zinc content in ten bean plants[a] (mgm)				
Zinc applied (lb/acre)	Zinc carrier	No additional P (b)(d)	87 additional lb P/acre (c)(d)	174 additional lb P/acre (b)(d)	348 additional lb P/acre (b)(d)	696 additional lb P/acre (c)(d)
0	--	0.53	0.41	0.45	0.49	0.57
3.0	$ZnSO_4$	1.20	1.10	0.94	1.08	0.94
0.3	ZnEDTA	0.90	0.75	0.86	0.85	0.95
0.6	ZnEDTA	0.96	0.91	0.94	0.93	1.02
0.9	ZnEDTA	1.12	0.92	0.91	1.03	1.18
1.2	ZnEDTA	1.05	0.97	0.94	1.02	1.10
LSD, P=.05[e]						
Zinc treatment (Z)				0.13		
Phosphorus treatment (P)				ns		
Z x P				ns		

(a) Sampled at pre-bloom stage.
(b) Average of six replications.
(c) Average of three replications.
(d) 87 lb P plots and half of 174 and 348 lb P plots received all of P in fall of 1959. Balance of 174 and 348 lb P plots and 696 lb P plots received half of P in fall of 1959 and remainder in fall of 1962.
(e) Analysis of 22 treatments.

Table 22: Yield of dry beans from pea bean plants (var. Sanilac) as affected by carrier and rate of zinc application and rate of phosphorus application. (Field Experiment 4, location 11, 1964)

Treatment		Yield of dry beans[a] (bu/acre)				
Zinc applied (lb/acre)	Zinc carrier	No additional P (b)(d)	87 additional lb P/acre (c)(d)	174 additional lb P/acre (b)(d)	348 additional lb P/acre (b)(d)	696 additional lb P/acre (c)(d)
0	--	27.7	30.9	21.2	17.1	10.2
3.0	$ZnSO_4$	29.0	27.0	28.7	27.2	19.0
0.3	ZnEDTA	27.2	24.2	23.6	21.1	14.2
0.6	ZnEDTA	25.8	24.2	25.3	23.1	21.2
0.9	ZnEDTA	33.0	26.2	30.6	27.5	26.2
1.2	ZnEDTA	27.2	23.9	25.2	27.5	26.4

(a) Harvested at 90 to 99 days.
(b) Average of six replications.
(c) Average of three replications.
(d) 87 lb P plots and half of 174 and 348 lb P plots received all of P in fall of 1959. Balance of 174 and 348 lb P plots and 696 lb P plots received half of P in fall of 1959 and remainder in fall of 1962.

As the rate of applied phosphorus increased, the zinc concentration in plants was reduced more on the 3.0 pound zinc sulfate plots than on the 1.2 pound zinc EDTA plots (Table 20). The yield of beans was lower on the 0, 87, and 174 pound phosphorus plots but higher on the 348 and 696 pound phosphorus plots with this zinc chelate treatment than with the zinc sulfate treatment (Table 22).

Zinc concentration in plants increased as the rate of applied zinc EDTA increased; bean yields also tended to increase with each increment of the chelated zinc.

V-A-5. Results of Field Experiment 5, 1964

The effect of soil applied zinc sulfate and zinc EDTA on the zinc concentration in pea bean plants and on the yield of dry beans is reported in Table 23.

Zinc deficiency symptoms appeared after emergence and persisted until harvest on plants on all except the 1.6 pound zinc EDTA treatment. The symptoms increased in severity as the rate of applied zinc decreased. Only slight symptoms appeared on the 8.0 pound zinc sulfate plot.

There was a significant increase in zinc concentration in plants due to zinc treatment on the 4.0 and 8.0 pound zinc sulfate plots and on the 0.8 and 1.6 pound zinc EDTA plots (Table 23). Zinc concentration increased as rate of applied zinc increased. All zinc treatments significantly increased the yield of beans.

Even though the same zinc concentration was in the plants on the 2.0 pound zinc sulfate plot as on the plot which did not

Table 23: Zinc concentration in pea bean plants (var. Sanilac) and yield of dry beans as affected by carrier and rate of zinc application. (Field Experiment 5, location 12, 1964)

Treatment		Zinc concentration and yield of beans[a]	
Zinc applied (lb/acre)	Zinc carrier	Zinc concentration[b] (ppm)	Yield[c] (bu/acre)
0	--	19.6	7.6
2.0	$ZnSO_4$	19.4	23.3
4.0	$ZnSO_4$	31.9	30.5
8.0	$ZnSO_4$	36.0	37.4
0.4	ZnEDTA	24.1	32.5
0.8	ZnEDTA	28.5	38.7
1.6	ZnEDTA	31.7	39.1
LSD, P=.05 Zinc treatment		5.3	5.3

(a) Average of four replications.
(b) Sampled at pre-bloom stage.
(c) Harvested at 101 days.

receive any zinc, the bean yield increased from 7.6 to 23.3 bushels per acre (Table 23).

When 1.6 pounds of zinc as the chelate were applied, the concentration of this element in the plants was equivalent to that in plants on the 2.0 and 4.0 pound zinc sulfate plots and the yield of beans was higher than the yield on the 2.0, 4.0 and 8.0 pound zinc sulfate plots (Table 23).

V-B. Greenhouse Experiment Results

The objective of the greenhouse experiments was to observe the availability of zinc sulfate and zinc EDTA as indicated by the uptake and distribution of zinc in the plant, the dry matter weight, and the yield of pods.

In all experiments, zinc deficiency symptoms were observed on plants grown on pots which did not receive zinc.

V-B-1. Results of Greenhouse Experiment 1

The effect of soil applied zinc sulfate, soil applied phosphorus, and soil type on dry matter weight of plant parts, pod yield, and zinc uptake of the above-ground plant is reported in Table 24.

When zinc was applied, the dry matter weight of plant parts and zinc content of plants tended to increase.

The yield of pods, weight of above-ground plants and zinc content of plants were significantly reduced when phosphorus was applied on the Wisner clay loam soil.

Zinc content in plants and yield of plant parts was greater on

Table 24: Weight of pea bean plant parts and zinc concentration and zinc content of the total above-ground pea bean plants (var. Sanilac) as affected by rate of zinc and phosphorus application and soil type. (Greenhouse Experiment 1)

Zinc sulfate treatment (lb Zn/acre)	Weight and zinc uptake of plant parts[a]									
	No additional P					1000 lb additional P/acre				
	Weight of leaves and stems (g)	Weight of pods (g)	Total above-ground plants			Weight of leaves and stems (g)	Weight of pods (g)	Total above-ground plants		
			Weight (g)	Zinc concentration (ppm)	Zinc content (mgm)			Weight (g)	Zinc concentration (ppm)	Zinc content (mgm)
	Wisner clay loam									
0	4.35	6.05	10.40	19.5	0.207	4.75	0.65	5.40	19.2	0.107
8.0	5.68	7.10	12.78	17.7	0.228	5.88	5.78	11.65	21.7	0.250
	Bach silt loam									
0	5.00	9.13	14.13	16.7	0.234	3.53	9.83	13.35	15.6	0.206
8.0	5.28	9.25	14.53	16.3	0.236	4.45	7.25	11.70	15.0	0.175

(a) Average of four replications. Harvested 97 days after planting.

Table 25: Differences between means required for significance at the five and one per cent levels obtained by analysis of variance of the data reported in Table 24. (Greenhouse Experiment 1)

Treatment	LSD values at five and one per cent levels				
	Weight of leaves and stems (g)	Weight of pods (g)	Total above-ground plants		
			Weight (g)	Zinc concen-tration (ppm)	Zinc content (mgm)
Soil type (S)	2.67,3.56	ns	4.56,6.07	ns	0.13,0.17
Phosphorus level (P)	2.67,3.56	ns	4.56,6.07	ns	0.13,0.17
Zinc level (Z)	2.67,3.56	ns	4.56,6.07	ns	0.13,0.17
S x P	*	*	ns	ns	ns
S x Z	**	ns	**	ns	**
P x Z	ns	ns	ns	ns	ns
S x P x Z	**	ns	ns	ns	ns

the Bach silt loam than on the Wisner soil.

Although the 467.4 pounds of nitrogen per acre were a relatively large quantity to apply, it was necessary to apply over 400 pounds of nitrogen per acre before the zinc concentration in field-grown Bermuda grass was affected[55].

V-B-2. Results of Greenhouse Experiment 2

The effect of soil applied zinc sulfate and zinc EDTA on the dry matter weight and zinc uptake in parts of pea bean plants is reported in Table 26. The data for weight and zinc uptake of plant parts on each pot were arithmetically combined and are reported as the total above-ground plant in Table 27.

There was a significant increase in dry matter weight, zinc concentration and zinc content in the leaf, stem, vine, and total above-ground plant on pots which received any zinc treatment (Tables 26 and 27).

Plants grown on pots which had not received any zinc were growing very slowly and the petiole, stem, and vine were not as long as those on zinc treated pots. The zinc concentration in the vine was 33.70 parts per million compared to 15.34 and 35.89 parts per million in the vine of plants grown on the 4.0 pound zinc sulfate and zinc EDTA treatments,respectively (Table 26). This relatively high zinc concentration in zinc deficient plants is in agreement with observations of other researchers[52,69].

The zinc concentration and zinc content in the leaf, stem, vine, and total above-ground plant were all significantly higher

Table 26: Weight, zinc concentration, and zinc content of pea bean plant parts (var. Sanilac) as affected by carrier and rate of zinc application. (Greenhouse Experiment 2)

Treatment		Weight and zinc uptake of bean plant parts[(a)]								
Zinc applied (lb/acre)	Zinc carrier	Leaves			Stems			Vines		
		Weight (g)	Zinc concen-tration (ppm)	Zinc content (mgm)	Weight (g)	Zinc concen-tration (ppm)	Zinc content (mgm)	Weight (g)	Zinc concen-tration (ppm)	Zinc content (mgm)
0	--	2.02	13.03	0.026	0.55	11.18	0.006	0.12	33.70	0.004
4.0	$ZnSO_4$	2.49	14.81	0.037	0.68	11.30	0.008	0.44	15.34	0.007
4.0	ZnEDTA	2.55	24.42	0.063	0.72	15.83	0.011	0.82	35.89	0.029
20.0	$ZnSO_4$	2.30	20.61	0.047	0.60	14.73	0.009	0.63	31.03	0.019
20.0	ZnEDTA	2.50	74.61	0.186	0.59	60.20	0.035	0.92	59.01	0.054
LSD, P=.05 and .01										
Treatment		0.17, 0.24	7.48, 10.51	0.017, 0.024	0.06, 0.09	6.35, 8.92	0.003, 0.005	0.28. 0.40	4.45, 6.24	0.010, 0.014
Zinc level (L)		ns	**	**	ns	**	**	*	**	**
Zinc carrier (C)		ns	**	**	**	**	**	ns	**	**
L x C		ns	**	**	ns	**	**	ns	*	ns

(a) Average of four replications. Harvested 29 days after planting.

Table 27: Weight, zinc concentration, and zinc content of the total above-ground pea bean plants (var. Sanilac) as affected by carrier and rate of zinc application. (Greenhouse Experiment 2)

Treatment		Weight and zinc uptake of bean plants[a]		
Zinc applied (lb/acre)	Zinc carrier	Weight (g)	Zinc concentration (ppm)	Zinc content (mgm)
0	--	2.69	13.53	0.036
4.0	$ZnSO_4$	3.60	14.24	0.051
4.0	ZnEDTA	4.09	25.08	0.103
20.0	$ZnSO_4$	3.52	21.26	0.075
20.0	ZnEDTA	4.00	68.84	0.275
LSD, P=.05 and .01				
Zinc treatment		0.34,0.47	5.81,8.15	0.022,0.031
Zinc level (L)		**	**	**
Zinc carrier (C)		ns	**	**
L x C		ns	**	**

(a) Average of four replications. Harvested 29 days after planting.

in the plants grown on zinc EDTA treated pots than in those plants grown on zinc sulfate treated pots.

The zinc concentration in the most recent growth portion of the plant, the vine, was significantly higher on zinc EDTA treatments than on zinc sulfate treatments.

As the rate of applied zinc was increased, more zinc was taken up by plants grown on zinc EDTA treatments than by plants grown on zinc sulfate treatments. When applied zinc was increased by a factor of 5, the zinc uptake by plants was increased 1.5 times on zinc sulfate treated pots and 2.7 times on zinc EDTA treated pots (Table 27).

The zinc content in parts of the plant is related to soil applied zinc in Figures 1 through 4.

There was a higher correlation obtained between zinc applied as zinc EDTA and the zinc content of the leaf (Figure 1), stem (Figure 2), vine (Figure 3), or total above-ground plant (Figure 4) than was obtained between zinc applied as zinc sulfate and the zinc content of these plant parts.

V-B-3. Results of Greenhouse Experiment 3

The effect of soil applied nitrogen-phosphorus-potassium-manganese and EDTA on the dry matter weight and zinc uptake in parts of pea bean plants is reported in Table 28. The data for weight and zinc uptake of plant parts on each pot were arithmetically combined and are reported in Table 29.

The plants grown on the EDTA treatment contained a significantly

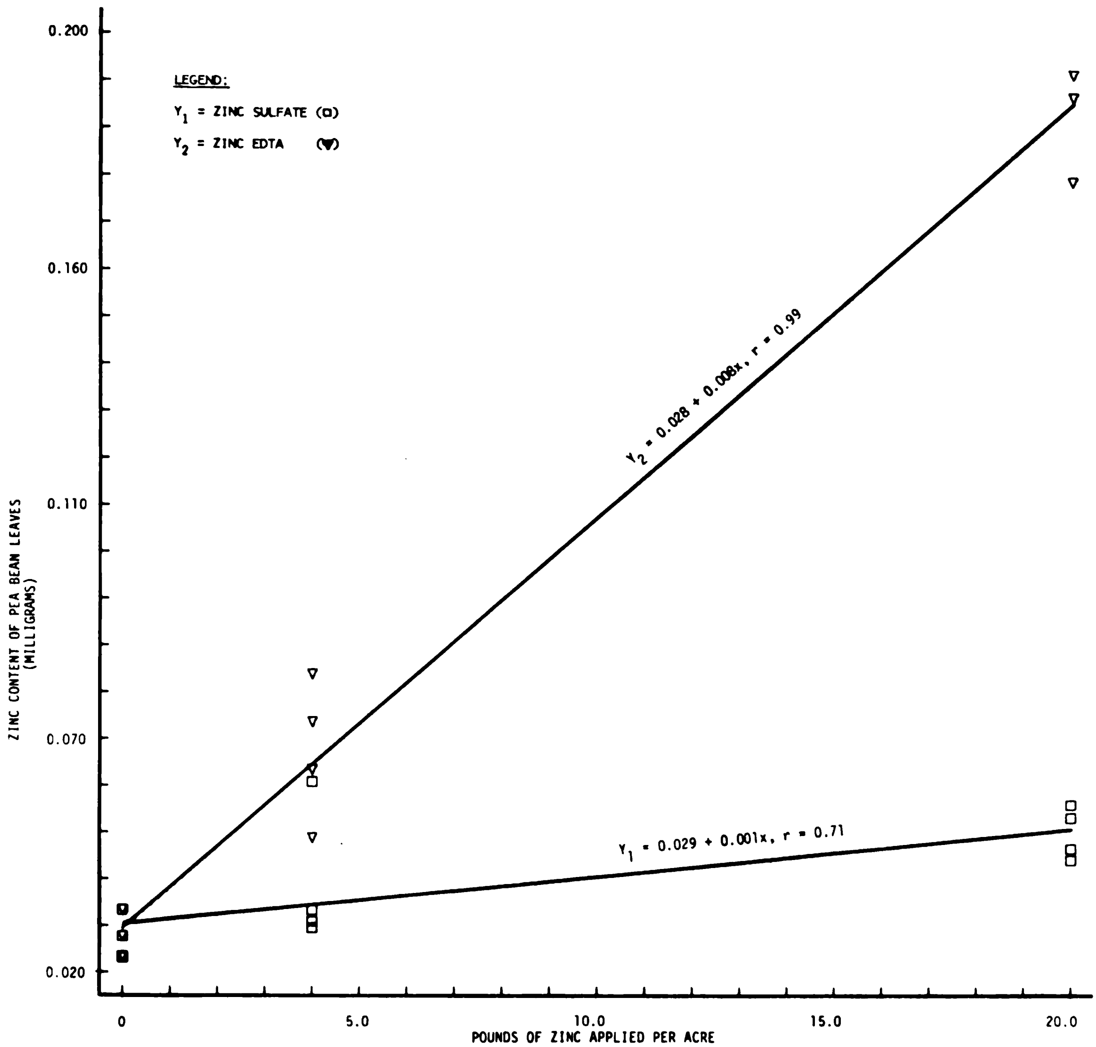

FIGURE 1: THE RELATIONSHIP BETWEEN RATES OF ZINC APPLIED AS ZINC SULFATE AND ZINC EDTA AND THE ZINC CONTENT OF LEAVES OF PEA BEAN PLANTS GROWN ON A WISNER CLAY LOAM SOIL. (GREENHOUSE EXPERIMENT 2)

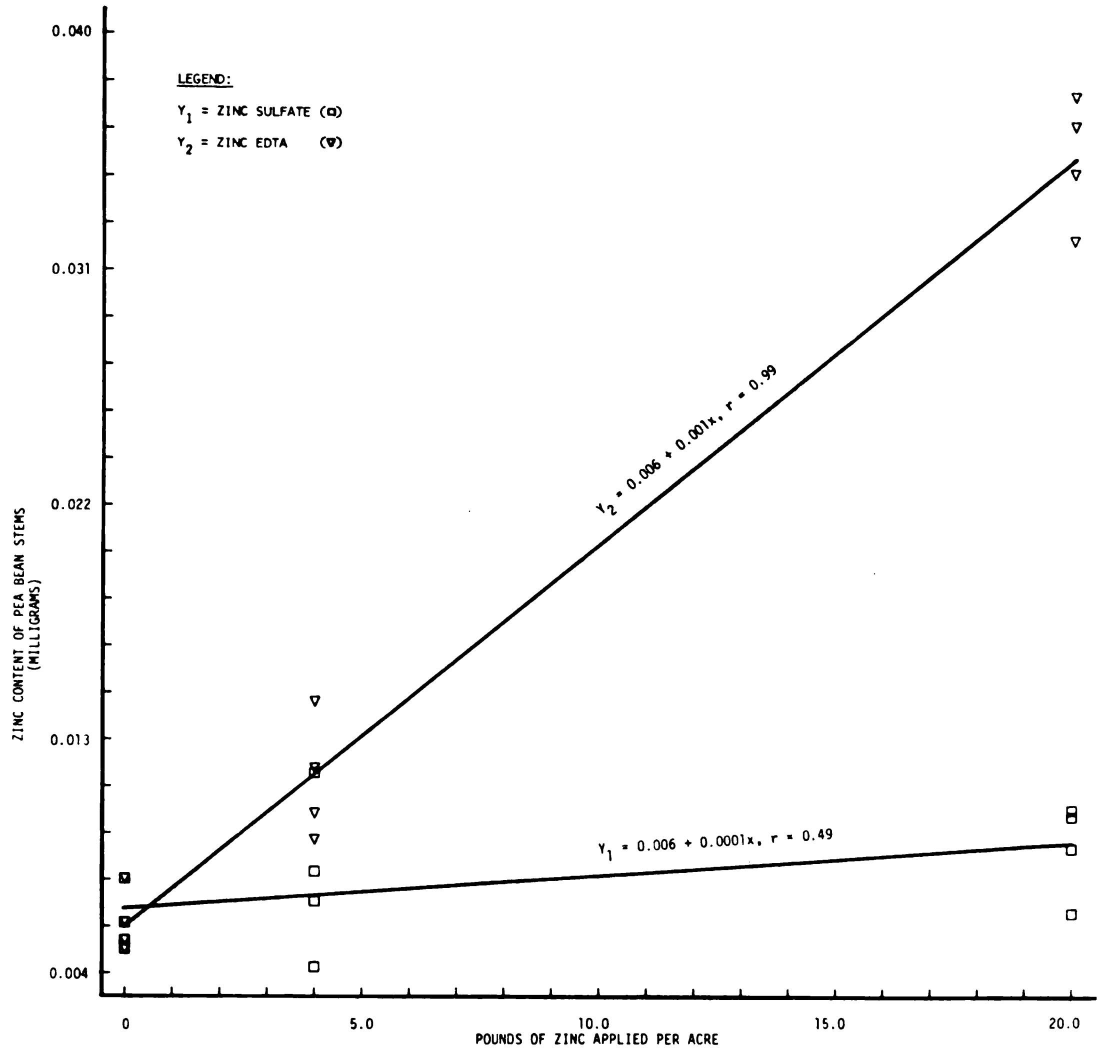

FIGURE 2: THE RELATIONSHIP BETWEEN RATES OF ZINC APPLIED AS ZINC SULFATE AND ZINC EDTA AND THE ZINC CONTENT OF STEMS OF PEA BEAN PLANTS GROWN ON A WISNER CLAY LOAM SOIL. (GREENHOUSE EXPERIMENT 2)

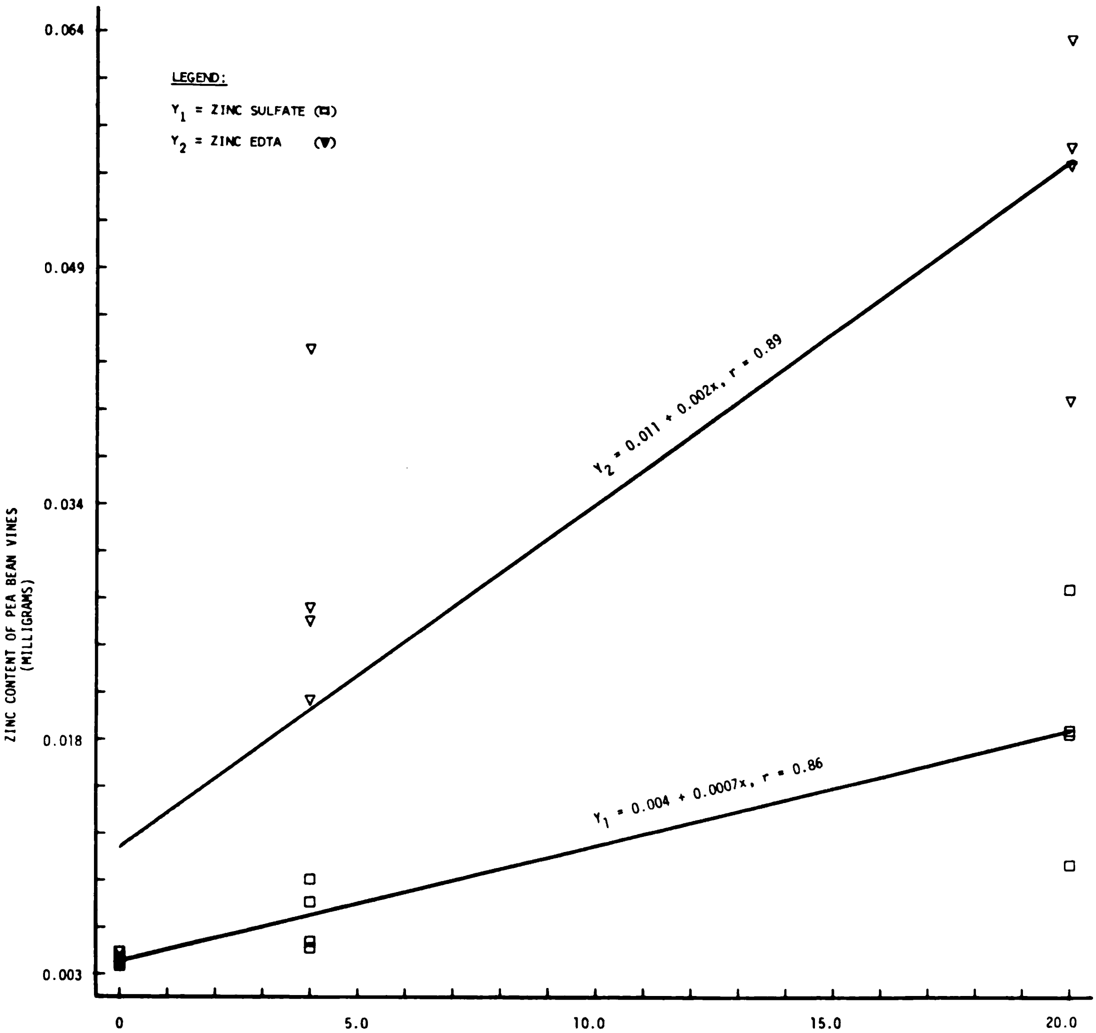

FIGURE 3: THE RELATIONSHIP BETWEEN RATES OF ZINC APPLIED AS ZINC SULFATE AND ZINC EDTA AND THE ZINC CONTENT OF VINES OF PEA BEAN PLANTS GROWN ON A WISNER CLAY LOAM SOIL. (GREENHOUSE EXPERIMENT 2)

