THE UNIVERSITY OF MANITOBA

THE EFFECT OF ZINC RATE AND METHOD OF PLACEMENT ON YIELD AND ZINC UTILIZATION OF BLACK BEANS (*PHASEOLUS VULGARIS* VAR. *BLACK TURTLE*) AND FABABEANS (*VICIA FABA L.* VAR. *MINOR*)

by

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ABSTRACT

Zinc nutrition of fababeans (*Vicia faba*) and black beans (*Phaseolus vulgaris*) on several Manitoba soils was studied in the environmental growth chamber. Growth of fababeans was increased by addition of 2 ppm Zn as $Na_2ZnEDTA$ on five soils which contained 1.1 ppm or less of DTPA extractable Zn. Fababeans did not respond to Zn on a soil which contained 3.05 ppm DTPA extractable Zn. Zinc uptake into fababean shoots was increased approximately three fold by Zn addition on all six soils and was correlated positively with DTPA extractable soil Zn and negatively with soil pH.

Application of $ZnSO_4$ in a point below the seed did not increase growth or Zn concentration of black beans on Lakeland silty clay loam, a gleyed carbonated rego black containing 0.35 ppm DTPA extractable Zn. Banding $ZnSO_4$ below the seed and mixing $ZnSO_4$ throughout the soil at rates up to 2 ppm Zn were equally effective in increasing dry matter yield of black beans. Banding or mixing $ZnSO_4$ at rates greater than 2 ppm Zn did not further increase dry matter yield. Zinc uptake into black bean shoots was greater when $ZnSO_4$ was mixed throughout than when banded below the seed. In another study on Lakeland silty clay loam, Zn uptake into bean shoots increased substantially with increasing rate of Zn as $ZnSO_4$ or with increasing size of the $ZnSO_4$ reaction zone. The relationship between Zn rate and Zn uptake was curvilinear. Percent utilization of added Zn decreased curvilinearly with increasing Zn concentration in the reaction zone. Zinc uptake increased linearly with reaction zone size not only when concentration of added Zn in the reaction zone was held constant, but also when concentration of added Zn in the entire soil mass was held constant.

It was hypothesized that the effects of Zn rate and reaction zone size upon Zn uptake could be explained by assuming that Zn uptake was directly proportional to the mass of roots in contact with the applied Zn times the concentration of Zn in the soil solution and that when the concentration of added Zn in the entire soil mass was held constant the concentration of Zn in the soil solution decreased curvininearly rather than linearly with increasing reaction zone size. In the same experiment the critical level of Zn in 7 week old black bean shoots was estimated at 13.5 ppm. Plant Zn concentrations were