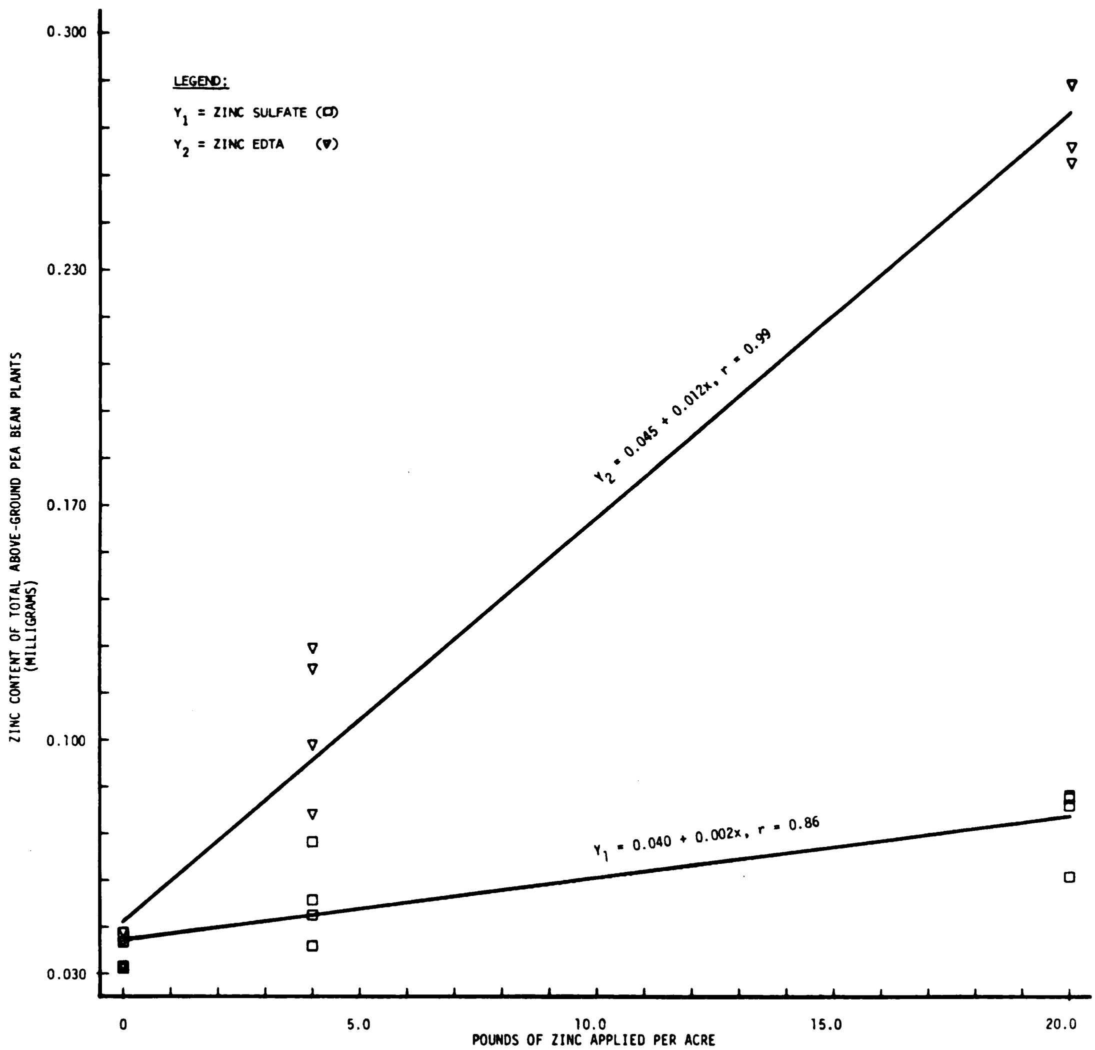

FIGURE 4: THE RELATIONSHIP BETWEEN RATES OF ZINC APPLIED AS ZINC SULFATE AND ZINC EDTA AND THE ZINC CONTENT OF THE TOTAL ABOVE-GROUND PEA BEAN PLANTS GROWN ON A WISNER CLAY LOAM SOIL. (GREENHOUSE EXPERIMENT 2)

Table 28: Weight, zinc concentration, and zinc content of pea bean plant parts (var. Sanilac) as affected by nitrogen-phosphorus-potassium-manganese and EDTA application. (Greenhouse Experiment 3)

Treatment		Weight and zinc uptake of bean plant parts[a]								
Nutrients	Rate (lb/acre)	Leaves			Stems			Vines		
		Weight (g)	Zinc concentration (ppm)	Zinc content (mgm)	Weight (g)	Zinc concentration (ppm)	Zinc content (mgm)	Weight (g)	Zinc concentration (ppm)	Zinc content (mgm)
--	--	1.98	13.23	0.026	0.57	10.91	0.006	0.37	22.90	0.008
N-P-K-Mn	36-63-60-20	2.02	13.03	0.026	0.55	11.18	0.006	0.12	33.70	0.004
EDTA	100	1.98	23.81	0.047	0.56	14.43	0.008	0.45	21.89	0.010
LSD, P=.05 and .01 Treatment		ns	4.42, 6.70	0.008, 0.013	ns	ns	0.002, 0.004	0.21, 0.32	7.16, 10.84	0.003, 0.005

(a) Average of four replications. Harvested 29 days after planting.

Table 29: Weight, zinc concentration, and zinc content of the total above-ground pea bean plants (var. Sanilac) as affected by nitrogen-phosphorus-potassium-manganese and EDTA application. (Greenhouse Experiment 3)

Treatment		Weight and zinc uptake of bean plants[a]		
Nutrients	Rate (lb/acre)	Weight (g)	Zinc concentration (ppm)	Zinc content (mgm)
--	--	2.91	13.82	0.040
N-P-K-Mn	36-63-60-20	2.69	13.53	0.036
EDTA	100	3.00	21.76	0.065
LSD, P=.05 and .01 Treatment		0.29,ns	4.08,6.18	0.011,0.017

(a) Average of four replications. Harvested at 29 days after planting.

higher zinc concentration and zinc content in the leaf, stem, vine, and total above-ground plant.

The plants grown without any treatment tended to be taller, to have a greater dry matter weight, and to take up more zinc than those plants grown on the nitrogen-phosphorus-potassium-manganese treatment.

A quantity of 116.5 pounds of zinc EDTA is equivalent to 100 pounds of EDTA and 16.5 pounds of zinc. The zinc concentration of 21.76 parts per million in the total above-ground plant grown on the 100 pound EDTA treatment (Table 29) compared favorably with the 21.26 parts per million of zinc in plants grown on the 20.0 pound zinc sulfate treatment and the 25.08 parts per million of zinc in plants grown on the 4.0 pound zinc EDTA treatment (Table 27).

V-B-4. Results of Greenhouse Experiment 4

The effect of soil applied zinc sulfate and zinc EDTA on the dry matter weight and zinc uptake in parts of pea bean plants is reported for the Wisner clay loam soil in Table 30 and for the Kawkawlin loam soil in Table 31. The data for weight and zinc uptake of plant parts on each pot were arithmetically combined and are reported as the total above-ground plant along with the data for zinc uptake by plants at the first sampling in Table 33 for the Wisner soil and in Table 34 for the Kawkawlin soil.

Moderate zinc deficiency symptoms were observed on plants grown on the 0.5 and 1.0 pound zinc treatments. Symptoms were less severe on plants on the Kawkawlin loam soil.

Table 30: Weight, zinc concentration, and zinc content of pea bean plant parts (var. Sanilac) as affected by carrier and rate of zinc application on a Wisner clay loam soil. (Greenhouse Experiment 4)

Treatment[a]		Weight and zinc uptake of plant parts[b]								
Zinc applied (lb/acre)	Zinc carrier	Leaves			Stems			Pods		
		Weight (g)	Zinc concentration (ppm)	Zinc content (mgm)	Weight (g)	Zinc concentration (ppm)	Zinc content (mgm)	Weight (g)	Zinc concentration (ppm)	Zinc content (mgm)
0	--	4.04	18.7	0.077	2.27	17.8	0.038	0.31	15.8	0.006
0.5	$ZnSO_4$	5.81	24.5	0.142	3.12	15.7	0.049	1.42	22.8	0.032
0.5	ZnEDTA	5.93	18.4	0.109	3.14	18.9	0.059	2.05	25.4	0.051
1.0	$ZnSO_4$	5.65	23.9	0.130	2.94	18.1	0.053	1.98	22.3	0.044
1.0	ZnEDTA	5.31	20.7	0.110	2.85	21.7	0.061	4.54	19.7	0.089
2.0	$ZnSO_4$	5.50	20.2	0.111	3.44	20.0	0.068	3.17	19.2	0.061
2.0	ZnEDTA	5.47	21.9	0.118	2.89	23.9	0.069	5.34	21.2	0.113
4.0	$ZnSO_4$	5.93	23.7	0.143	4.04	16.7	0.068	2.78	16.9	0.047
4.0	ZnEDTA	5.73	23.6	0.135	3.14	33.5	0.104	3.98	29.3	0.113
8.0	$ZnSO_4$	5.67	19.9	0.111	3.20	21.5	0.069	3.10	22.3	0.067
8.0	ZnEDTA	5.36	39.1	0.208	2.94	41.8	0.123	4.55	34.2	0.157
16.0	$ZnSO_4$	5.60	27.4	0.150	2.88	24.5	0.070	3.81	20.6	0.078
16.0	ZnEDTA	5.67	62.3	0.346	3.28	49.2	0.159	4.95	37.7	0.185
48.0	$ZnSO_4$	5.46	32.2	0.173	2.66	38.5	0.101	5.04	30.1	0.149
48.0	ZnEDTA	5.03	195.9	0.970	2.88	79.3	0.228	4.61	50.6	0.232

(a) Six hundred pounds of additional phosphorus per acre mixed into soil.
(b) Average of four replications. Harvested 56 days after planting.

Table 31: Weight, zinc concentration, and zinc content of pea bean plant parts (var. Sanilac) as affected by carrier and rate of zinc aplication on a Kawkawlin loam soil. (Greenhouse Experiment 4)

Treatment[a]		Weight and zinc uptake of plant parts[b]								
Zinc applied (lb/acre)	Zinc carrier	Leaves			Stems			Pods		
		Weight (g)	Zinc concentration (ppm)	Zinc content (mgm)	Weight (g)	Zinc concentration (ppm)	Zinc content (mgm)	Weight (g)	Zinc concentration (ppm)	Zinc content (mgm)
0	--	4.56	19.7	0.090	2.69	23.4	0.063	4.00	21.9	0.088
0.5	$ZnSO_4$	4.80	21.1	0.100	2.60	22.3	0.058	3.46	21.9	0.075
0.5	ZnEDTA	5.59	18.5	0.104	3.15	22.7	0.070	2.41	19.2	0.055
1.0	$ZnSO_4$	4.51	17.6	0.080	2.85	19.4	0.055	3.11	20.3	0.062
1.0	ZnEDTA	4.91	20.7	0.100	2.54	28.4	0.072	3.92	26.4	0.100
2.0	$ZnSO_4$	5.18	23.9	0.124	2.70	21.4	0.057	2.96	22.7	0.064
2.0	ZnEDTA	5.19	18.4	0.095	2.85	27.5	0.079	4.68	26.1	0.121
4.0	$ZnSO_4$	4.79	16.5	0.079	2.59	21.1	0.054	3.50	20.9	0.073
4.0	ZnEDTA	5.14	29.7	0.153	2.77	36.0	0.098	3.19	34.1	0.096
8.0	$ZnSO_4$	5.36	17.3	0.093	3.09	21.7	0.066	2.85	21.8	0.061
8.0	ZnEDTA	5.03	41.0	0.206	2.73	37.4	0.102	3.82	36.2	0.138
16.0	$ZnSO_4$	4.56	22.4	0.103	2.72	24.7	0.067	3.25	26.7	0.086
16.0	ZnEDTA	5.41	76.6	0.410	2.58	45.4	0.117	3.15	47.1	0.137
48.0	$ZnSO_4$	5.32	51.4	0.261	2.92	44.0	0.127	3.42	36.1	0.124
48.0	ZnEDTA	5.23	183.7	0.970	2.85	66.2	0.189	2.94	52.2	0.154

(a) Six hundred pounds of additional phosphcrus per acre mixed into soil.
(b) Average of four replications. Harvested 56 days after planting.

Table 32: Differences between means required for significance at the five and one per cent levels obtained by analysis of variance of the data reported in Tables 30 and 31. (Greenhouse Experiment 4)

Treatment	LSD values at five and one per cent levels								
	Leaves			Stems			Pods		
	Weight (g)	Zinc concen-tration (ppm)	Zinc content (mgm)	Weight (g)	Zinc concen-tration (ppm)	Zinc content (mgm)	Weight (g)	Zinc concen-tration (ppm)	Zinc content (mgm)
Zinc treatment	0.33,0.44	10.2,13.5	0.054,0.072	0.24,0.32	2.5,3.3	0.007,0.009	0.57,0.75	2.5,3.3	0.016,0.021
Zinc level (L)	ns	22.8,30.3	0.121,0.168	ns	5.4,7.2	0.016,0.021	1.27,0.69	5.0,6.7	0.036,0.047
Zinc carrier (C)	ns	39.5,52.4	0.210,0.278	ns	9.4,12.4	0.027,0.036	2.20,2.92	8.7,11.5	0.062,0.082
Soil type (S)	1.24,1.64	ns	ns	0.92,1.22	ns	ns	ns	8.7,11.5	ns
L x C	ns	**	**	ns	**	**	*	**	**
L x S	ns	ns	ns	ns	*	*	*	*	*
C x S	ns	ns	ns	ns	ns	*	*	ns	*
L x C x S	ns	ns	ns	ns	*	**	ns	ns	ns

Table 33: Weight, zinc concentration, and zinc content of the total above-ground pea bean plants (var. Sanilac) at two sampling dates as affected by carrier and rate of zinc application on a Wisner clay loam soil. (Greenhouse Experiment 4)

Treatment[a]		Weight and zinc uptake of bean plants[b]					
Zinc applied (lb/acre)	Zinc carrier	1st sampling[c]			2nd sampling[d]		
		Weight (g)	Zinc concentration (ppm)	Zinc content (mgm)	Weight (g)	Zinc concentration (ppm)	Zinc content (mgm)
0	--	3.42	15.5	0.053	6.62	18.4	0.121
0.5	$ZnSO_4$	4.39	15.5	0.068	10.35	21.8	0.223
0.5	ZnEDTA	4.78	16.6	0.079	11.11	19.6	0.218
1.0	$ZnSO_4$	4.55	14.3	0.065	10.57	22.0	0.227
1.0	ZnEDTA	5.12	17.4	0.088	12.70	20.5	0.260
2.0	$ZnSO_4$	4.56	19.1	0.087	12.11	19.8	0.241
2.0	ZnEDTA	5.25	21.3	0.111	13.69	22.0	0.300
4.0	$ZnSO_4$	5.12	17.4	0.090	12.75	20.7	0.258
4.0	ZnEDTA	5.59	28.9	0.161	12.84	27.5	0.352
8.0	$ZnSO_4$	5.67	19.3	0.109	11.96	20.6	0.247
8.0	ZnEDTA	5.54	36.3	0.201	12.84	38.0	0.488
16.0	$ZnSO_4$	5.37	23.5	0.126	12.29	24.7	0.298
16.0	ZnEDTA	5.61	58.4	0.329	13.90	50.4	0.691
48.0	$ZnSO_4$	5.88	57.4	0.334	13.16	32.7	0.423
48.0	ZnEDTA	5.84	95.2	0.555	12.52	113.4	1.431

(a) Six hundred pounds of additional phosphorus per acre mixed into soil.
(b) Average of four replications.
(c) Sampled 28 days after planting.
(d) Sampled 56 days after planting.

Table 34: Weight, zinc concentration, and zinc content of the total above-ground pea bean plants (var. Sanilac) at two sampling dates as affected by carrier and rate of zinc application on a Kawkawlin loam soil. (Greenhouse Experiment 4)

Treatment[a]		Weight and zinc uptake of bean plants[b]					
		1st sampling[c]			2nd sampling[d]		
Zinc applied (lb/acre)	Zinc carrier	Weight (g)	Zinc concen-tration (ppm)	Zinc content (mgm)	Weight (g)	Zinc conten-tration (ppm)	Zinc content (mgm)
0	--	5.08	19.6	0.100	11.26	21.4	0.241
0.5	$ZnSO_4$	4.44	18.3	0.082	10.86	21.5	0.233
0.5	ZnEDTA	4.56	21.9	0.100	11.15	20.6	0.230
1.0	$ZnSO_4$	5.20	16.4	0.085	10.46	19.1	0.198
1.0	ZnEDTA	5.40	25.8	0.139	11.37	24.1	0.273
2.0	$ZnSO_4$	5.26	18.6	0.098	10.84	22.7	0.246
2.0	ZnEDTA	5.45	29.8	0.163	12.72	23.2	0.294
4.0	$ZnSO_4$	5.23	23.3	0.122	10.88	19.0	0.206
4.0	ZnEDTA	5.26	39.0	0.204	11.10	32.1	0.347
8.0	$ZnSO_4$	5.57	23.5	0.131	11.30	19.4	0.219
8.0	ZnEDTA	5.28	59.4	0.314	11.58	38.6	0.447
16.0	$ZnSO_4$	5.19	30.0	0.156	10.53	24.3	0.256
16.0	ZnEDTA	5.05	86.8	0.435	11.13	59.5	0.664
48.0	$ZnSO_4$	5.55	63.3	0.348	11.66	44.5	0.512
48.0	ZnEDTA	4.87	142.6	0.688	11.02	118.1	1.313

(a) Six hundred pounds of additional phosphorus per acre mixed into soil.
(b) Average of four replications.
(c) Sampled 28 days after planting.
(d) Sampled 56 days after planting.

Table 35: Differences between means required for significance at the five and one per cent levels obtained by analysis of variance of the data reported in Tables 33 and 34. (Greenhouse Experiment 4)

Treatment	LSD values at five and one per cent levels					
	1st sampling			2nd sampling		
	Weight (g)	Zinc concen-tration (ppm)	Zinc content (mgm)	Weight (g)	Zinc concen-tration (ppm)	Zinc content (mgm)
Zinc treatment	0.26,0.35	3.2,4.3	0.019,0.025	0.69,0.92	4.2,5.5	0.060,0.079
Zinc level (L)	0.58,0.77	7.3,9.7	0.043,0.057	1.49,ns	9.3,12.4	0.134,0.178
Zinc carrier (C)	ns	12.6,16.7	0.074,0.098	2.58,3.42	16.1,21.4	0.232,0.308
Soil type (S)	ns	12.6,16.7	0.074,0.098	2.58,3.42	ns	ns
L x C	ns	**	**	ns	**	**
L x S	*	**	ns	ns	ns	ns
C x S	*	**	**	ns	ns	ns
L x C x S	ns	**	ns	ns	ns	ns

Between 28 and 56 days, the above-ground plant quadrupled in dry matter weight. The weight of the plants grown on the Wisner clay loam soil was lower when zinc was not applied (Table 33).

On the Kawkawlin soil, the plants contained more zinc at both sampling times than did plants grown on the Wisner soil, whether zinc was applied or not (Tables 33 and 34). The zinc concentration in plants remained constant over time on the lower levels of applied zinc but concentration tended to decrease on the higher zinc treatments.

The plants grown on the Wisner clay loam soil increased in zinc concentration between sampling times (Table 33).

The plants grown on zinc EDTA treatments were higher in zinc concentration and zinc content than were plants grown on zinc sulfate treatments (Tables 33 and 34). Up to 16.0 pounds of zinc as zinc sulfate were applied before there was a response in zinc uptake by plants; there was an increase in zinc uptake on the 1.0 pound zinc EDTA treatment.

The per cent of the quantity of applied zinc which was recovered by the plant decreased as the amount of applied zinc was increased. More zinc was recovered by plants on zinc EDTA treatments than by plants on zinc sulfate treatments. On the Wisner soil, as the rate of applied zinc as zinc sulfate was increased by a factor of 3, the content of zinc in plants increased 1.4; for the same three-fold increase in applied zinc EDTA, the zinc content in plants increased 2.1 (Table 33).

In the most recent growth portion of the plant, the pod, the zinc concentration increased as the level of applied zinc EDTA increased (Tables 30 and 31). On zinc sulfate treatments, zinc concentration in the pods did not increase until 16.0 pounds or more of zinc had been applied on the Kawkawlin soil and 48.0 pounds of zinc had been applied on the Wisner soil. At the highest treatments of zinc EDTA, the pod yield tended to decrease, whereas pod yields tended to increase with each increment of applied zinc sulfate.

The accumulation of zinc in plant parts on zinc sulfate treatments was indiscriminate on all levels of applied zinc on either soil (Tables 33 and 34). When the level of applied zinc EDTA was increased, zinc tended to accumulate first in the stem and next in the leaf.

The zinc content of plant parts and of the total above-ground plant was related to applied zinc sulfate and zinc EDTA for plants grown on the Wisner clay loam soil in Figures 5 through 8. This same relationship for the Kawkawlin loam soil is shown in Figures 9 through 12.

Higher correlations were obtained between applied zinc EDTA and the zinc content of leaves (Figures 5 and 9), stems (Figures 6 and 10), and total above-ground plants (Figures 8 and 12) than between applied zinc sulfate and zinc content of these plant parts. The higher correlations between zinc sulfate treatment and zinc content of pods (Figures 7 and 11) was the reflection of the increase in pod weight with increase in applied zinc; the pod yields on zinc EDTA treated pots varied from medium to high to medium (relative to pod yields on the zinc sulfate treatments) with the increase in applied zinc.

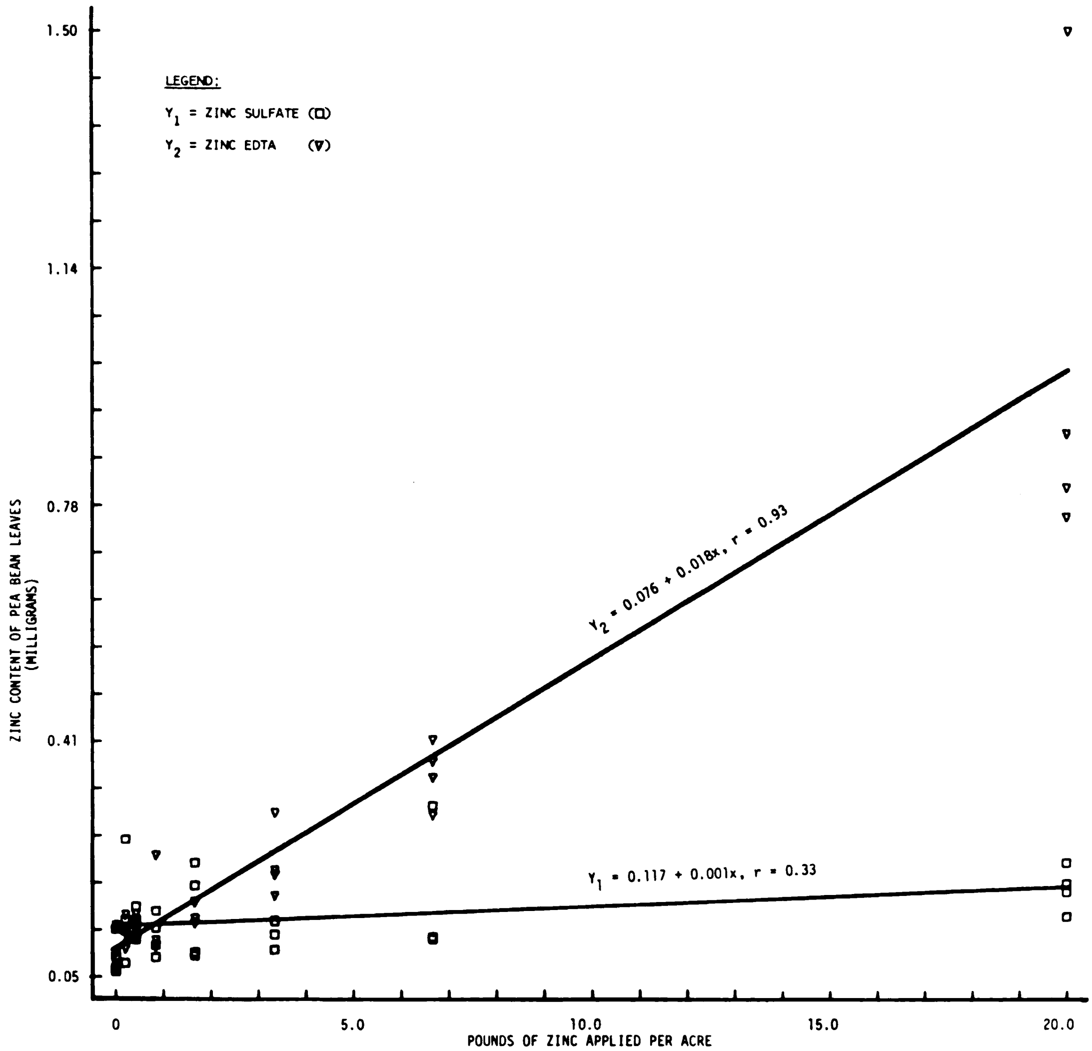

FIGURE 5: THE RELATIONSHIP BETWEEN RATES OF ZINC APPLIED AS ZINC SULFATE AND ZINC EDTA AND THE ZINC CONTENT OF LEAVES OF PEA BEAN PLANTS GROWN ON A WISNER CLAY LOAM SOIL. (GREENHOUSE EXPERIMENT 4)

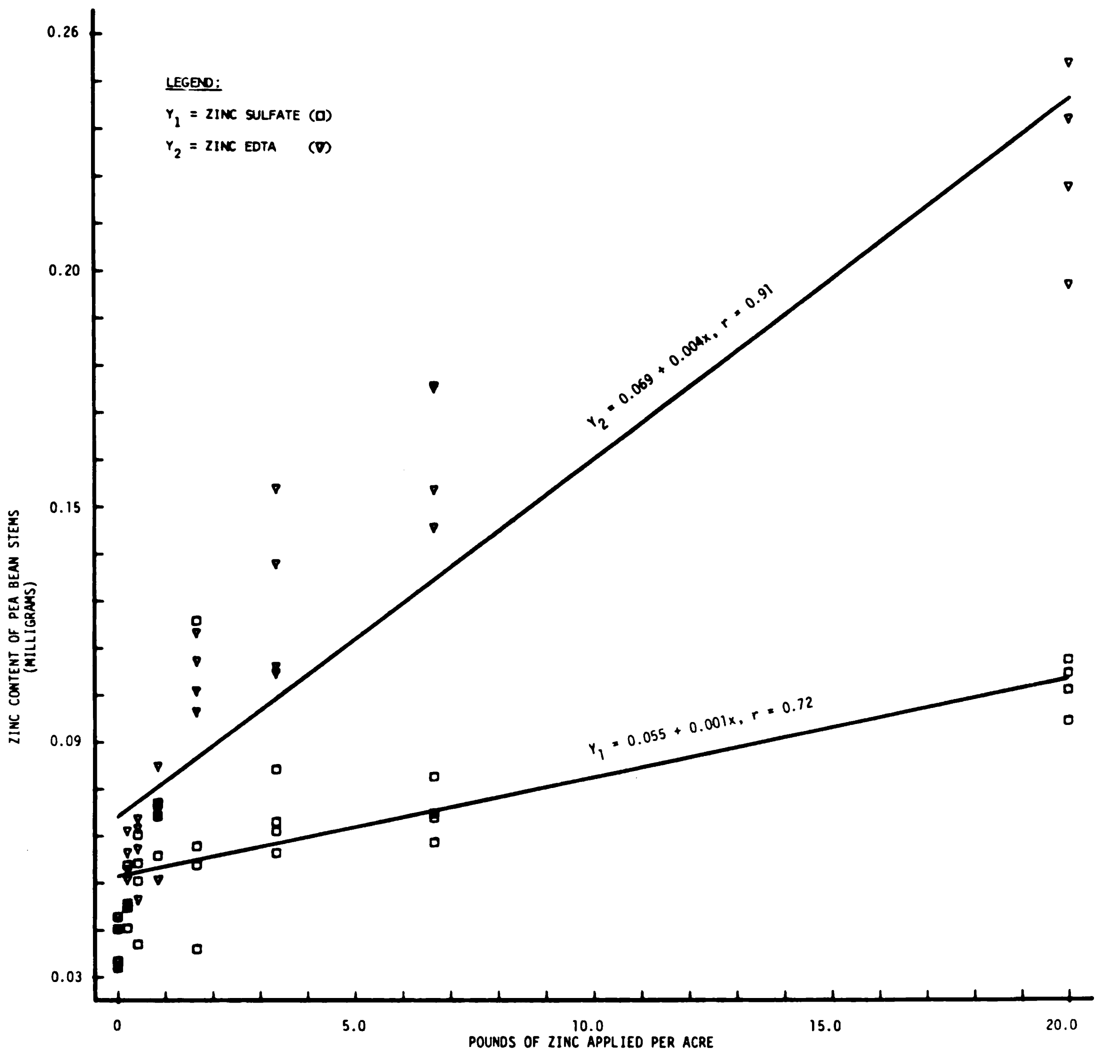

FIGURE 6: THE RELATIONSHIP BETWEEN RATES OF ZINC APPLIED AS ZINC SULFATE AND ZINC EDTA AND THE ZINC CONTENT OF STEMS OF PEA BEAN PLANTS GROWN ON A WISNER CLAY LOAM SOIL. (GREENHOUSE EXPERIMENT 4)

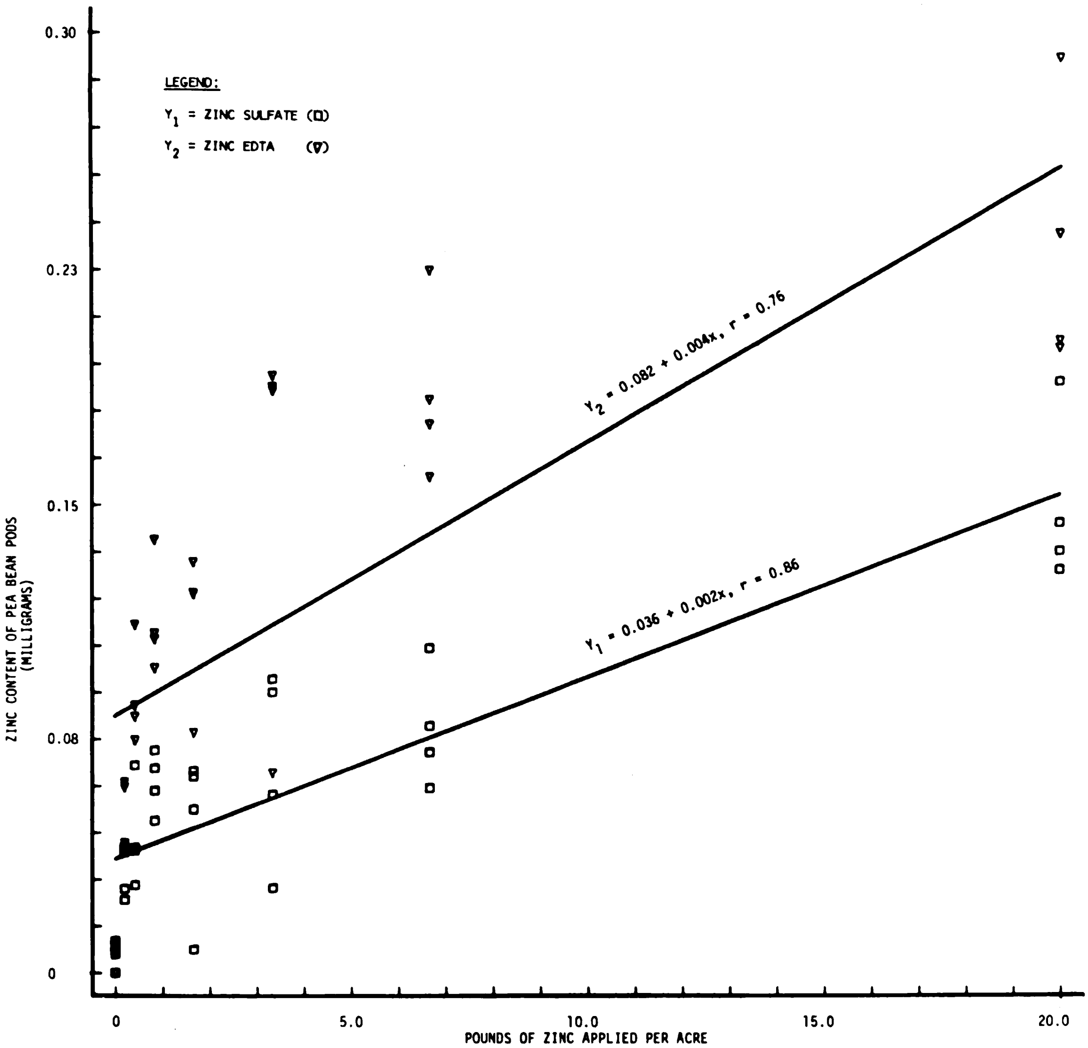

FIGURE 7: THE RELATIONSHIP BETWEEN RATES OF ZINC APPLIED AS ZINC SULFATE AND ZINC EDTA AND THE ZINC CONTENT OF PODS OF PEA BEAN PLANTS GROWN ON A WISNER CLAY LOAM SOIL. (GREENHOUSE EXPERIMENT 4)

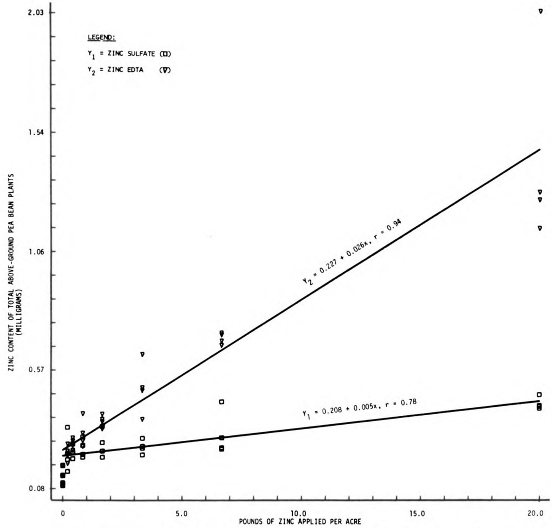

FIGURE 8: THE RELATIONSHIP BETWEEN RATES OF ZINC APPLIED AS ZINC SULFATE AND ZINC EDTA AND THE ZINC CONTENT OF THE TOTAL ABOVE-GROUND PEA BEAN PLANTS GROWN ON A WISNER CLAY LOAM SOIL. (GREENHOUSE EXPERIMENT 4)

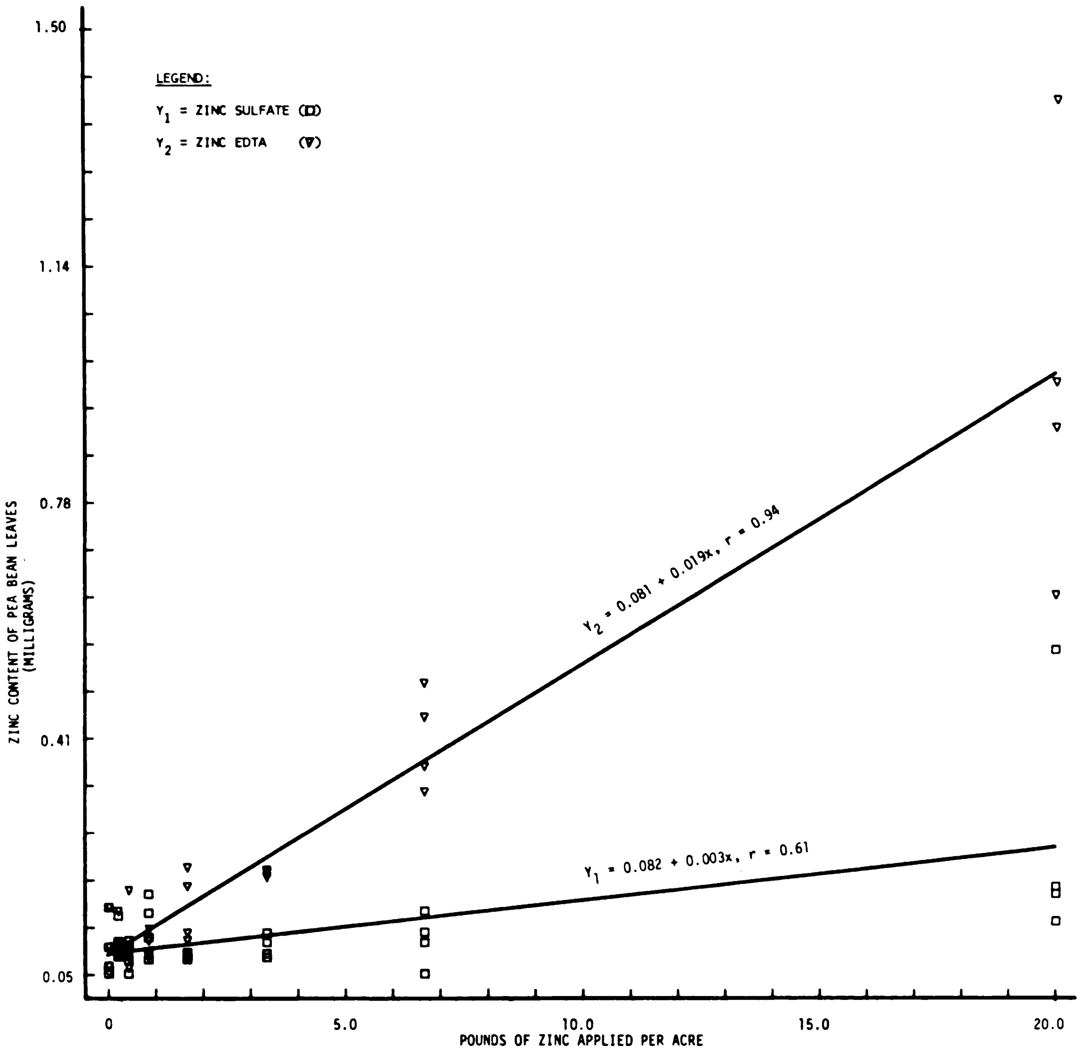

FIGURE 9: THE RELATIONSHIP BETWEEN RATES OF ZINC APPLIED AS ZINC SULFATE AND ZINC EDTA AND THE ZINC CONTENT OF LEAVES OF PEA BEAN PLANTS GROWN ON A KAWKAWLIN LOAM SOIL. (GREENHOUSE EXPERIMENT 4)

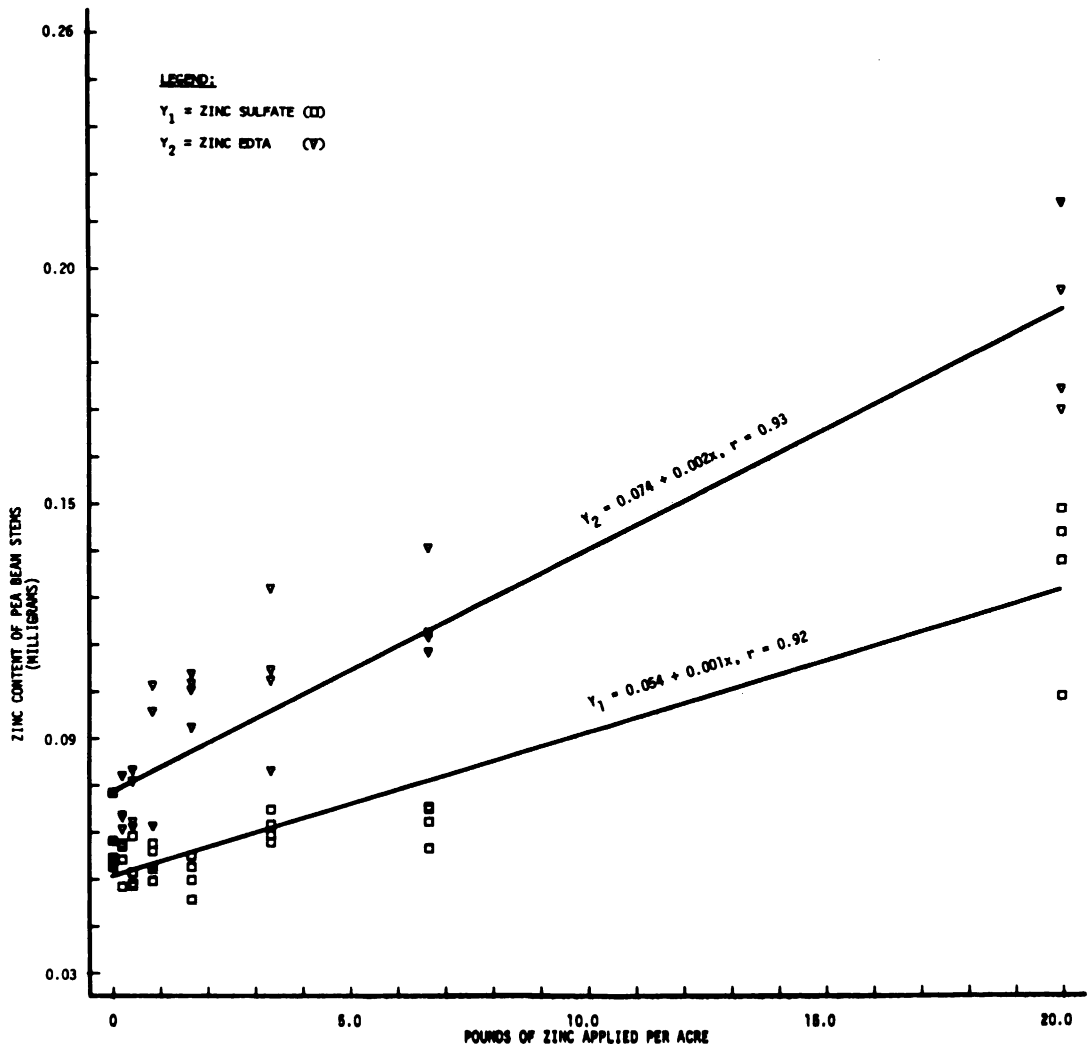

FIGURE 10: THE RELATIONSHIP BETWEEN RATES OF ZINC APPLIED AS ZINC SULFATE AND ZINC EDTA AND THE ZINC CONTENT OF STEMS OF PEA BEAN PLANTS GROWN ON A KANKAWLIN LOAM SOIL. (GREENHOUSE EXPERIMENT 4)

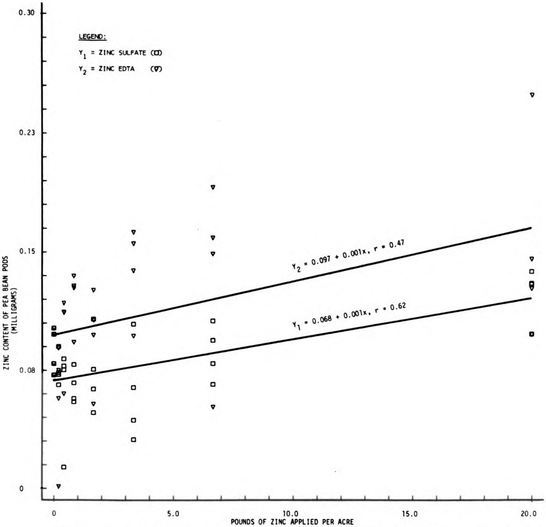

FIGURE 11: THE RELATIONSHIP BETWEEN RATES OF ZINC APPLIED AS ZINC SULFATE AND ZINC EDTA AND THE ZINC CONTENT OF PODS OF PEA BEAN PLANTS GROWN ON A KAWKAWLIN LOAM SOIL. (GREENHOUSE EXPERIMENT 4)

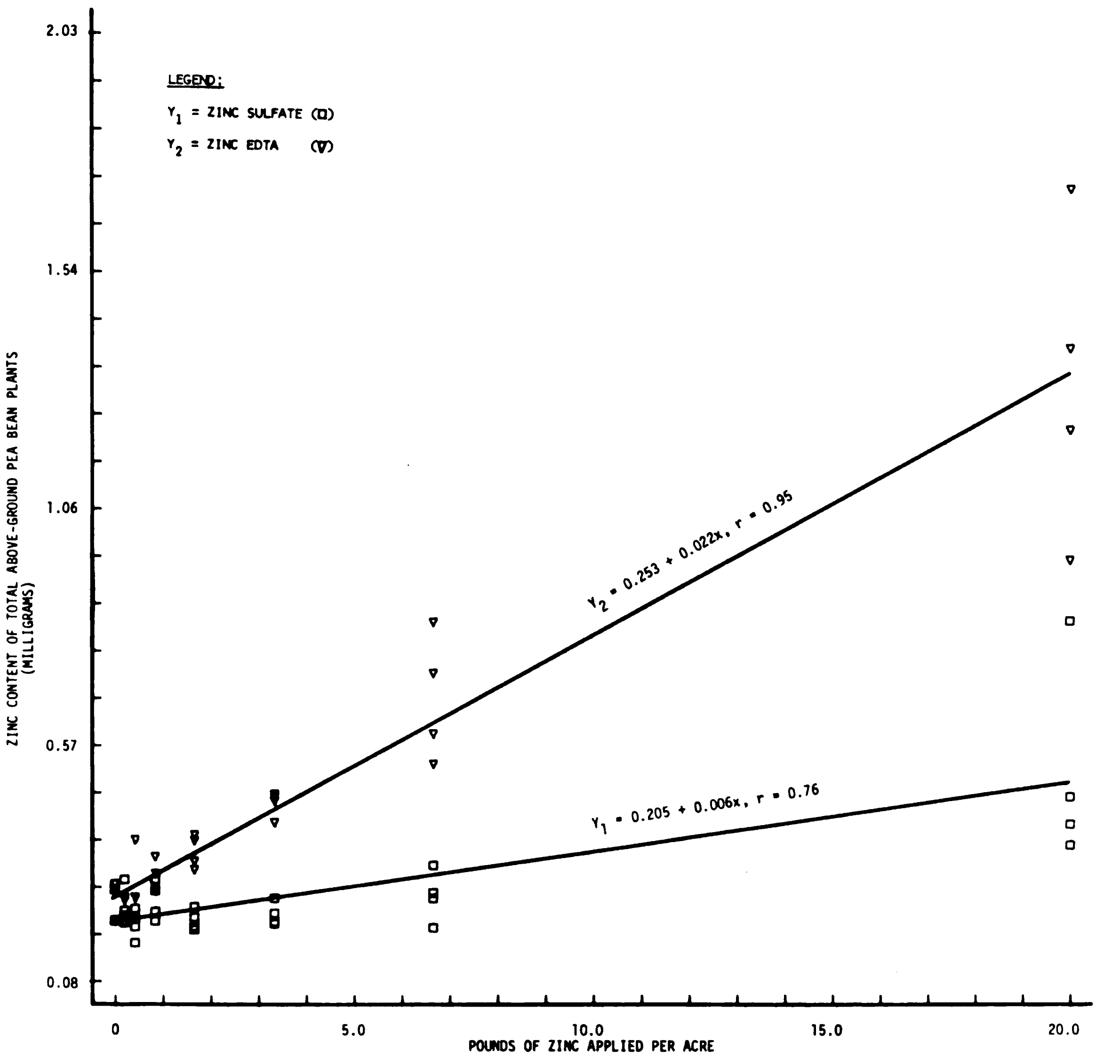

FIGURE 12: THE RELATIONSHIP BETWEEN RATES OF ZINC APPLIED AS ZINC SULFATE AND ZINC EDTA AND THE ZINC CONTENT OF THE TOTAL ABOVE-GROUND PEA BEAN PLANTS GROWN ON A KAWKAWLIN LOAM SOIL. (GREENHOUSE EXPERIMENT 4)

The zinc concentrations for the leaf, stem, pod, and total plant were all plotted on one figure for those plants grown on one of the soil types which received treatment by one of the zinc carriers. These relationships for zinc sulfate or zinc EDTA when applied to either the Wisner clay loam soil or the Kawkawlin loam soil are shown in Figures 13 through 16.

The correlations between zinc concentration in the plant portions and applied zinc were higher for zinc EDTA treatments than for zinc sulfate treatments on both the Wisner and Kawkawlin soils (Figures 13 through 16). The highest correlations for zinc EDTA treatments were obtained with the data for zinc concentration in the above-ground plant (Figures 14 and 16); for zinc sulfate treatments, the highest correlations were obtained with the data for zinc concentration in the stem (Figures 13 and 15). There was no consistent relationship between zinc concentration in the above-ground plant and zinc concentration in the leaf, stem, or pod of plants grown on soil treatments of either zinc carrier.

V-C. Incubation Experiment Results

The objective of the Incubation Experiment was to study the availability and form of soil applied zinc sulfate and zinc EDTA as affected by soil applied phosphorus and length of incubation. Water, neutral normal ammonium chloride and tenth normal hydrochloric acid were utilized to extract zinc from the soil.

In Tables 36 through 38, extractable zinc in pounds per acre is reported according to extractant, phosphorus treatment, and length of incubation. The relationship between the zinc applied

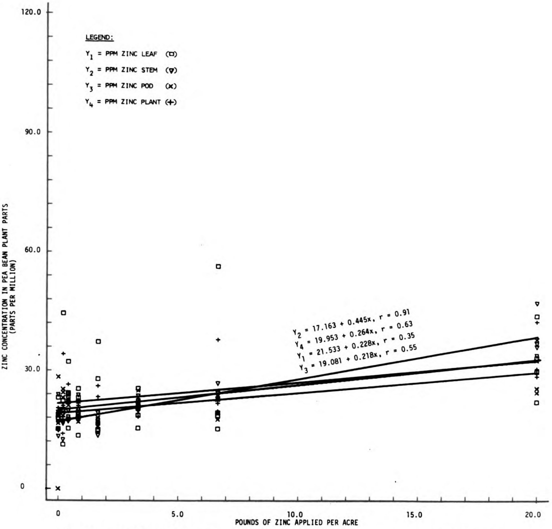

FIGURE 13: THE RELATIONSHIP BETWEEN RATES OF ZINC APPLIED AS ZINC SULFATE AND THE ZINC CONCENTRATION IN LEAVES, STEMS, PODS, AND TOTAL ABOVE-GROUND PEA BEAN PLANTS GROWN ON A WISNER CLAY LOAM SOIL. (GREENHOUSE EXPERIMENT 4)

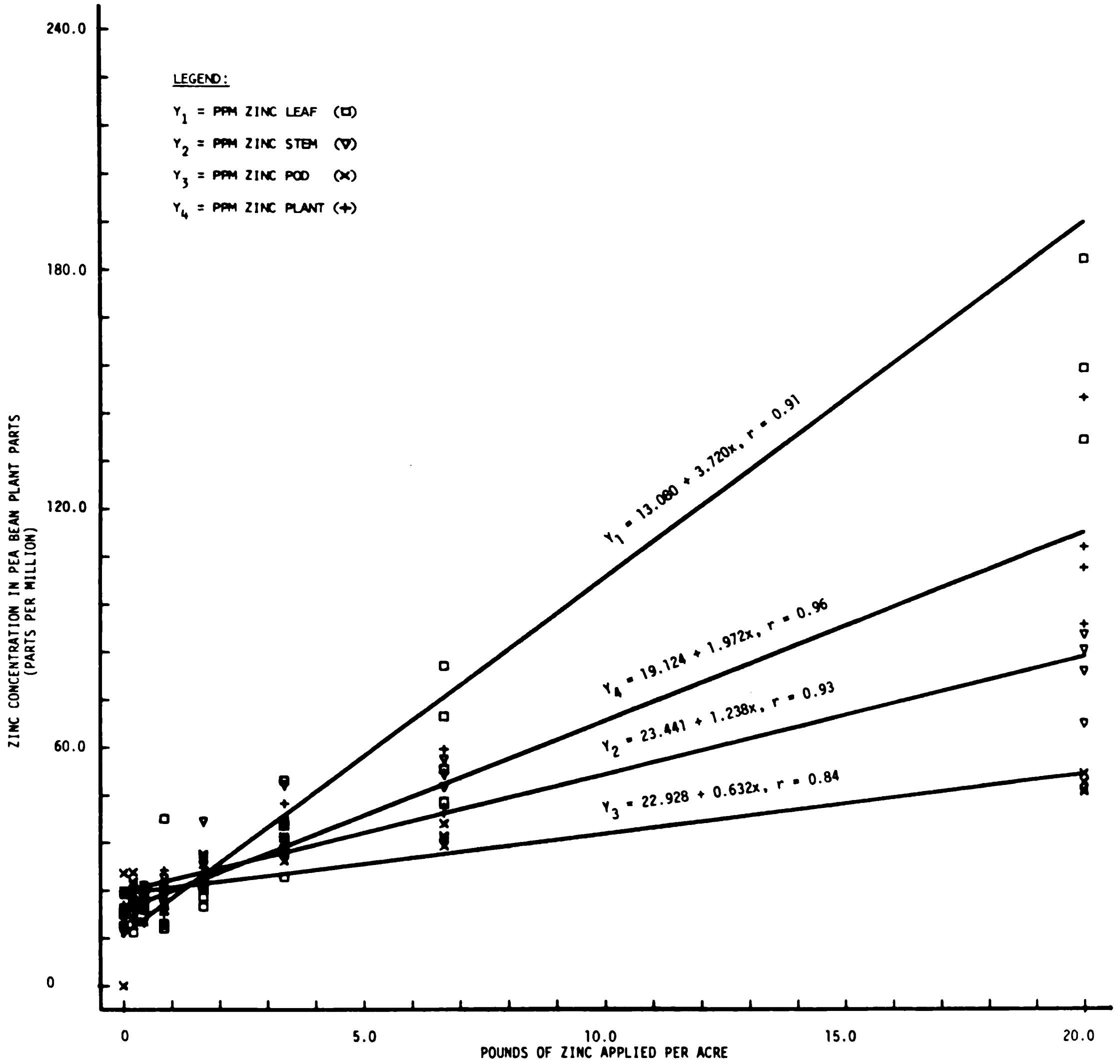

FIGURE 14: THE RELATIONSHIP BETWEEN RATES OF ZINC APPLIED AS ZINC EDTA AND THE ZINC CONCENTRATION IN LEAVES, STEMS, PODS, AND TOTAL ABOVE-GROUND PEA BEAN PLANTS GROWN ON A WISNER CLAY LOAM SOIL. (GREENHOUSE EXPERIMENT 4)

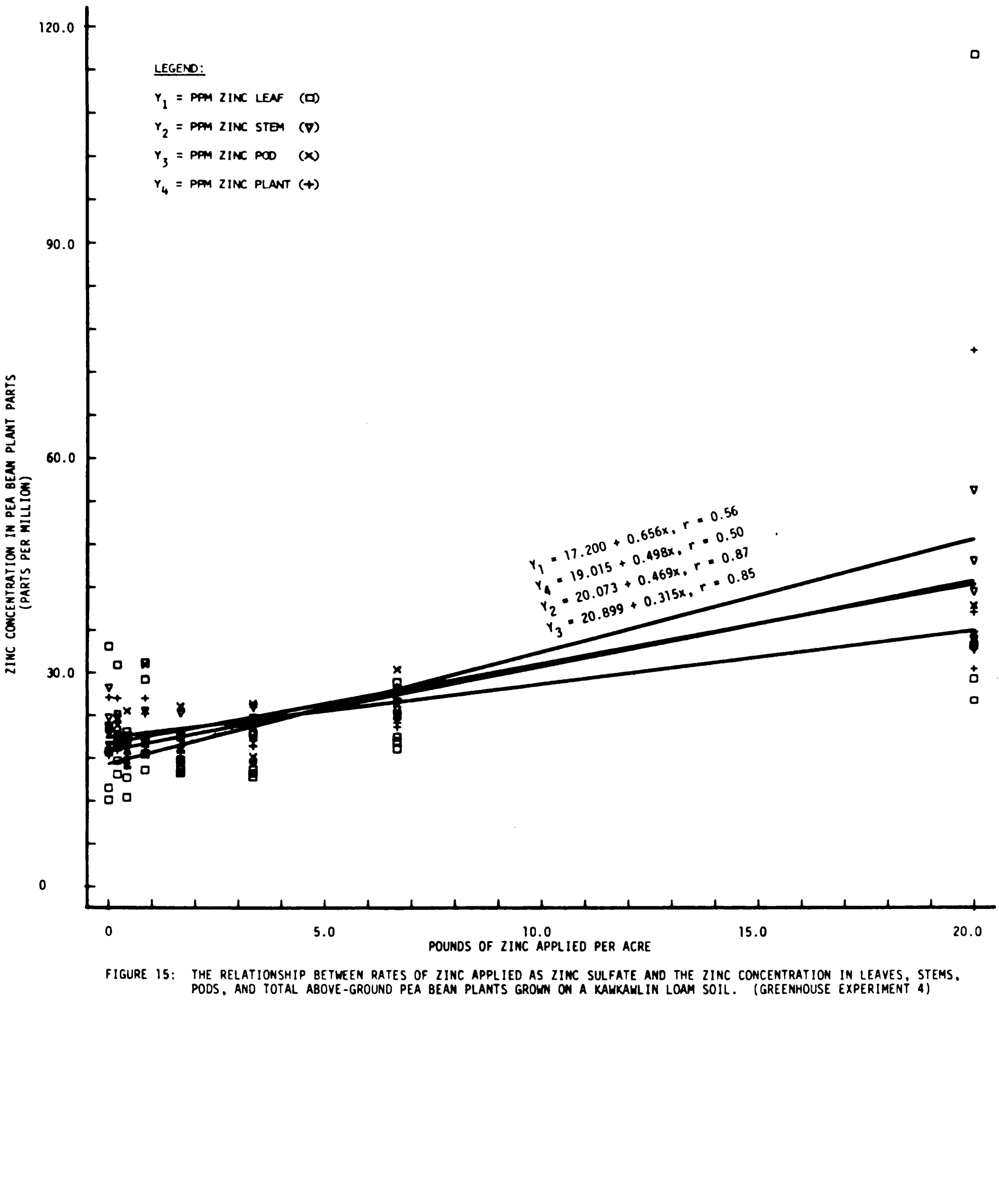

FIGURE 15: THE RELATIONSHIP BETWEEN RATES OF ZINC APPLIED AS ZINC SULFATE AND THE ZINC CONCENTRATION IN LEAVES, STEMS, PODS, AND TOTAL ABOVE-GROUND PEA BEAN PLANTS GROWN ON A KAWKAWLIN LOAM SOIL. (GREENHOUSE EXPERIMENT 4)

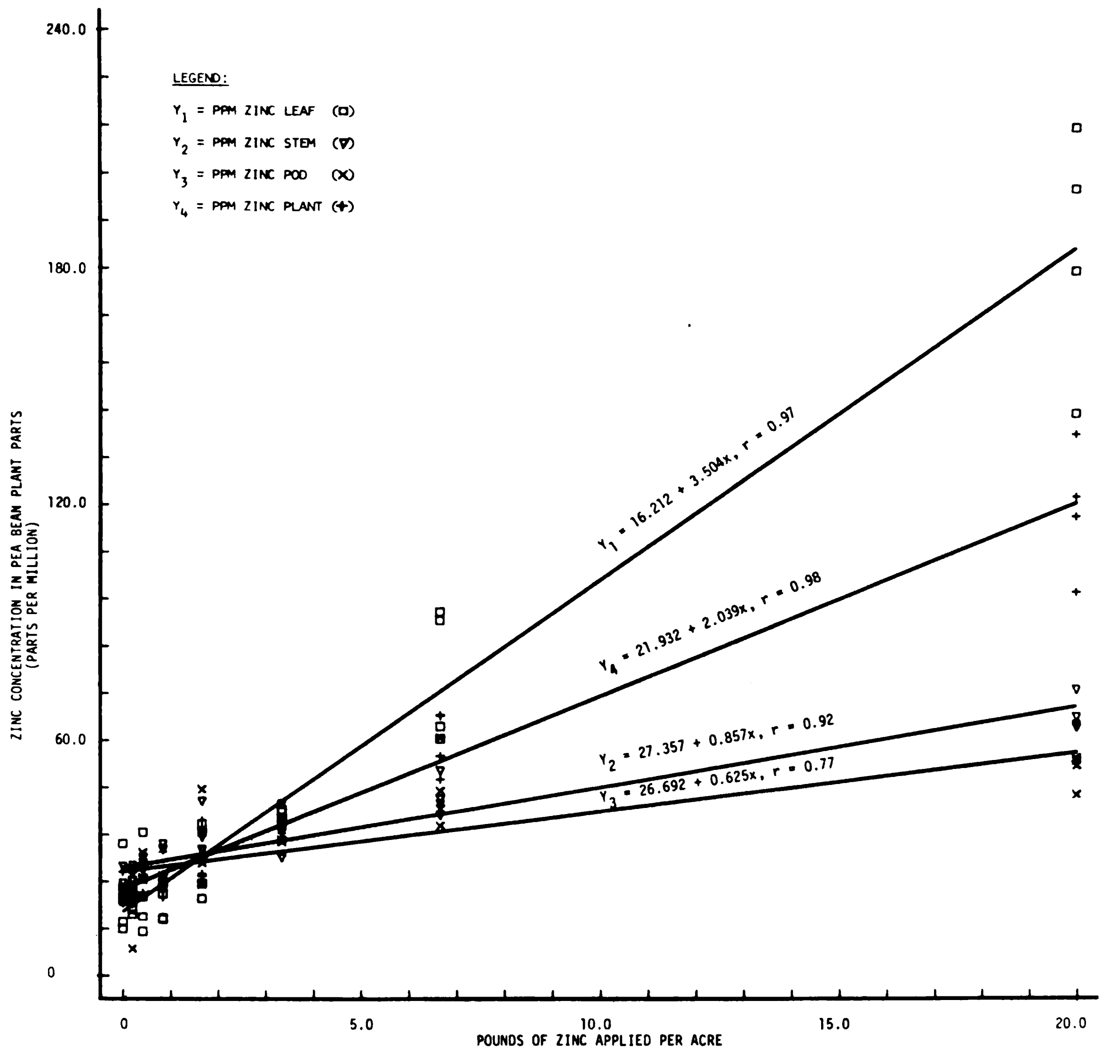

FIGURE 16: THE RELATIONSHIP BETWEEN RATES OF ZINC APPLIED AS ZINC EDTA AND THE ZINC CONCENTRATION IN LEAVES, STEMS, PODS, AND TOTAL ABOVE-GROUND PEA BEAN PLANTS GROWN ON A KAWKAWLIN LOAM SOIL. (GREENHOUSE EXPERIMENT 4)

Table 36: Water, 1N neutral NH_4Cl, and 0.1N HCl extractable zinc obtained from a Wisner clay loam soil incubated 90 days at 30 degrees centigrade as affected by carrier and rate of zinc application and rate of phosphorus application. (Incubation Experiment)

Treatment		Extractable zinc[a] (lb/acre)									
Zinc applied (lb/acre)	Zinc carrier	Water		NH_4Cl[b]		Water + NH_4Cl[b]		0.1N HCl		Water + NH_4Cl[b] + 0.1N HCl	
		No P	1000 lb P/acre	No P	1000 lb P/acre	No P	1000 lb P/acre	No P	1000 lb P/acre	No P	1000 lb P/acre
0	--	0	0	0	0	0	0	1.6	2.0	1.6	2.0
2.0	$ZnSO_4$	0	0	0	0	0	0	2.7	3.0	2.7	3.0
2.0	ZnEDTA	0	0	0	0	0	0	1.8	3.4	1.8	3.4
6.0	$ZnSO_4$	0	0	0	0	0	0	3.1	3.7	3.1	3.7
6.0	ZnEDTA	0	0	0	0	0	0	2.8	3.2	2.8	3.2
18.0	$ZnSO_4$	0	0	0	0	0	0	5.6	7.2	5.6	7.2
18.0	ZnEDTA	1.7	2.1	0.7	0.8	2.4	2.9	5.0	6.5	7.4	9.4
54.0	$ZnSO_4$	0	0	0.5	0.4	0.5	0.4	18.8	24.7	19.3	25.1
54.0	ZnEDTA	11.4	13.2	2.7	2.5	14.1	15.7	10.8	11.9	24.9	27.6
162.0	$ZnSO_4$	0	0.4	1.2	1.9	1.2	2.3	53.4	80.0	54.6	82.3
162.0	ZnEDTA	71.6	82.3	8.6	8.5	80.2	90.8	24.5	30.0	104.7	120.8

(a) Average of two replications.
(b) 1N neutral NH_4CL.

Table 37: Water, 1N neutral NH_4Cl, and 0.1N HCl extractable zinc obtained from a Wisner clay loam soil incubated 180 days at 30 degrees centigrade as affected by carrier and rate of zinc application and rate of phosphorus application. (Incubation Experiment)

Treatment		Extractable zinc[a] (lb/acre)									
Zinc applied (lb/acre)	Zinc carrier	Water		NH_4Cl[b]		Water + NH_4Cl[b]		0.1N HCl		Water + NH_4Cl[b] + 0.1N HCl	
		No P	1000 lb P/acre	No P	1000 lb P/acre	No P	1000 lb P/acre	No P	1000 lb P/acre	No P	1000 lb P/acre
0	--	0	0	0	0	0	0	1.6	3.1	1.6	3.1
2.0	$ZnSO_4$	0	0	0	0	0	0	2.1	3.1	2.1	3.1
2.0	ZnEDTA	0	0	0	0	0	0	2.0	2.7	2.0	2.7
6.0	$ZnSO_4$	0	0	0	0	0	0	2.7	5.3	2.7	5.3
6.0	ZnEDTA	0	0	0	0	0	0	3.4	3.3	3.4	3.3
18.0	$ZnSO_4$	0	0	0	0.4	0	0.4	5.3	9.9	5.3	10.3
18.0	ZnEDTA	1.3	1.6	0	0.4	1.3	2.0	4.7	7.0	6.0	9.0
54.0	$ZnSO_4$	0	0	0.4	0.4	0.4	0.4	15.8	30.0	16.2	30.4
54.0	ZnEDTA	11.4	12.1	2.8	2.2	14.2	14.3	14.7	21.5	28.9	35.8
162.0	$ZnSO_4$	0	0	1.1	1.9	1.1	1.9	53.2	75.0	54.3	76.9
162.0	ZnEDTA	69.3	76.9	8.4	7.5	77.7	84.3	23.7	44.9	101.4	129.2

(a) Average of two replications.
(b) 1N neutral NH_4Cl.

Table 38: Water, 1N neutral NH_4Cl, and 0.1N HCl extractable zinc obtained from a Wisner clay loam soil incubated 270 days at 30 degrees centigrade as affected by carrier and rate of zinc application and rate of phosphorus application. (Incubation Experiment)

Treatment		Extractable zinc[a] (lb/acre)									
Zinc applied (lb/acre)	Zinc carrier	Water		NH_4Cl[b]		Water + NH_4Cl[b]		0.1N HCl		Water + NH_4Cl[b] + 0.1N HCl	
		No P	1000 lb P/acre	No P	1000 lb P/acre	No P	1000 lb P/acre	No P	1000 lb P/acre	No P	1000 lb P/acre
0	--	0	0	0	0	0	0	2.4	2.6	2.4	2.6
2.0	$ZnSO_4$	0	0	0	0	0	0	3.1	3.2	3.1	3.2
2.0	ZnEDTA	0	0	0	0	0	0	2.6	3.4	2.6	3.4
6.0	$ZnSO_4$	0	0	0	0	0	0	3.6	5.4	3.6	5.4
6.0	ZnEDTA	0	0	0	0	0	0	3.1	4.3	3.1	4.3
18.0	$ZnSO_4$	0	0	0	0	0	0	5.6	8.8	5.6	8.8
18.0	ZnEDTA	1.2	1.3	0.5	0.5	1.7	1.8	4.9	8.0	6.6	9.8
54.0	$ZnSO_4$	0	0	0	0.5	0	0.5	14.6	21.6	14.6	22.1
54.0	ZnEDTA	9.0	9.6	2.5	2.2	11.5	11.8	13.2	13.3	24.7	25.1
162.0	$ZnSO_4$	0.7	0	0.9	1.0	1.6	1.0	48.2	68.5	49.8	69.5
162.0	ZnEDTA	60.1	74.2	8.7	7.7	68.8	81.9	28.4	36.9	97.2	118.8

(a) Average of two replications.
(b) 1N neutral NH_4Cl.

Table 39: Differences between means required for significance at the five and one per cent levels obtained by analysis of variance of the data reported in Tables 36 through 38. (Incubation Experiment)

Treatment	LSD values at five and one per cent levels				
	Water extractable zinc (lb/acre)	NH_4Cl[a] extractable zinc (lb/acre)	Water + NH_4Cl[a] extractable zinc (lb/acre)	0.1N HCl extractable zinc (lb/acre)	Water + NH_4Cl[a] + 0.1N HCl extractable zinc (lb/acre)
Zinc treatment	0.2,0.3	<0.1,0.1	1.0,1.4	0.2,0.3	1.0,1.4
Zinc level (L)	0.6,0.8	0.2,0.3	1.8,2.4	0.7,0.9	2.0,2.6
Zinc carrier (C)	1.2,1.6	0.5,0.6	3.6,4.8	1.4,1.9	3.9,5.2
Phosphorus (P)	1.2,1.6	ns	3.6,4.8	1.4,1.9	3.9,5.2
Incubation (I)	0.9,1.2	ns	2.6,3.4	1.0,1.3	2.8,3.7
L x C	**	**	**	**	**
L x P	**	ns	**	**	**
L x I	**	ns	*	**	**
C x P	**	**	**	**	ns
C x I	**	ns	**	**	ns
P x I	ns	ns	*	ns	ns
L x C x P	**	**	**	**	ns
L x C x I	**	ns	**	**	ns
L x P x I	ns	ns	ns	ns	ns
C x P x I	ns	ns	ns	ns	ns
L x C x P x I	ns	ns	ns	ns	ns

(a) 1N neutral NH_4Cl

to the soil and the zinc extracted by water (water soluble zinc), neutral normal ammonium chloride (exchangeable zinc), and tenth normal hydrochloric acid (acid soluble zinc) is shown according to zinc carrier and phosphorus treatment in Figures 17 through 22. In Figures 23 through 34, the zinc removed from the soil by the extractant for all three incubation intervals was plotted on one figure according to the zinc carrier, phosphorus treatment, and extractant.

The amount of zinc which could be extracted from the soil increased with the increase in applied zinc, regardless of the zinc carrier or phosphorus treatment (Figures 17 through 22). Disproportionately more zinc could be recovered as additional amounts were applied (Table 40).

The quantity of zinc which could be extracted from the soil varied with the length of incubation but this effect was inconsistent among zinc and phosphorus treatments and extractants (Figures 23 through 34). The quantity of exchangeable zinc was not affected by length of incubation (Tables 36 through 38).

Virtually none of the zinc applied as zinc sulfate remained water soluble. Only 1.0 to 2.0 pounds as exchangeable zinc could be recovered from soil which received the highest, or 162.0 pound zinc sulfate treatment (Tables 36 through 38). None of the zinc applied in the 2.0 and 6.0 pound zinc EDTA treatment remained water soluble or exchangeable.

The amount of soil zinc which was water soluble, exchangeable, or water soluble and exchangeable, decreased with time (Tables 36 through 38). Acid soluble zinc in zinc EDTA treated soil increased

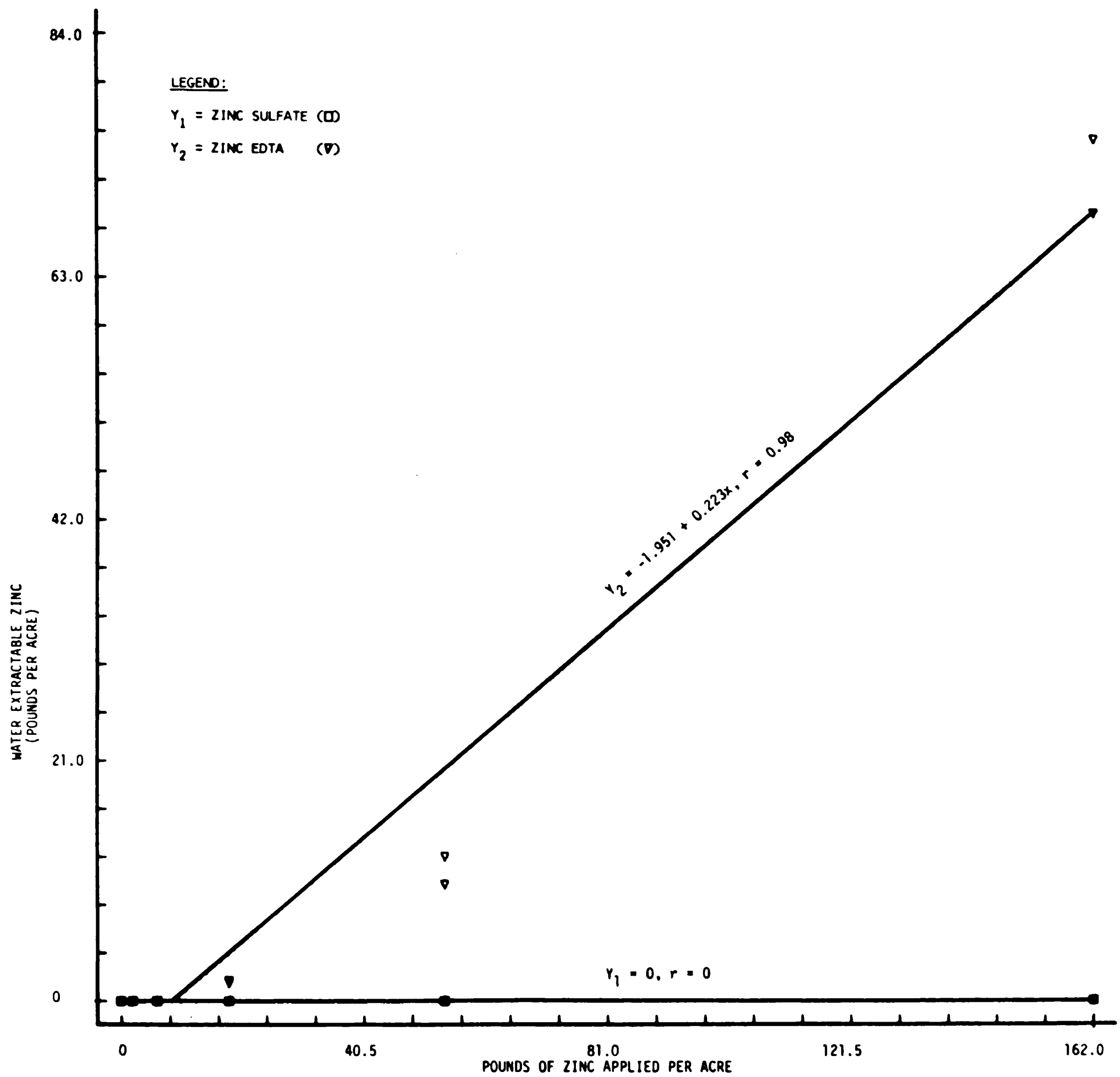

FIGURE 17: THE RELATIONSHIP BETWEEN RATES OF ZINC APPLIED AS ZINC SULFATE AND ZINC EDTA AND WATER EXTRACTABLE ZINC ON A WISNER CLAY LOAM SOIL INCUBATED FOR 90 DAYS. (INCUBATION EXPERIMENT)

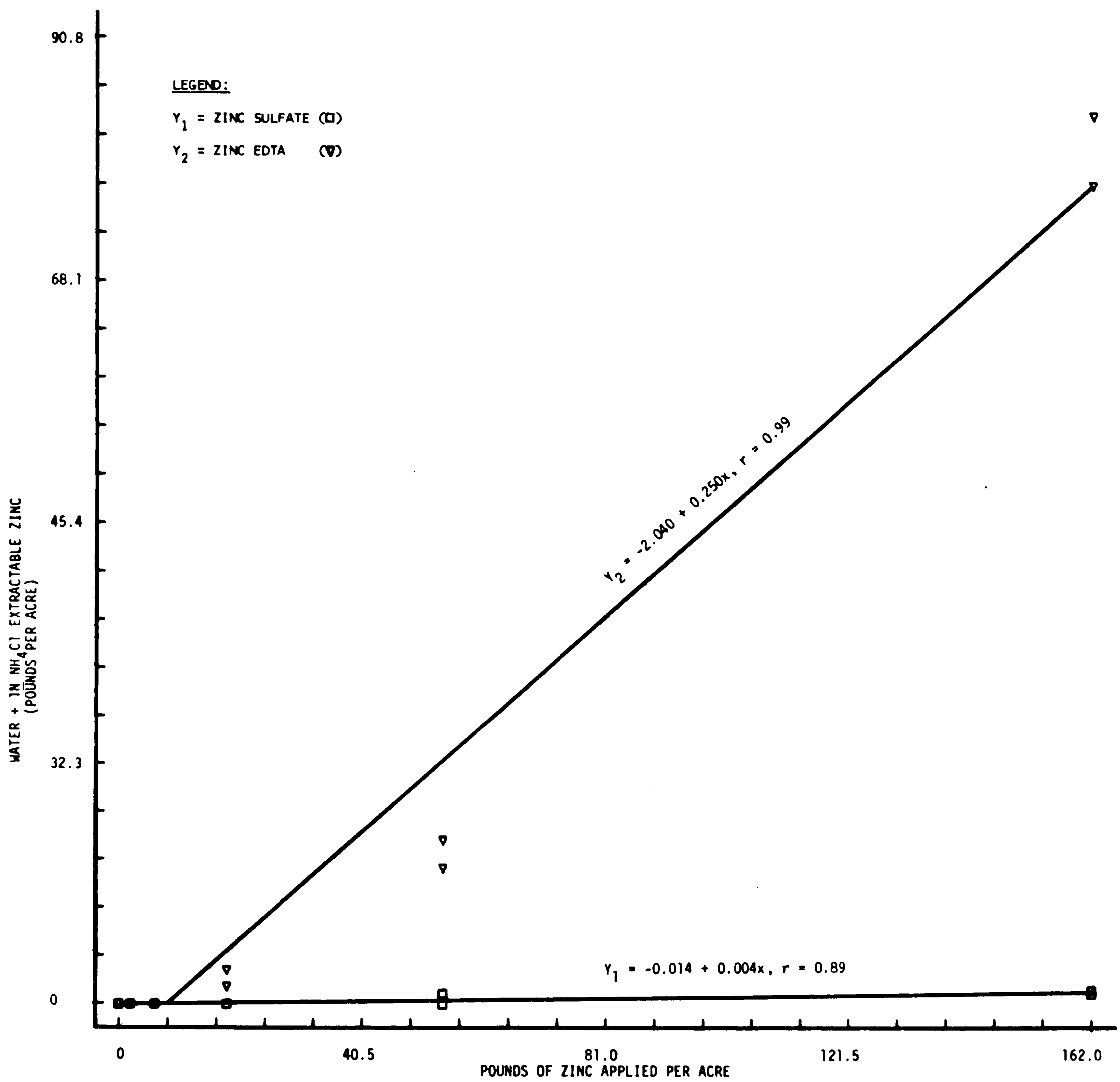

FIGURE 18: THE RELATIONSHIP BETWEEN RATES OF ZINC APPLIED AS ZINC SULFATE AND ZINC EDTA AND WATER PLUS 1N NEUTRAL NH_4Cl EXTRACTABLE ZINC ON A WISNER CLAY LOAM SOIL INCUBATED FOR 90 DAYS. (INCUBATION EXPERIMENT)

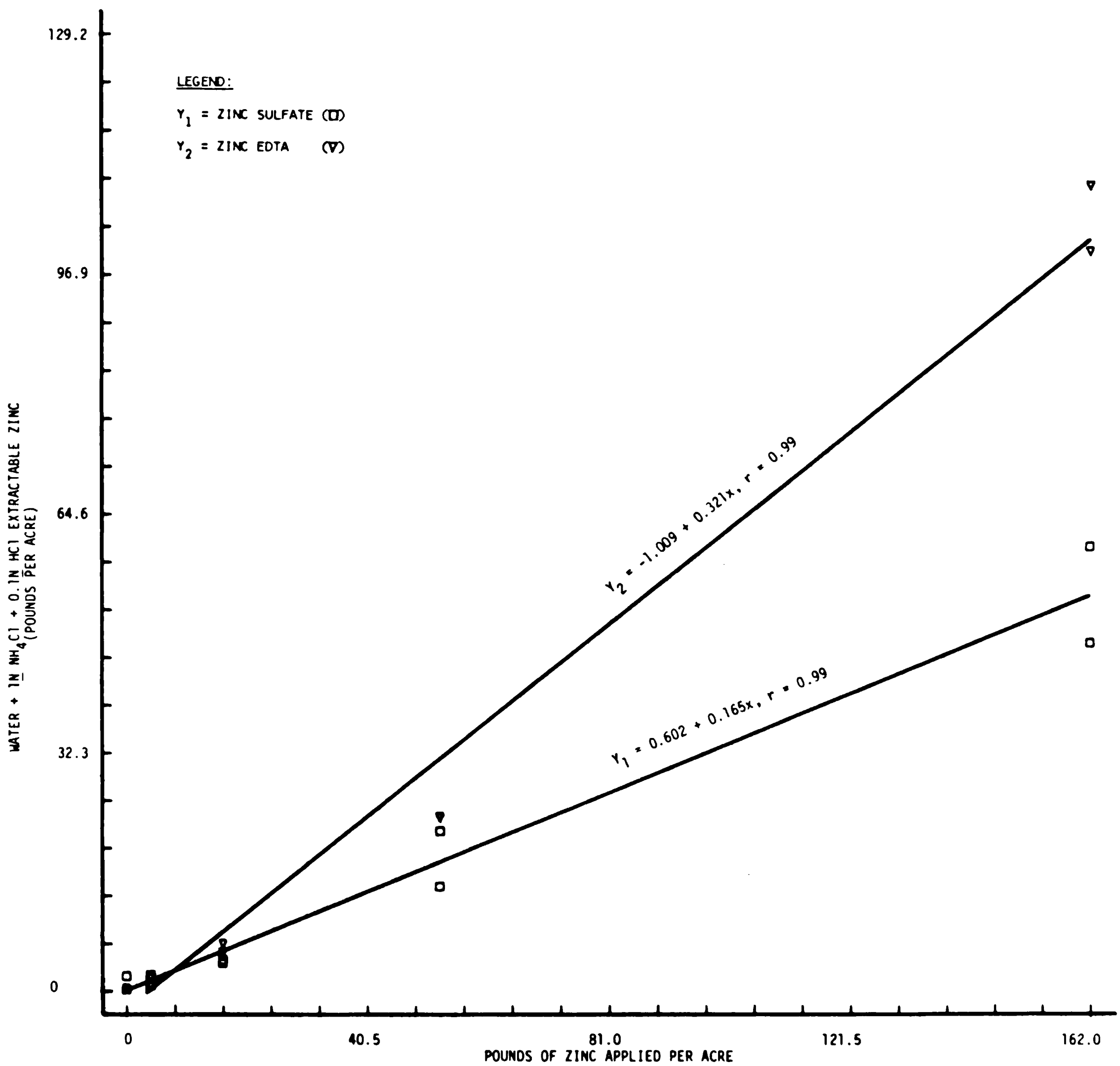

FIGURE 19: THE RELATIONSHIP BETWEEN RATES OF ZINC APPLIED AS ZINC SULFATE AND ZINC EDTA AND WATER PLUS 1N NEUTRAL NH_4Cl PLUS 0.1N HCl EXTRACTABLE ZINC ON A WISNER CLAY LOAM SOIL INCUBATED FOR 90 DAYS. (INCUBATION EXPERIMENT)

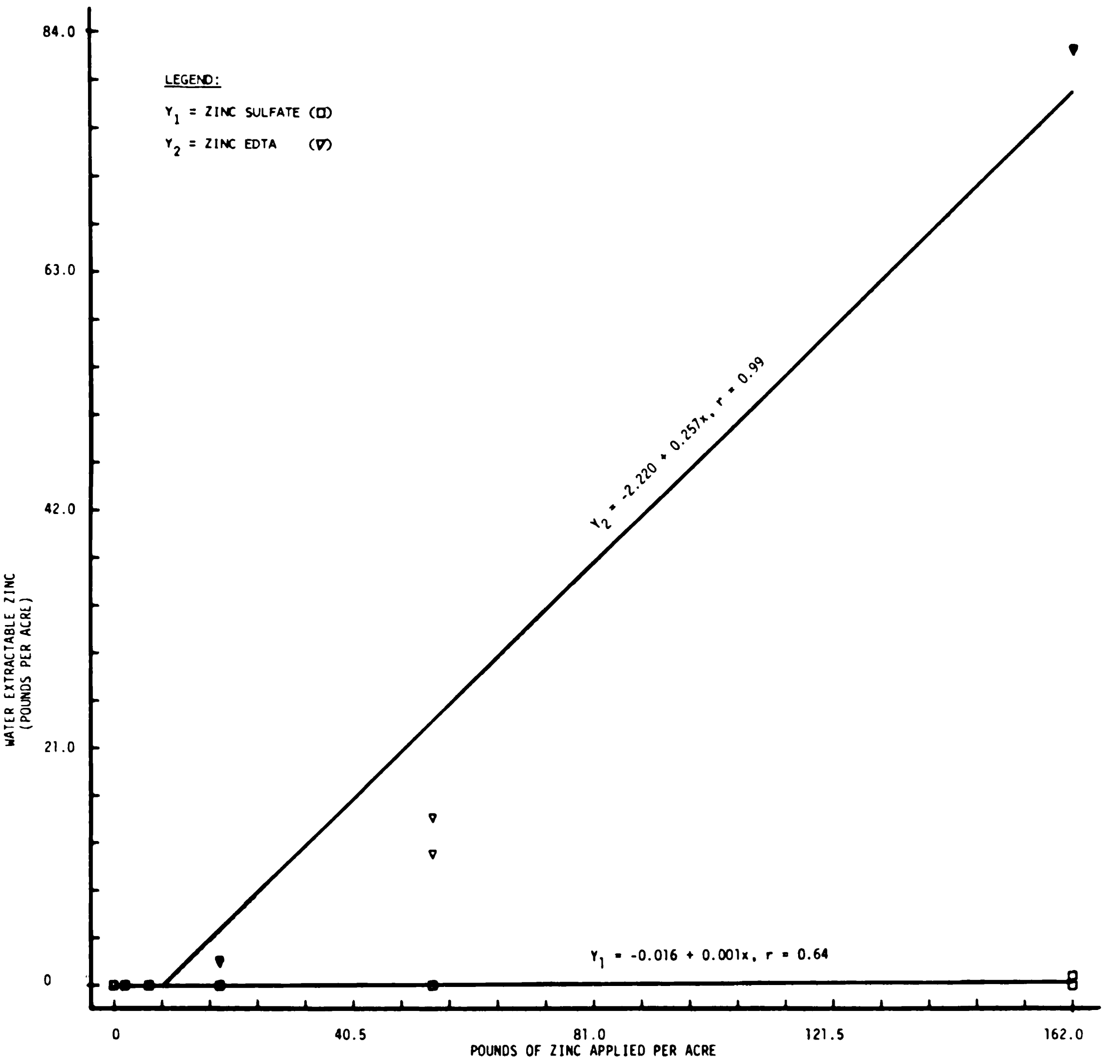

FIGURE 20: THE RELATIONSHIP BETWEEN RATES OF ZINC APPLIED AS ZINC SULFATE AND ZINC EDTA AND WATER EXTRACTABLE ZINC ON A WISNER CLAY LOAM SOIL INCUBATED FOR 90 DAYS; PHOSPHORUS WAS ALSO APPLIED. (INCUBATION EXPERIMENT)

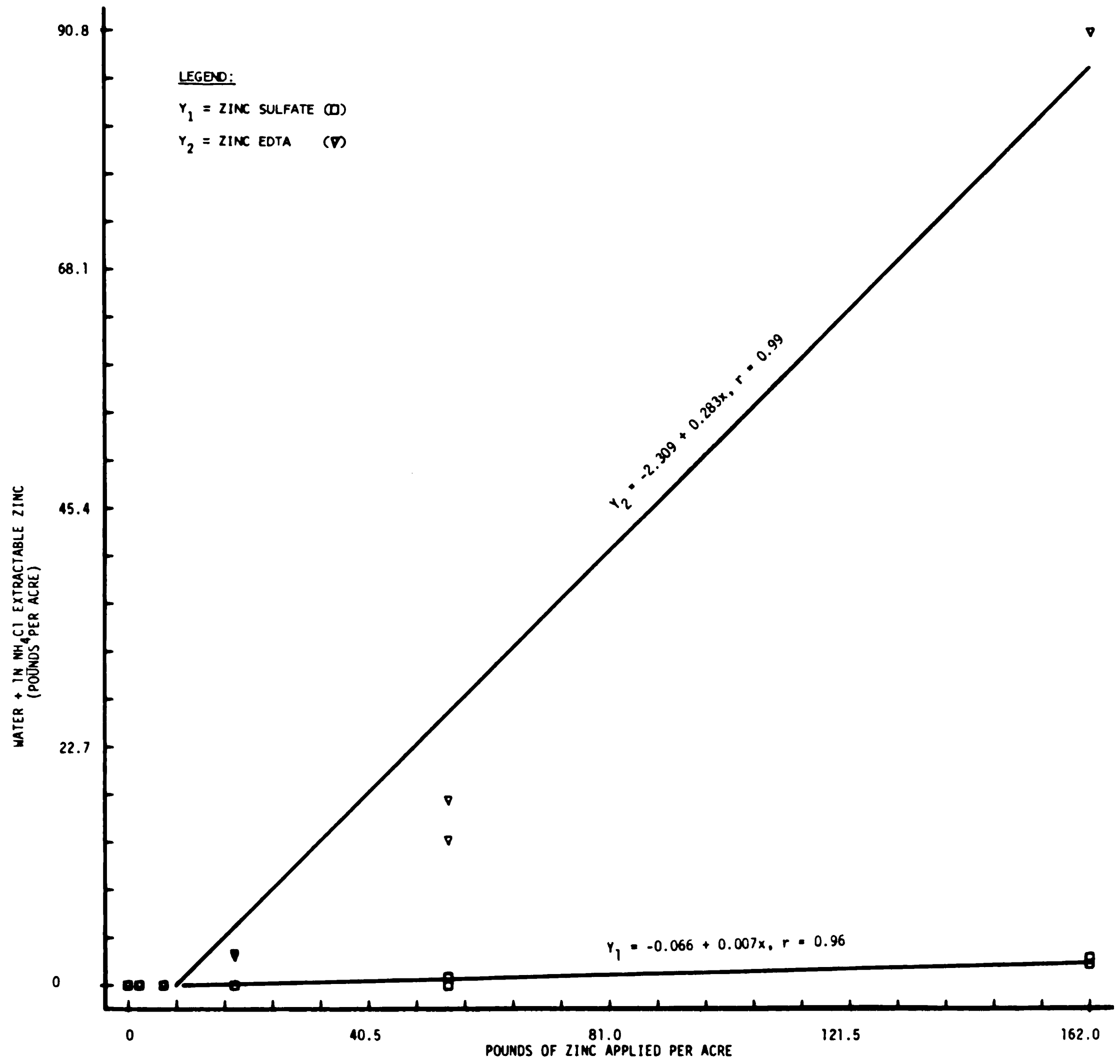

FIGURE 21: THE RELATIONSHIP BETWEEN RATES OF ZINC APPLIED AS ZINC SULFATE AND ZINC EDTA AND WATER PLUS 1N NEUTRAL NH_4Cl EXTRACTABLE ZINC ON A WISNER CLAY LOAM SOIL INCUBATED FOR 90 DAYS; PHOSPHORUS WAS ALSO APPLIED. (INCUBATION EXPERIMENT)

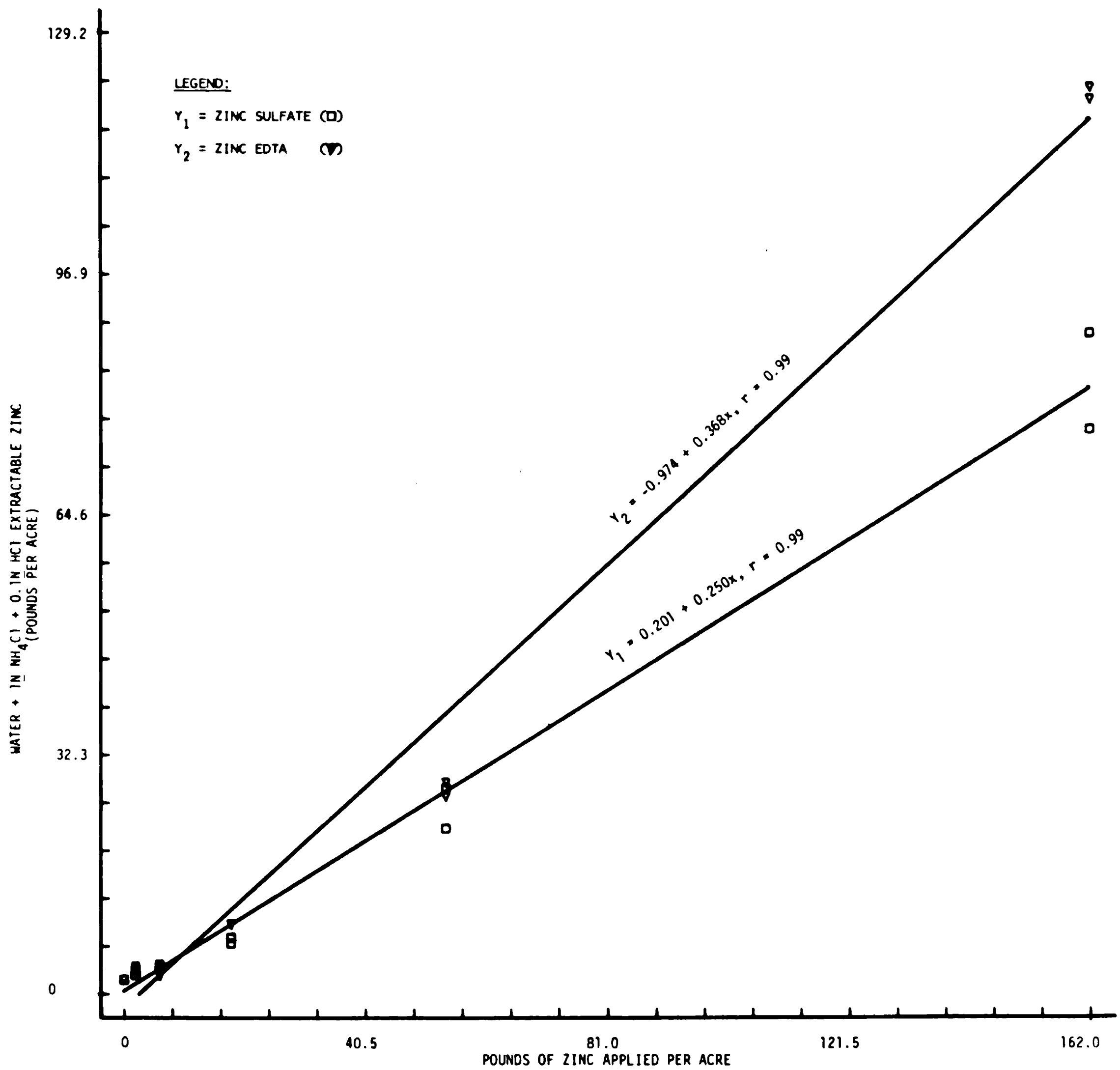

FIGURE 22: THE RELATIONSHIP BETWEEN RATES OF ZINC APPLIED AS ZINC SULFATE AND ZINC EDTA AND WATER PLUS 1N NEUTRAL NH_4Cl PLUS 0.1N HCl EXTRACTABLE ZINC ON A WISNER CLAY LOAM SOIL INCUBATED FOR 90 DAYS; PHOSPHORUS WAS ALSO APPLIED. (INCUBATION EXPERIMENT)

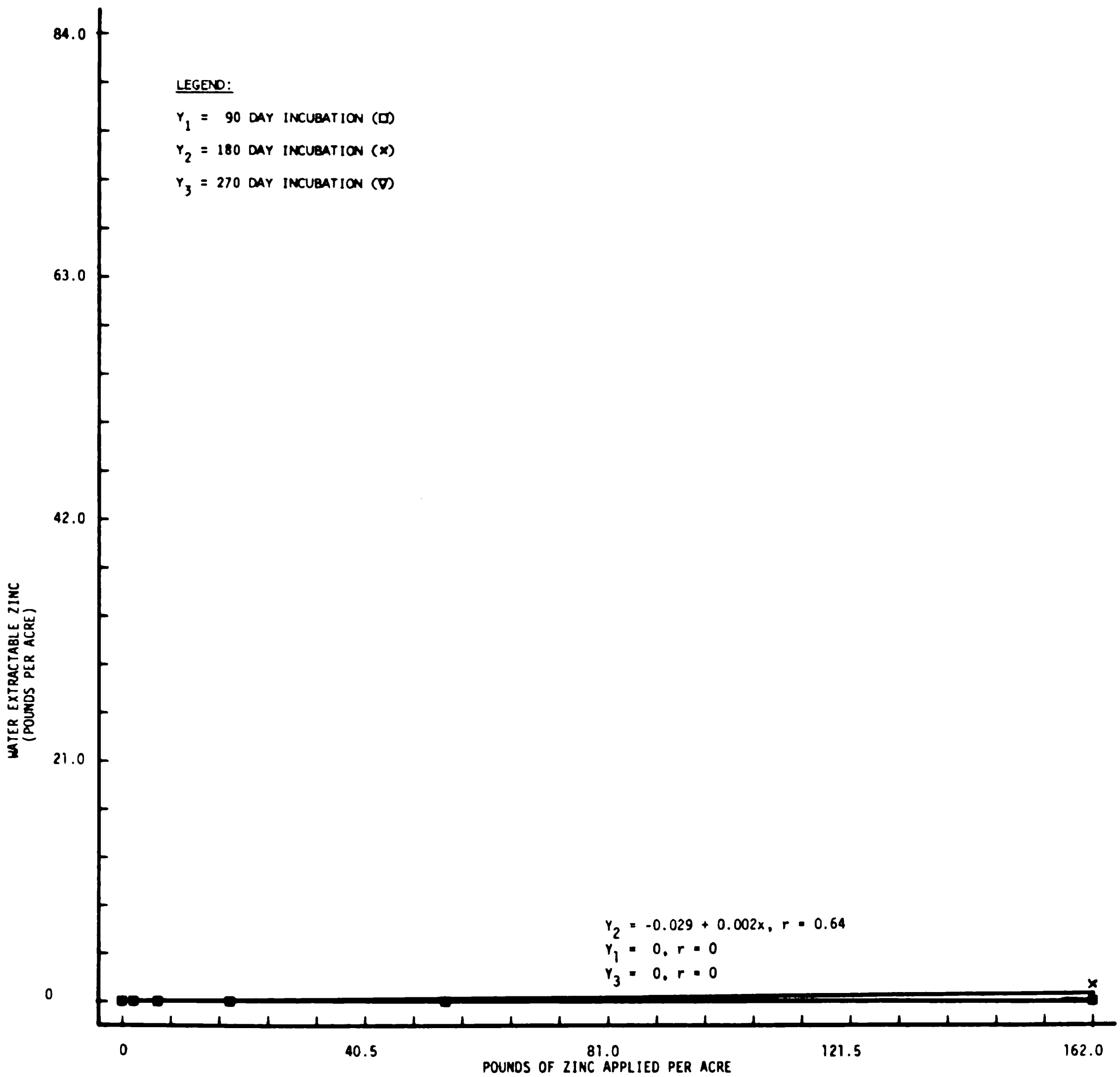

FIGURE 23: THE RELATIONSHIP BETWEEN RATES OF ZINC APPLIED AS ZINC SULFATE AND WATER EXTRACTABLE ZINC ON A WISNER CLAY LOAM SOIL INCUBATED FOR 90, 180, AND 270 DAYS. (INCUBATION EXPERIMENT)

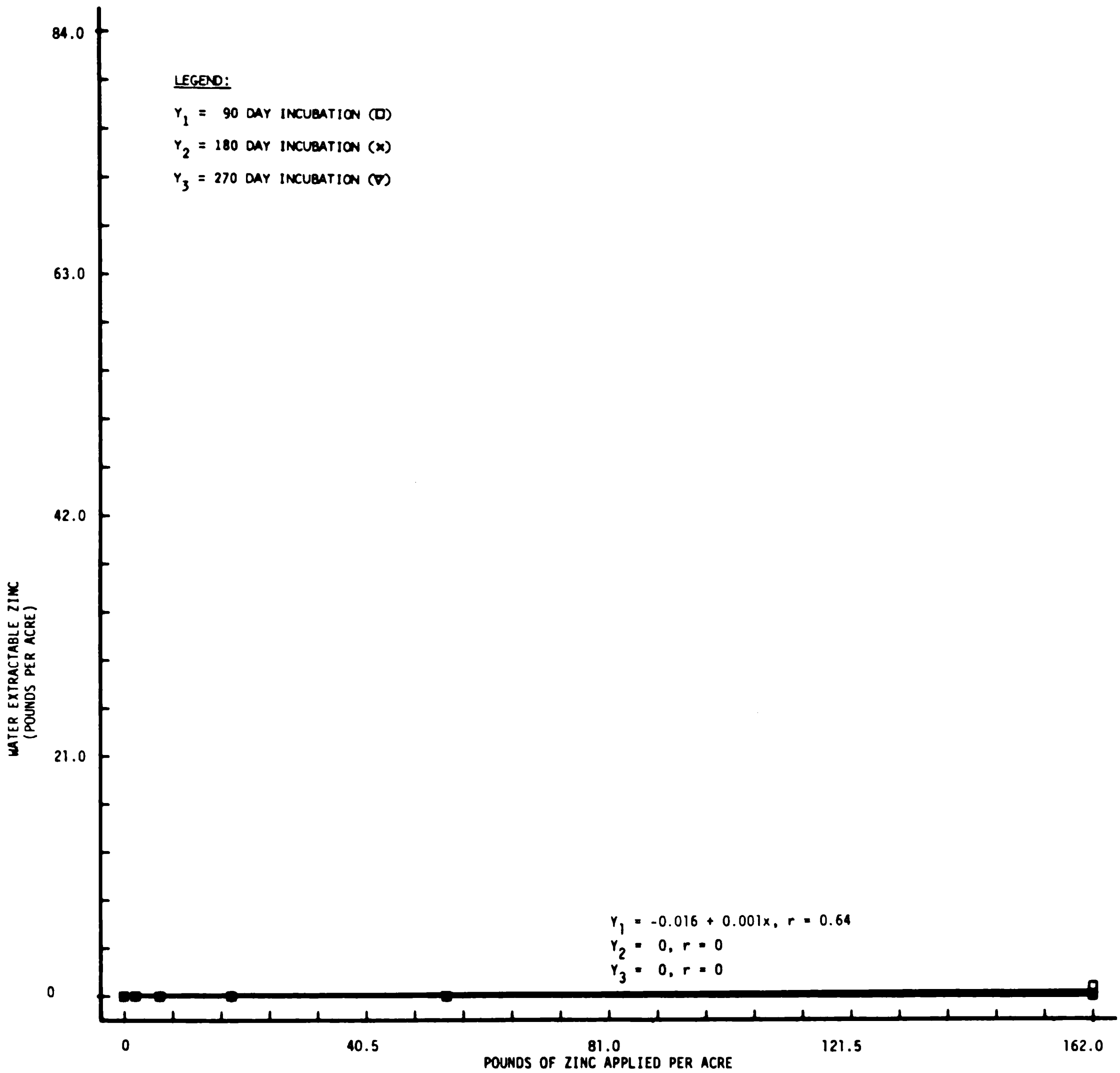

FIGURE 24: THE RELATIONSHIP BETWEEN RATES OF ZINC APPLIED AS ZINC SULFATE AND WATER EXTRACTABLE ZINC ON A WISNER CLAY LOAM SOIL INCUBATED FOR 90, 180, AND 270 DAYS; PHOSPHORUS WAS ALSO APPLIED. (INCUBATION EXPERIMENT)

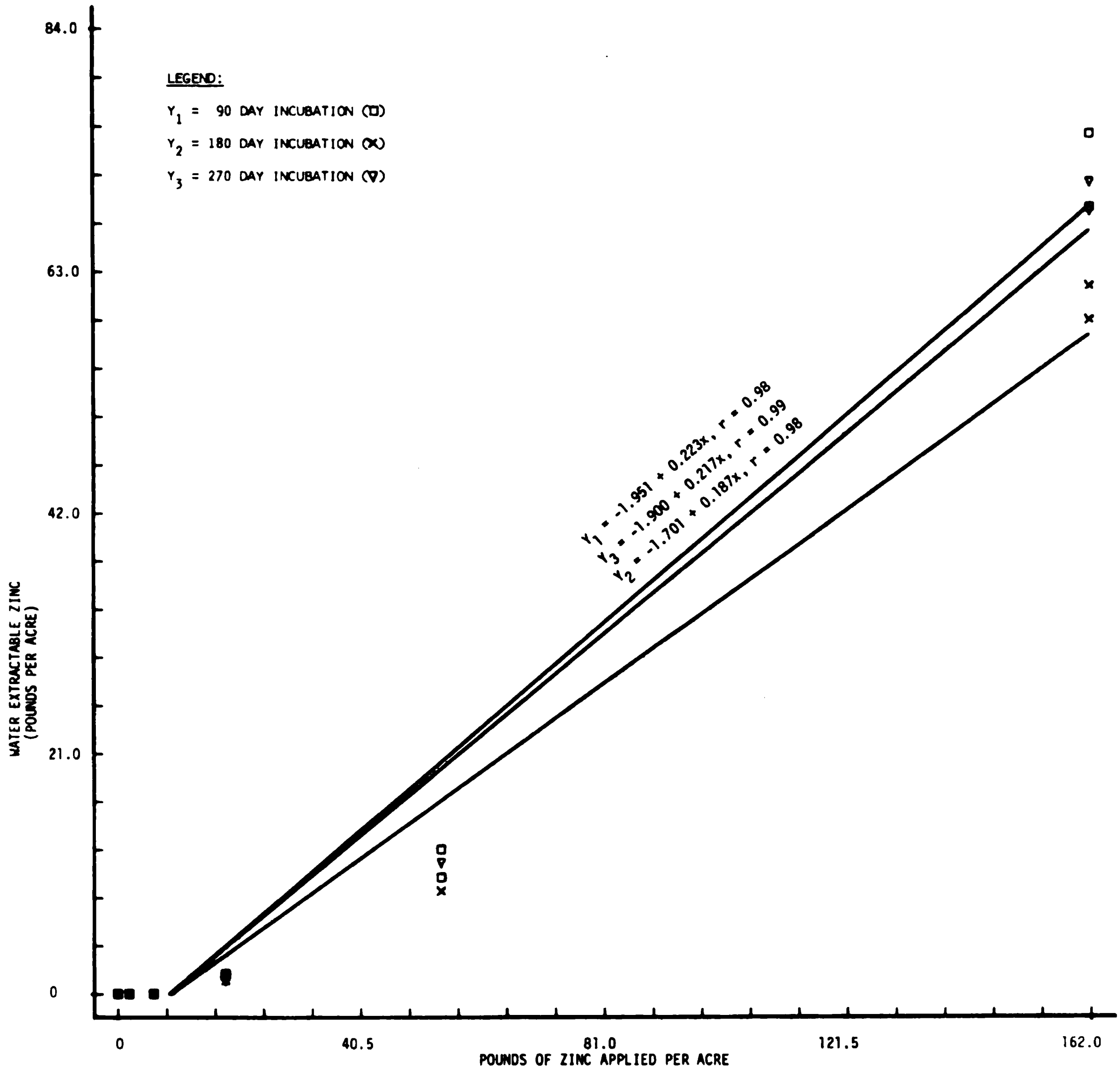

FIGURE 25: THE RELATIONSHIP BETWEEN RATES OF ZINC APPLIED AS ZINC EDTA AND WATER EXTRACTABLE ZINC ON A WISNER CLAY LOAM SOIL INCUBATED FOR 90, 180, AND 270 DAYS. (INCUBATION EXPERIMENT)

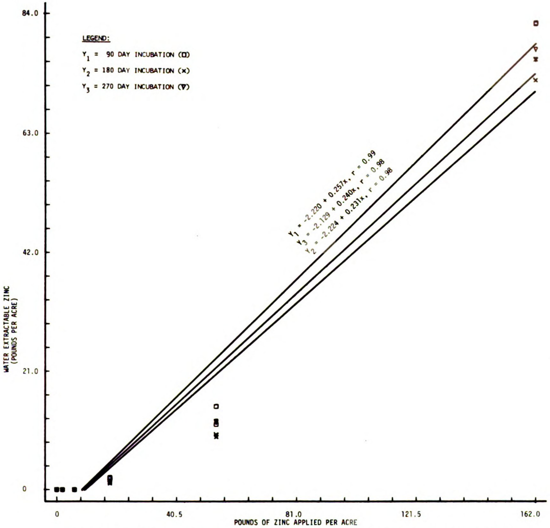

FIGURE 26: THE RELATIONSHIP BETWEEN RATES OF ZINC APPLIED AS ZINC EDTA AND WATER EXTRACTABLE ZINC ON A WISNER CLAY LOAM SOIL INCUBATED FOR 90, 180, AND 270 DAYS; PHOSPHORUS WAS ALSO APPLIED. (INCUBATION EXPERIMENT)

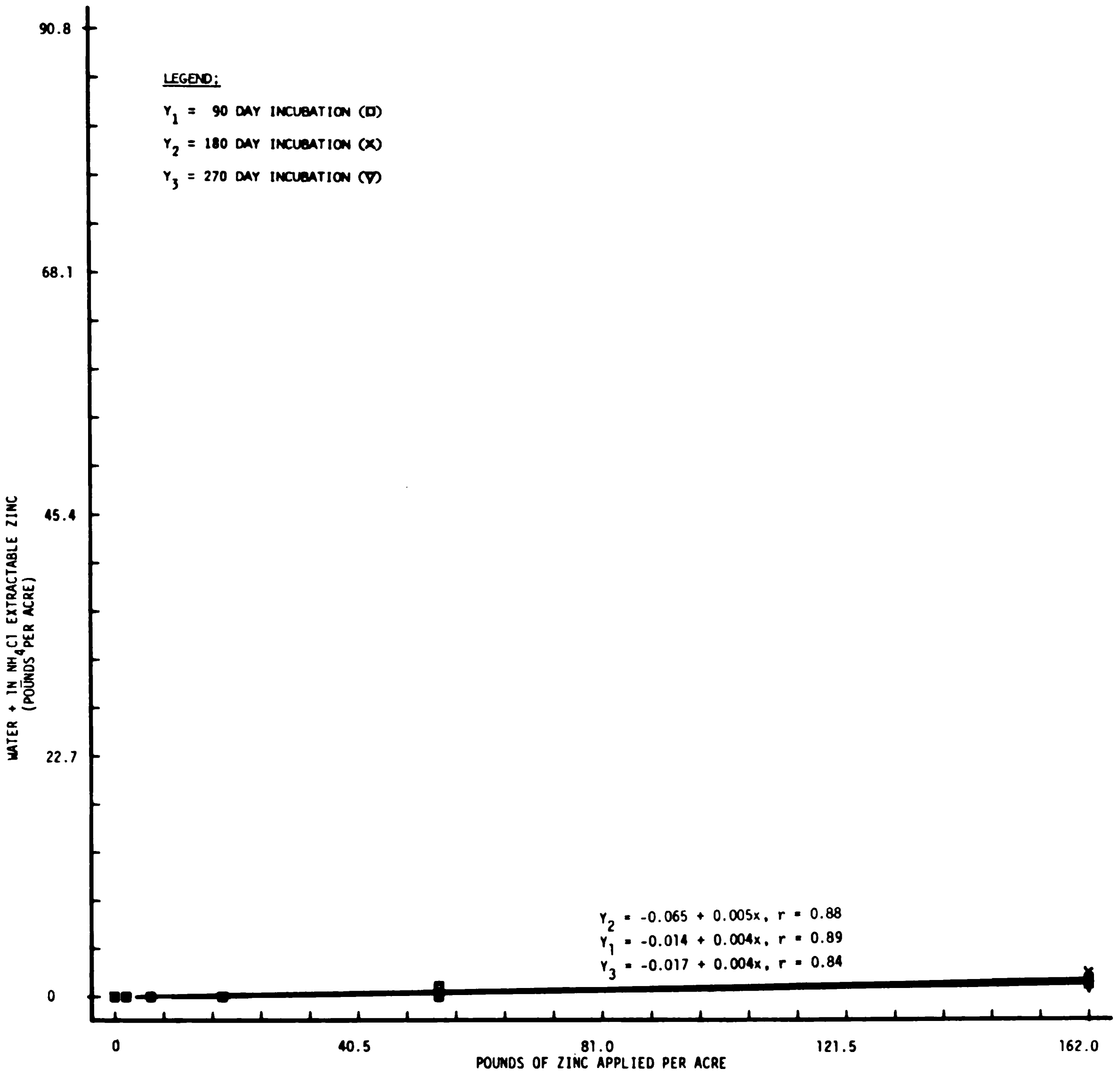

FIGURE 27: THE RELATIONSHIP BETWEEN RATES OF ZINC APPLIED AS ZINC SULFATE AND WATER PLUS 1N NEUTRAL NH_4Cl EXTRACTABLE ZINC ON A WISNER CLAY LOAM SOIL INCUBATED FOR 90, 180, AND 270 DAYS. (INCUBATION EXPERIMENT)

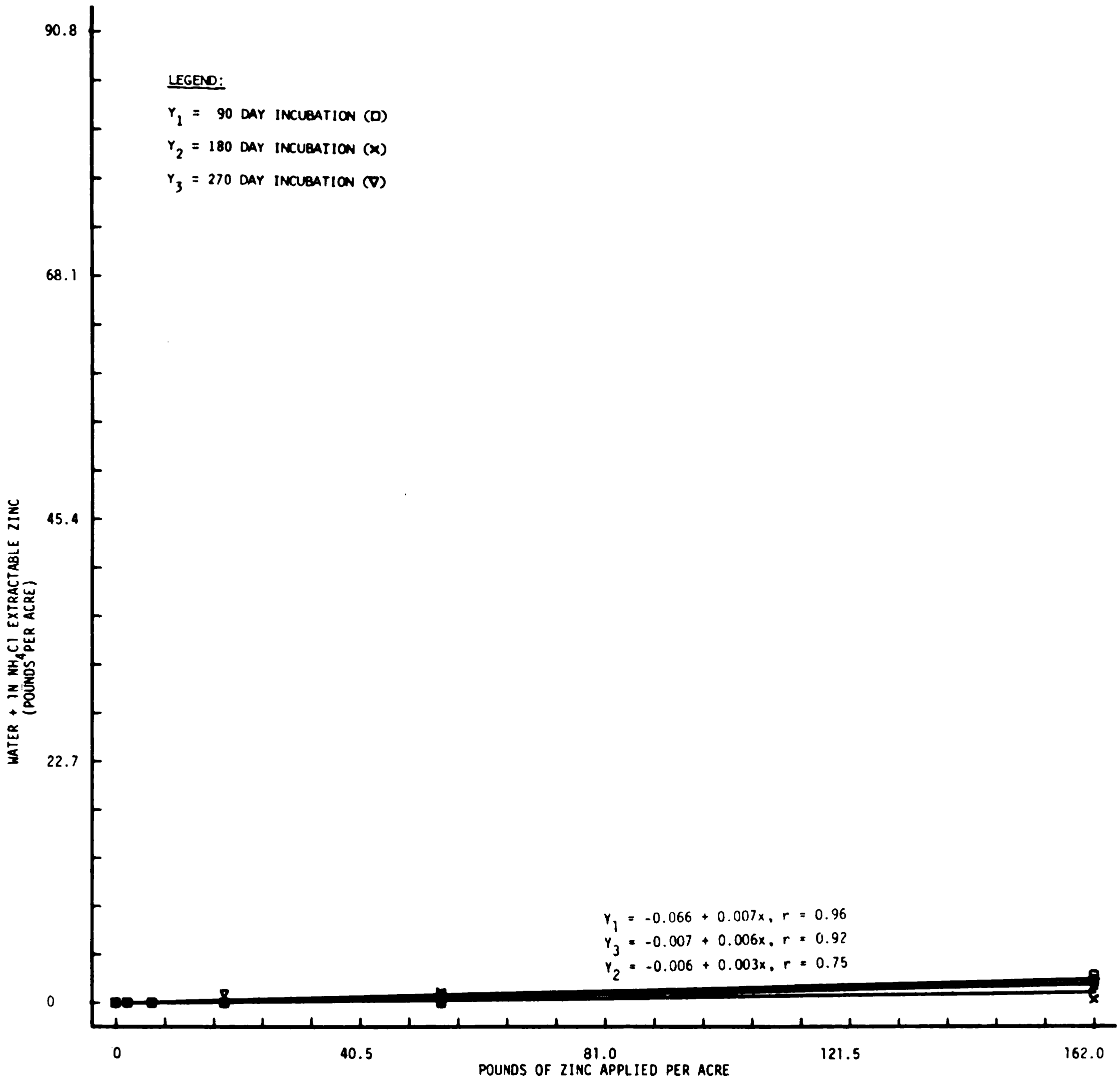

FIGURE 28: THE RELATIONSHIP BETWEEN RATES OF ZINC APPLIED AS ZINC SULFATE AND WATER PLUS 1N NEUTRAL NH_4Cl EXTRACTABLE ZINC ON A WISNER CLAY LOAM SOIL INCUBATED FOR 90, 180, AND 270 DAYS; PHOSPHORUS WAS ALSO APPLIED. (INCUBATION EXPERIMENT)

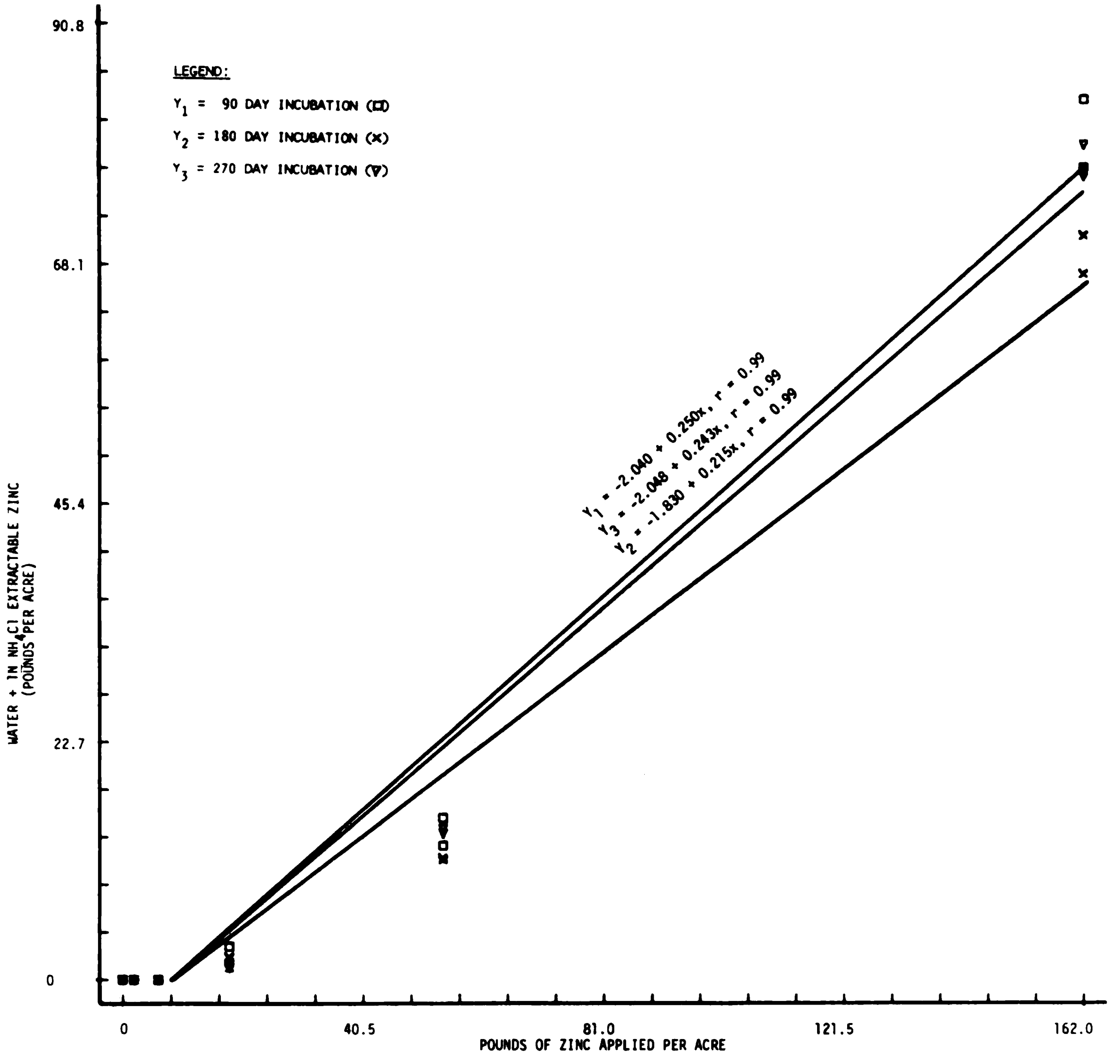

FIGURE 29: THE RELATIONSHIP BETWEEN RATES OF ZINC APPLIED AS ZINC EDTA AND WATER PLUS 1N NEUTRAL NH_4Cl EXTRACTABLE ZINC ON A WISNER CLAY LOAM SOIL INCUBATED FOR 90, 180, AND 270 DAYS. (INCUBATION EXPERIMENT)

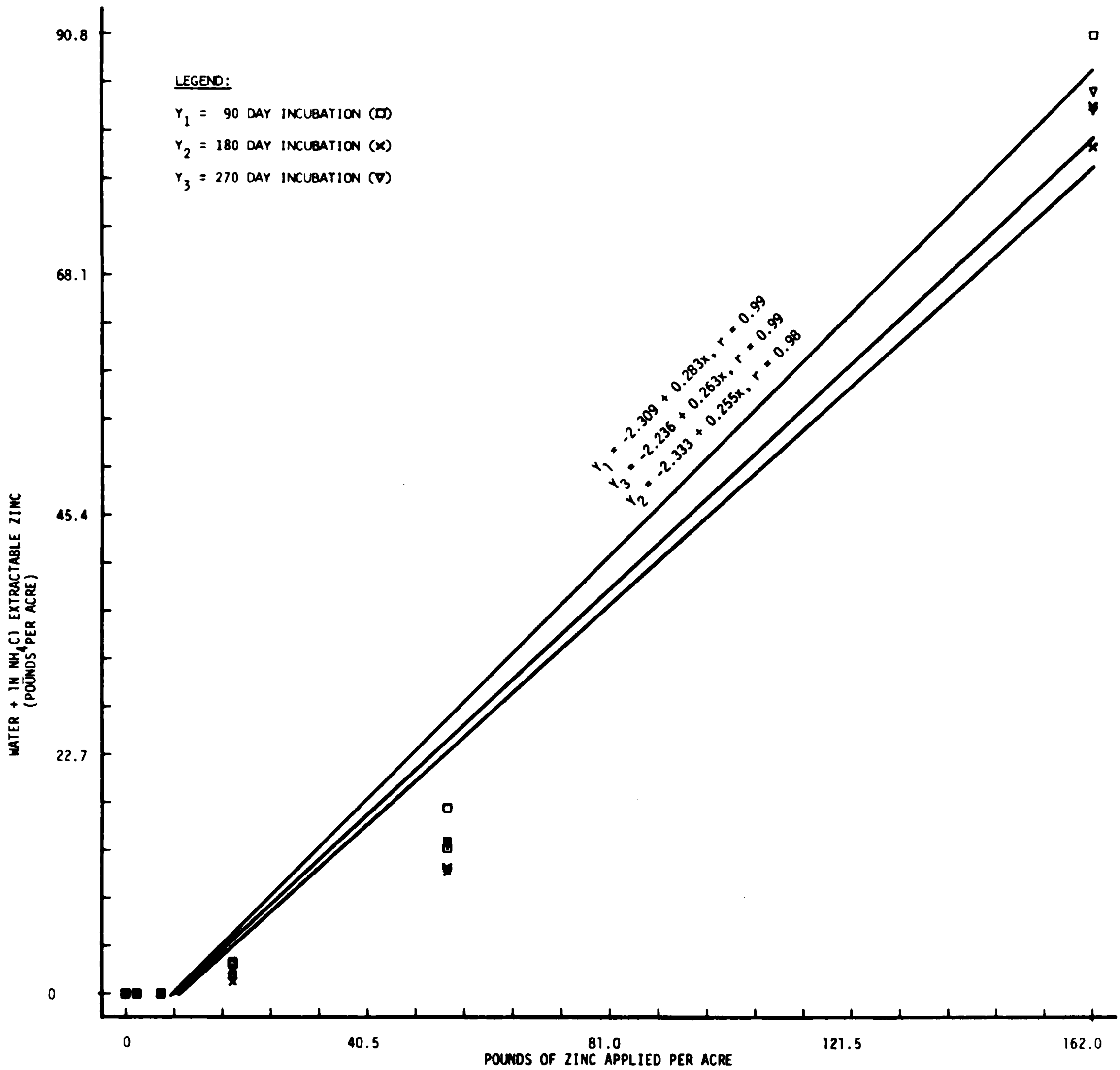

FIGURE 30: THE RELATIONSHIP BETWEEN RATES OF ZINC APPLIED AS ZINC EDTA AND WATER PLUS 1N NEUTRAL NH_4Cl EXTRACTABLE ZINC ON A WISNER CLAY LOAM SOIL INCUBATED FOR 90, 180, AND 270 DAYS; PHOSPHORUS WAS ALSO APPLIED. (INCUBATION EXPERIMENT)

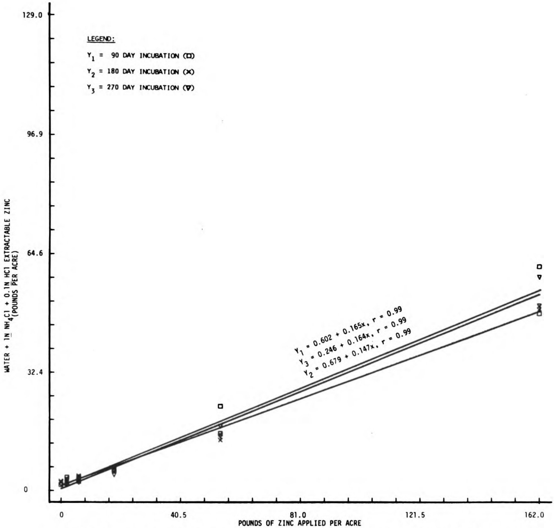

FIGURE 31: THE RELATIONSHIP BETWEEN RATES OF ZINC APPLIED AS ZINC SULFATE AND WATER PLUS 1N NEUTRAL NH_4Cl PLUS 0.1N HCl EXTRACTABLE ZINC ON A WISNER CLAY LOAM SOIL INCUBATED FOR 90, 180, AND 270 DAYS. (INCUBATION EXPERIMENT)

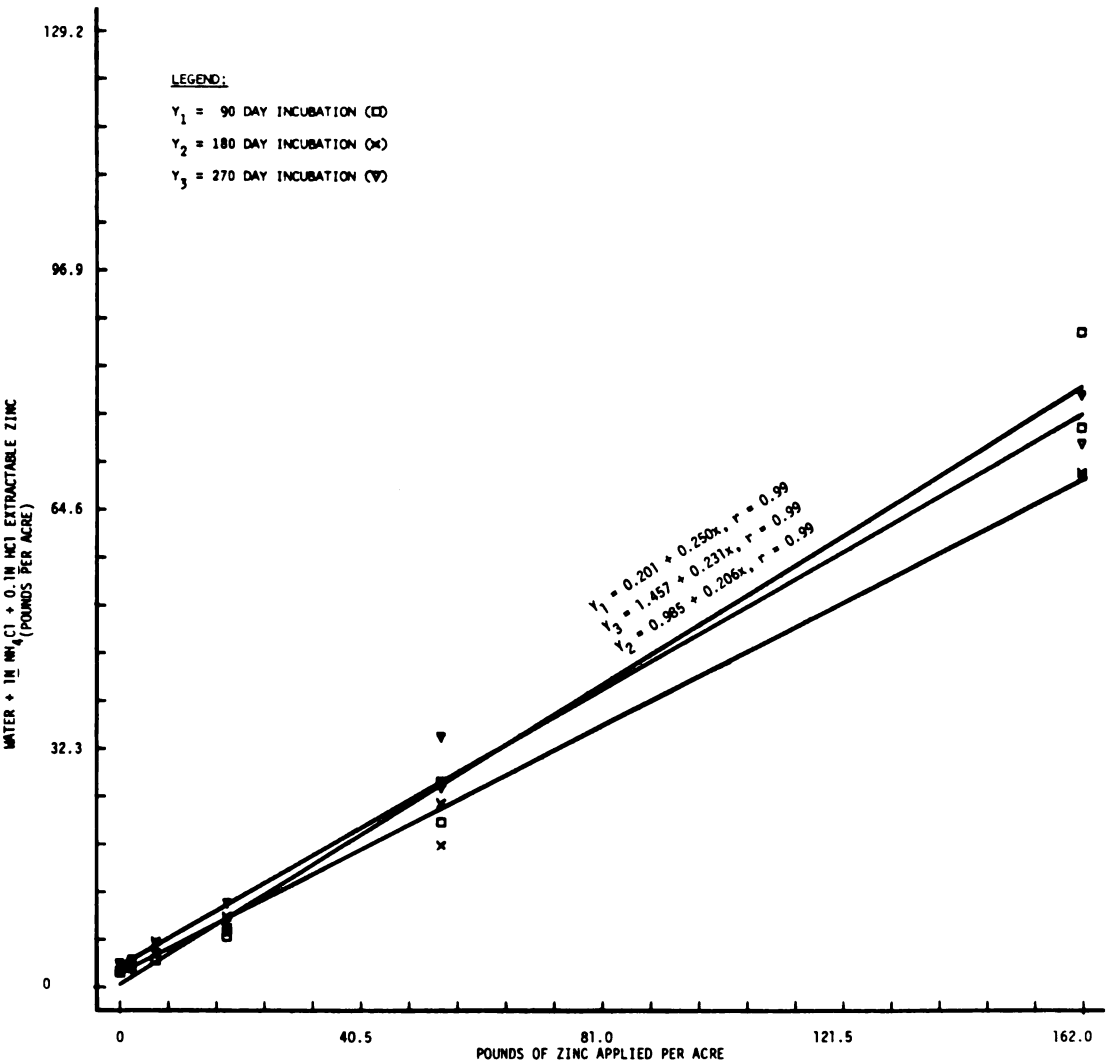

FIGURE 32: THE RELATIONSHIP BETWEEN RATES OF ZINC APPLIED AS ZINC SULFATE AND WATER PLUS 1N NEUTRAL NH_4Cl PLUS 0.1N HCl EXTRACTABLE ZINC ON A WISNER CLAY LOAM SOIL INCUBATED FOR 90, 180, AND 270 DAYS; PHOSPHORUS WAS ALSO APPLIED. (INCUBATION EXPERIMENT)

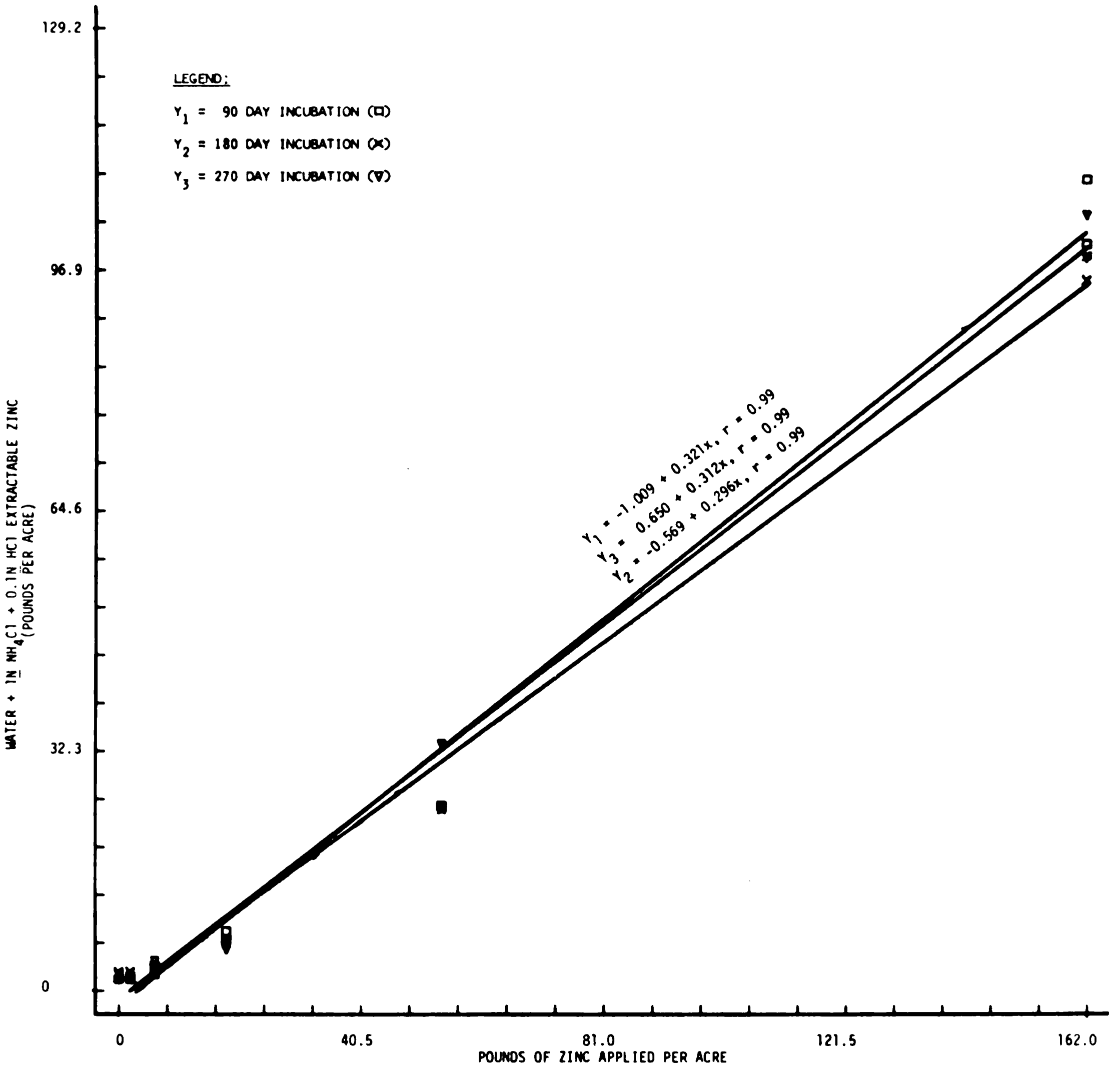

FIGURE 33: THE RELATIONSHIP BETWEEN RATES OF ZINC APPLIED AS ZINC EDTA AND WATER PLUS 1N NEUTRAL NH_4Cl PLUS 0.1N HCl EXTRACTABLE ZINC ON A WISNER CLAY LOAM SOIL INCUBATED FOR 90, 180, AND 270 DAYS. (INCUBATION EXPERIMENT)

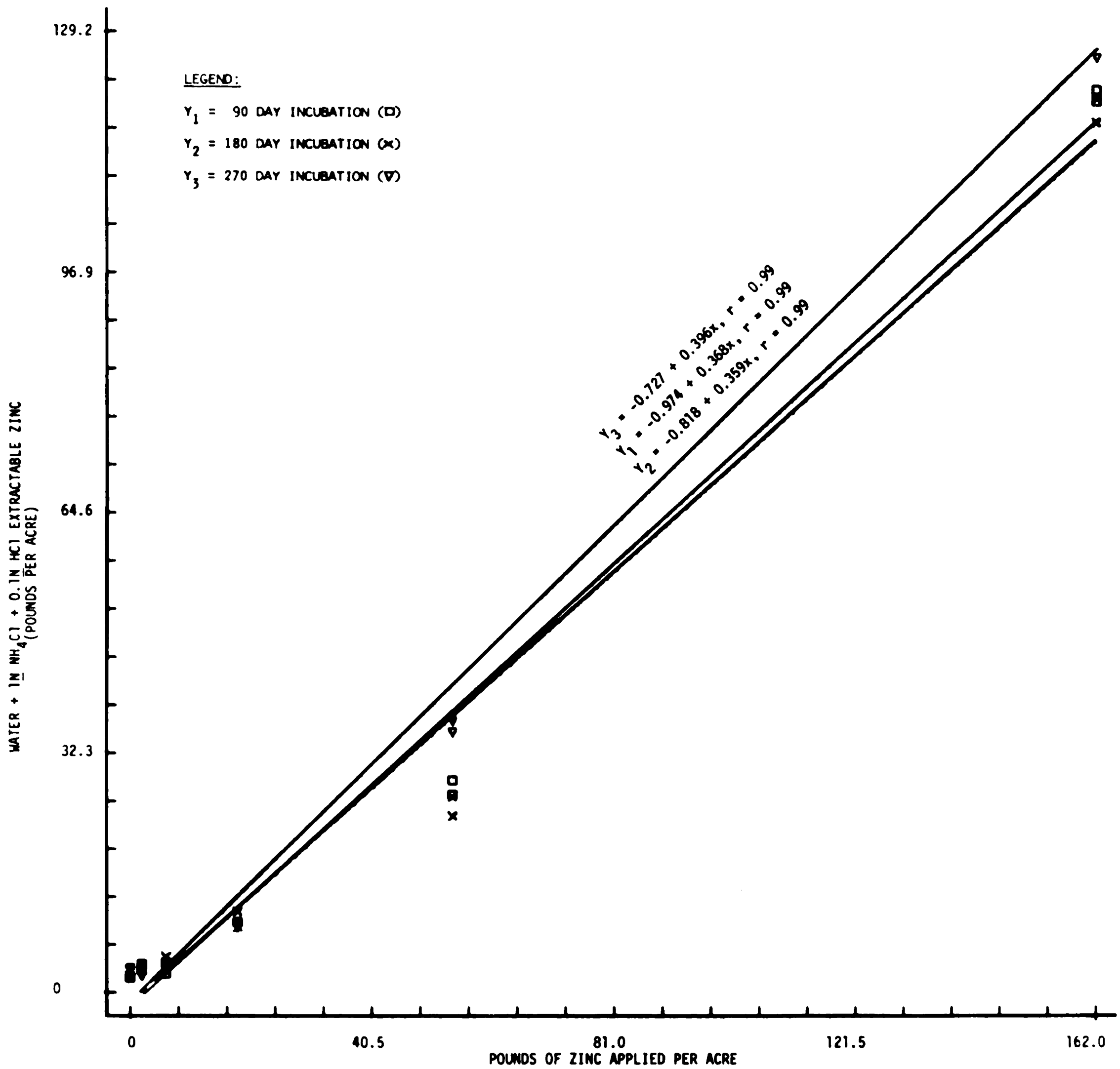

FIGURE 34: THE RELATIONSHIP BETWEEN RATES OF ZINC APPLIED AS ZINC EDTA AND WATER PLUS 1N NEUTRAL NH_4Cl PLUS 0.1N HCl EXTRACTABLE ZINC ON A WISNER CLAY LOAM SOIL INCUBATED FOR 90, 180, AND 270 DAYS; PHOSPHORUS WAS ALSO APPLIED. (INCUBATION EXPERIMENT)

Table 40: The per cent of applied zinc recovered by water plus 1N neutral NH_4Cl plus 0.1N HCl extraction from a Wisner clay loam soil incubated 90 days as affected by carrier and rate of zinc application and rate of phosphorus application. (Incubation Experiment)

Treatment		Per cent of applied zinc recovered[a]	
Zinc applied (lb/acre)	Zinc carrier	No P	1000 lb P/acre
2.0	$ZnSO_4$	55.0	50.0
2.0	ZnEDTA	10.0	70.0
6.0	$ZnSO_4$	25.0	28.3
6.0	ZnEDTA	20.0	20.0
18.0	$ZnSO_4$	22.2	28.9
18.0	ZnEDTA	32.2	41.1
54.0	$ZnSO_4$	32.8	42.8
54.0	ZnEDTA	43.2	47.5
162.0	$ZnSO_4$	32.7	49.6
162.0	ZnEDTA	63.6	73.3

(a) Average of two replications. The amount of zinc extracted from soil which had not received any zinc treatment was subtracted from the amount of zinc extracted from soil which had received zinc treatment.

with time; this form of zinc in zinc sulfate treated soil decreased with time.

The correlation coefficients obtained between zinc applied as zinc EDTA and water soluble zinc (Figures 17 and 20) or water soluble plus exchangeable zinc (Figures 18 and 21) were higher than those obtained between the zinc sulfate treatment and comparable forms of soil zinc. Comparable coefficients were obtained between zinc applied with either carrier and water soluble plus exchangeable plus acid soluble zinc (Figures 19 and 22).

The per cent of zinc applied to the soil which could be recovered by any of the three extractants increased as the rate of applied zinc increased from 6.0 to 162.0 pounds per acre (Table 40). More zinc could be recovered from zinc sulfate treated soil than from zinc EDTA treated soil when 2.0 and 6.0 pounds of zinc were applied (Tables 36 through 38), but this relationship was reversed as additional increments of zinc were applied. This increase in extractable zinc from higher levels of applied zinc EDTA was due primarily to an increase in water soluble and exchangeable zinc. Zinc applied as zinc sulfate was found in the acid soluble rather than water soluble or exchangeable fractions.

When 1000 pounds of phosphorus were applied to the soil, the amount of zinc which could be recovered by any extractant from soil treated with either zinc carrier was increased except for exchangeable zinc when zinc EDTA was applied (Table 41). This increase in extractable zinc due to phosphorus treatment was greater for zinc sulfate treated soil samples than for zinc EDTA

Table 41: The per cent increase in zinc extractable by water, 1N neutral NH_4Cl, and 0.1N HCl from a Wisner clay loam soil incubated 90 days which had received applied phosphorus over soil which had not received phosphorus as affected by carrier and rate of zinc application. (Incubation Experiment)

Treatment		Per cent increase in extractable zinc[a]		
Zinc applied (lb/acre)	Zinc carrier	Water extractable zinc	Water + NH_4Cl[b] extractable zinc	Water + NH_4Cl[b] + 0.1N HCl extractable zinc
0	--	--	--	25.0
2.0	$ZnSO_4$	--	--	11.1
2.0	ZnEDTA	--	--	88.9
6.0	$ZnSO_4$	--	--	19.4
6.0	ZnEDTA	--	--	14.3
18.0	$ZnSO_4$	--	--	28.6
18.0	ZnEDTA	23.5	20.8	27.0
54.0	$ZnSO_4$	--	Decrease	30.3
54.0	ZnEDTA	15.8	11.3	10.8
162.0	$ZnSO_4$	--	91.6	50.8
162.0	ZnEDTA	14.9	13.2	11.5

(a) From values in Table 36.
(b) 1N neutral NH_4Cl.

treated samples.

The pH of the water extracts of the soil samples ranged from 7.4 to 7.9. The pH of the neutral normal ammonium chloride extracts ranged from 7.0 to 7.2.

The relationship between the pH of the tenth normal hydrochloric acid soil extract and the amount of applied zinc remaining in the soil at 90 days is shown according to zinc carrier for samples which did not receive phosphorus in Figure 35 and for samples which received phosphorus in Figure 36. The amount of applied zinc remaining in the soil is a calculated value. The quantity of zinc extracted from the soil by water plus neutral normal ammonium chloride plus tenth normal hydrochloric acid was subtracted from the amount of zinc originally applied; to this value, was added the quantity of zinc extracted by tenth normal hydrochloric acid from those soil samples which did not receive any zinc treatment.

The pH of the tenth normal hydrochloric acid soil extract from soil samples which received 1000 pounds of phosphorus per acre exhibited a lower pH. The median pH for samples which received phosphorus was 4.27 compared to 4.38 for samples which did not receive phosphorus (Figures 35 and 36). When phosphorus was applied, 30.2 per cent of the extracts had a pH below 4.1, and 7.0 per cent, above pH 4.5; when no phosphorus was applied, only 20.9 per cent of the extracts had a pH below 4.1, and 25.6 per cent above pH 4.5.

There was poor correlation between the pH of the tenth normal hydrochloric acid extract and the amount of zinc extractable by water plus neutral normal ammonium chloride plus tenth normal

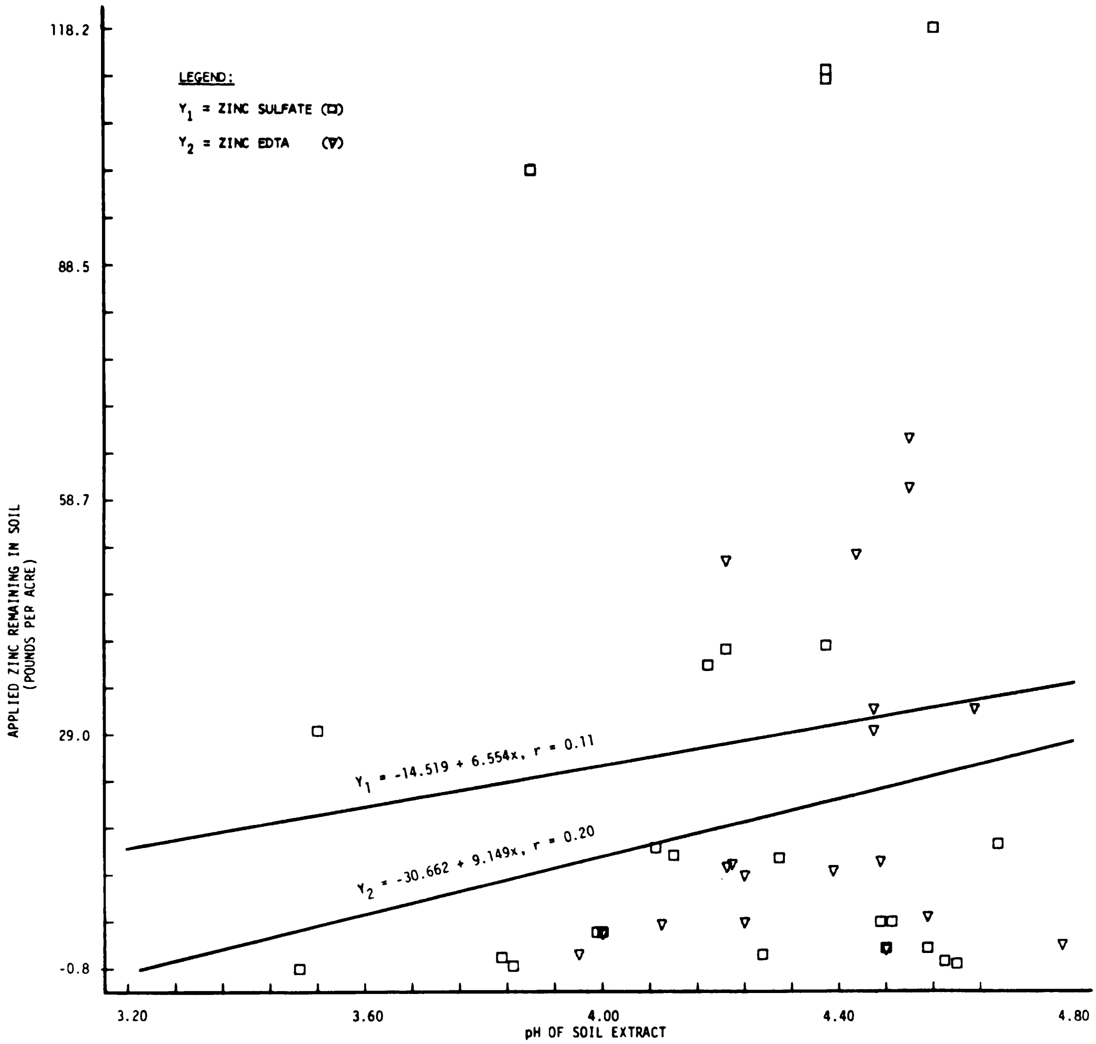

FIGURE 35: THE RELATIONSHIP BETWEEN THE pH OF THE 0.1N HCl SOIL EXTRACT AND THE POUNDS OF APPLIED ZINC AS ZINC SULFATE AND ZINC EDTA REMAINING AFTER EXTRACTION WITH WATER PLUS 1N NH_4Cl PLUS 0.1N HCl IN A WISNER CLAY LOAM SOIL INCUBATED 90 DAYS. (INCUBATION EXPERIMENT)

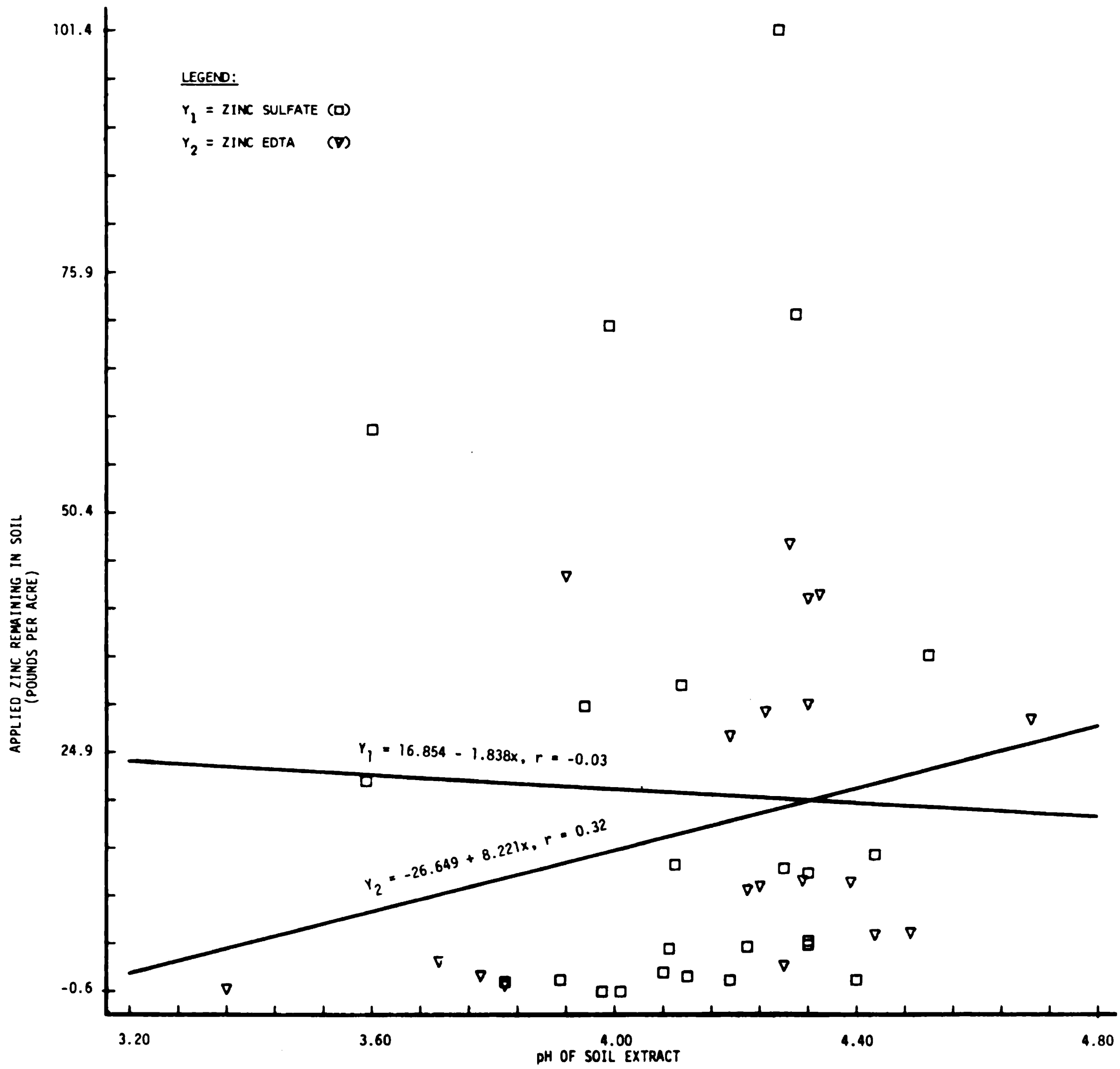

FIGURE 36: THE RELATIONSHIP BETWEEN THE pH OF THE 0.1N HCl SOIL EXTRACT AND THE POUNDS OF APPLIED ZINC AS ZINC SULFATE AND ZINC EDTA REMAINING AFTER EXTRACTION WITH WATER PLUS 1N NH_4Cl PLUS 0.1N HCl IN A WISNER CLAY LOAM SOIL INCUBATED 90 DAYS; PHOSPHORUS WAS ALSO APPLIED. (INCUBATION EXPERIMENT)

hydrochloric acid. Correlations ranged from a low of -0.03 to a high of 0.32 (Figures 35 and 36).

VI. CONCLUSIONS AND SUMMARY

Zinc deficiency symptoms were observed on pea bean plants where zinc was not applied at 10 of the 12 locations in the five field experiments and on plants in all four greenhouse experiments. Symptoms of zinc deficiency either were not observed on plants when zinc was applied to the soil with either carrier or the symptoms decreased as the rate of applied zinc increased. Dry matter weight of plants and yield of pods increased in the greenhouse experiments and more dry beans were harvested in the field experiments when zinc was applied. Zinc concentration in plants was higher when zinc was applied and the concentration also increased as the rate of soil applied zinc increased. Therefore, it is concluded that zinc deficiency did occur on pea bean plants in these experiments and that the deficiency was alleviated by soil applications of sufficient zinc with either carrier.

VI-A. Conclusion Concerning Hypothesis 1

Hypothesis 1: Uptake of zinc and yield of beans by pea bean plants are greater when zinc is applied to the soil as zinc EDTA than when applied as zinc sulfate.

Zinc uptake by pea bean plants grown in the field on treatments of soil applied zinc EDTA exceeded or was only slightly less than the zinc uptake by plants grown on a higher quantity of zinc applied as zinc sulfate. The same results were obtained for yield of dry beans harvested from plants grown on zinc EDTA plots.

No field experiments were conducted with equivalent levels of

zinc applied as zinc sulfate and zinc EDTA. However, over the range of quantities of zinc EDTA applied in these field experiments, zinc uptake by plants and yield of beans increased with each increment of zinc.

Lessman[38] obtained greater zinc uptake and bean yields from field grown plants on 1.6 pounds of zinc as zinc EDTA than from plants grown on 2.0 pounds of zinc as zinc sulfate at two locations (pages 399 and 400, Tables 9 and 10).

When zinc EDTA was applied in field plots, the zinc concentration in the plants decreased slightly more between samplings than did the concentration in plants grown on plots receiving more zinc as zinc sulfate. The lower zinc concentration in new growth of plants with both zinc carriers is consistent with the report of Viets et al[87].

The zinc concentration in field grown plants was higher on four of the five calcareous soil types and the yield of dry beans was higher on three of these five soil types when a lower quantity of zinc as zinc EDTA than as zinc sulfate was applied to the soil. Zinc EDTA was reported by Holden and Brown[35] to be six times as effective as zinc sulfate in supplying zinc to alfalfa on calcareous soil. Hodgson et al[34] found that very little zinc was complexed in calcareous soils and proposed that the lack of zinc mobility contributed to deficiency. The protection afforded zinc in the chelated form may explain the increased availability of zinc as zinc EDTA to plants grown on the calcareous soils in these experiments.

Zinc uptake by plants on zinc EDTA treated pots always exceeded that uptake obtained on zinc sulfate treatments in the greenhouse experiments. More zinc was found in the most recent growth of the plant when zinc EDTA was applied. The pod yield by plants grown on chelated zinc treatments exceeded the yield obtained with zinc sulfate except when zinc concentration in the total above-ground plant exceeded 50 parts per million.

Hypothesis 1 is concluded to be true.

Soil applied zinc, zinc concentration and zinc content of pea bean plants, and the yield of pods and dry matter weight of plants were not always directly interrelated. At high rates of soil applied zinc EDTA in Greenhouse Experiment 4, the yield of pods decreased as zinc concentration in the above-ground plant exceeded 50 to 60 parts per million. The reduction in plant weight and pod yield could be explained either by an imbalance of cations in the plant caused by excess zinc or by the interference of EDTA with plant metabolism[96,102].

When zinc was applied at rates from 0.5 to 8.0 pounds per acre as zinc sulfate, no response in zinc uptake was observed, although yield of pods increased when 2.0 or more pounds of zinc was applied. Chesnin[21] postulated that, although more zinc was taken up by plants as the chelate, the plant was able to utilize the zinc sulfate form of zinc more effectively than the chelated form.

VI-B. Conclusion Concerning Hypothesis 2

Hypothesis 2: Uptake of zinc and yield of beans by pea bean plants

<u>are reduced more by high soil phosphorus content when zinc is applied to the soil as zinc sulfate than when applied as zinc EDTA.</u>

Data from the field and greenhouse experiments conducted in this research indicated that soil applied phosphorus had a variable effect on zinc uptake. When zinc was not applied, zinc uptake by plants remained constant or was only slightly reduced as the level of applied phosphorus increased. When zinc with either carrier and additional phosphorus were both applied, the zinc concentration in the plant was reduced but the zinc content of the plant was not markedly affected. On five of the six locations where residual available phosphorus exceeded 30 pounds per acre, the zinc concentration in plants grown on zinc EDTA treatment was higher than in plants receiving more zinc as zinc sulfate.

The quantity of dry beans harvested was reduced by soil applied phosphorus but yields were much higher when zinc and phosphorus were applied. This is consistent with the findings of Brown and Krantz[13]. On three of the six field locations where residual available phosphorus exceeded 30 pounds per acre, the yield of dry beans by plants grown on zinc EDTA treatments exceeded the yield obtained from plants which received a higher rate of zinc as zinc sulfate.

When 600 pounds of phosphorus were mixed into the soil for one greenhouse experiment, the zinc uptake by plants was higher in both the early and late tissue samples and in the most recent growth when the chelated rather than the sulfated form of zinc was applied to the soil. The pod yield was higher on all zinc EDTA treatments except when the zinc concentration in the above-ground plant exceeded 50 parts per million.

In two field experiments where 300 pounds of phosphorus per acre were applied, Lessman[38] obtained a higher zinc concentration and yield of beans from plants when 1.6 pounds of zinc as zinc EDTA were applied than when 2.0 pounds of zinc as zinc sulfate were applied (pages 399 and 400, Tables 9 and 10).

Hypothesis 2 is concluded to be true.

VI-C. Conclusion Concerning Hypothesis 3

Hypothesis 3: More soil applied zinc remains available over a longer time when zinc is applied to the soil as zinc EDTA than when applied as zinc sulfate.

A higher zinc concentration was found at both early and late times of sampling in plants grown on zinc EDTA treated pots in the greenhouse than was found in plants grown on zinc sulfate treatments. More zinc was concentrated in the most recent plant growth, the vine and the pod, when zinc EDTA was applied on both soil types.

When zinc EDTA was applied to the soil in field experiments at a lower rate of zinc than zinc sulfate, the zinc concentration in the plants was comparable and the yield of dry beans higher at seven of the 12 locations.

More zinc remained in the water soluble and exchangeable forms from applied zinc EDTA than from zinc sulfate when the soil was incubated for 90, 180, and 270 days. This calcareous soil contained a large quantity of residual available phosphorus and only 1.2 pounds of tenth normal hydrochloric acid extractable zinc.

Hypothesis 3 is concluded to be true.

VI-D. Conclusion Concerning Hypothesis 4

Hypothesis 4: Extractable soil zinc is reduced more by high soil phosphorus content when zinc is applied as zinc sulfate than when applied as zinc EDTA.

Water soluble and acid soluble forms of soil zinc from both chelated and sulfated zinc treatments increased when phosphorus was applied to the soil; the exchangeable form of zinc from zinc sulfate treatment also increased. The pH value of the tenth normal hydrochloric acid soil extracts from phosphorus treated soil tended to be more acid, but the correlation between the pH of this soil extract and the total zinc recovered by three extractants was low.

When phosphorus was applied, a greater increase in recoverable zinc was obtained from zinc sulfate treated soil than from zinc EDTA treated soil.

More water soluble and exchangeable zinc could be extracted from zinc EDTA treated soil than from zinc sulfate treated soil.

Hypothesis 4 is concluded to be not true.

Extractable zinc from soil treated with either zinc carrier is not reduced by soil applied phosphorus. Although more zinc could be extracted from zinc EDTA treated soil, proportionately more zinc could be extracted from zinc sulfate treated soil when phosphorus was applied.

VI-E. Discussion of Results

Zinc EDTA was more effective than zinc sulfate in increasing zinc concentration and bean yield of pea bean plants in the field and greenhouse, whether phosphorus had been applied to the soil or not, and on soils which were calcareous, high in residual available phosphorus, and low in tenth normal hydrochloric acid extractable zinc.

More zinc from soil applied zinc EDTA than from zinc sulfate could be extracted from incubated soil as water soluble and exchangeable zinc whether phosphorus had been applied or not.

When chelated zinc is applied to a soil, several factors may be operative which keep this form of zinc more available. The chelate may prevent percipitation as the hydroxide of zinc[7]. It may increase mobility of zinc[13],or it may maintain solubility in calcareous soils in a complexed form[34].

The response by pea bean plants to zinc applied to the Wisner clay loam soil did not correspond to the amount and forms of zinc extractable from the same soil after incubation. In the incubated samples, no water soluble or exchangeable zinc could be extracted from soil treated with comparable levels of zinc at which zinc uptake, growth, and yield response by pea beans were observed in field and greenhouse experiments. Either the conditions in the incubation experiment did not approach field and greenhouse conditions, or the plant utilized acid soluble rather than water soluble or exchangeable zinc. The closer relationship between acid soluble zinc and plant growth response in these experiments is inconsistent

with results reported by Miller et al[55] and Stewart and Berger[80]. Martens et al[51] also reported that much of the zinc extracted from the soil by hydrochloric acid was not extracted by plants.

If the plant utilizes water soluble, exchangeable, and acid soluble forms of soil zinc, the results of this soil incubation experiment indicated that no water soluble or exchangeable zinc was available to the plant and that an equivalent amount of acid soluble zinc was available from soil applied zinc sulfate or zinc chelate when 2.0 and 6.0 pounds of zinc were applied. Yet, when comparable amounts of zinc EDTA were applied to the soil, the results of two greenhouse pot experiments indicated that more zinc was in the above-ground plant and that the zinc taken up by the plant was utilized more effectively for growth than when comparable amounts of zinc sulfate were applied. Apparently, zinc from zinc EDTA was more easily taken up by the plant roots, more effectively translocated within the plant, or assimilated more readily into the metabolic processes. Since phosphorus application increased extractable zinc in soil treated with zinc sulfate more than in soil treated with zinc EDTA, the solubility of zinc in the soil must not have been the factor controlling plant growth. Also, a higher zinc concentration was observed in plants grown on treatments of both zinc sulfate and zinc EDTA than was found in plants when zinc was not applied, even when up to 696 pounds of additional phosphorus were applied to the soil. Thus, the zinc which the plants took up from zinc EDTA treated soil must have been in a form more easily assimilatable into the metabolic processes of the plant. This interpretation is consistent with that of both Boawn and Leggett[8] and Watanabe et al[99] who postulated that phosphorus did not reduce zinc solubility or interfere with zinc movement but that a high phosphorus to zinc ratio in the plant was more closely associated with zinc deficiency than was low zinc concentration. Stuckenholtz et al[81] proposed that phosphorus interferes with zinc in the physiological activity of the plant.

Improved translocation within the plant probably had some significance. Khadr and Wallace[42] attributed more significance to translocation effects in the plant than to uptake effects. Millikan and Hanger[57] were able to increase zinc mobility in the plant by injecting EDTA into leaves on which zinc had been applied. Haertl[31] proposed that synthetic chelates may create an efficacious metal balance within the plant.

If residual magnesium in the soil substitutes for zinc or increases uptake of zinc by plants, this phenomenon should have occurred on the Wisner clay loam soil which contained nearly twice as much available magnesium as the other soils. However, plants grown on this soil were more severely zinc deficient than were the plants grown on any other soil.

VI-F. Summary

The zinc uptake by pea bean plants and the yield of pods or beans were increased when zinc sulfate or zinc EDTA was applied to the soil in field and greenhouse pot experiments.

Plants grown in the field on zinc EDTA treated plots more often than not contained a comparable or higher zinc concentration and zinc content and yielded more dry beans than did plants grown on plots which received more zinc as zinc sulfate.

The zinc uptake and yield of beans by plants increased with each increment of soil applied zinc sulfate and zinc EDTA.

When additional phosphorus was applied to field plots, the zinc concentration and zinc content of plants were affected but little; however, the yield of dry beans was severely reduced.

When additional phosphorus and zinc with either carrier were applied to field plots, the zinc concentration in plants and yield of beans were reduced as the rate of phosphorus increased, but the reduction in zinc uptake and yield was less by plants grown on the zinc EDTA treated plots than by plants grown on plots receiving more zinc as zinc sulfate.

In greenhouse pot experiments, the zinc concentration and zinc content in plants and the yield of pods were always higher when zinc EDTA was applied than when zinc sulfate was applied. The pod yield by plants grown on zinc EDTA treated pots was reduced when the zinc concentration in the total above-ground plant exceeded 50 parts per million.

When zinc EDTA was applied to greenhouse pots, more zinc was in the plant at two times of sampling and more zinc was in the most recent plant growth, the pod and the vine, than in plants grown on zinc sulfate treated pots.

More zinc could be extracted by water (water soluble zinc) and neutral normal ammonium chloride (exchangeable zinc) from soil incubated 90, 180, or 270 days with zinc EDTA than from soil incubated with zinc sulfate, whether 1000 pounds of phosphorus had been applied before incubation or not.

Virtually none of the applied zinc sulfate remained water soluble or exchangeable after incubation in the soil, but part of the applied zinc was recovered from the acid soluble fraction.

More water soluble, exchangeable, or acid soluble zinc (except for exchangeable zinc from zinc EDTA) could be recovered when phosphorus and zinc with either carrier were applied to the soil and incubated. A greater increase in zinc was obtained from the zinc sulfate treated soil.

The per cent recovery of zinc by chemical extraction from incubated soil increased as the rate of applied zinc increased, but the per cent recovery of applied zinc by plants decreased as the rate of applied zinc increased.

The median pH value of the tenth normal hydrochloric acid soil extracts from incubated soil which received applied phosphorus and zinc with either carrier was 0.1 unit more acid than was the median of extracts from soils which had not received phosphorus. However, the correlation was very low between the pH value of the tenth normal hydrochloric acid soil extract and the sum of zinc recovered by water plus neutral normal ammonium chloride plus tenth normal hydrochloric acid.

As the rate of applied zinc sulfate was increased in the greenhouse pot experiments, a plant growth response was obtained without an appreciable increase in zinc concentration in the plant. A greater growth response and an increased zinc uptake by plants were observed at comparable rates of applied zinc EDTA.

The increased growth response, zinc uptake, and yield of pods and beans by pea bean plants to lower rates of zinc EDTA than zinc sulfate were attributed to the increased solubility of zinc in the chelated form in calcareous soils and to the increased translocation and greater availability of the chelated form of zinc in the plant to the metabolic system, even when plants were grown on soil high in phosphorus.

VI-G. Implications for Further Research

Additional research is indicated to identify:

1. The form of the zinc in the plant which is taken up from soil applied zinc sulfate and zinc EDTA.
2. The mechanism of translocation of zinc in the plant, especially in relation to phosphorus translocation.
3. The fate of low levels of zinc EDTA in the soil.
4. The effect of soil applied zinc sulfate and zinc EDTA on the solubility of phosphorus in the soil.
5. The effect of soil applied zinc sulfate and zinc EDTA on phosphorus uptake by plants.
6. The reason for the favorable growth response by the plant when additional zinc as zinc sulfate is applied to the soil but the zinc concentration in the plant remains constant.
7. The form of the zinc in the soil when soil applied phosphorus increases the solubility of soil applied zinc sulfate and zinc EDTA.

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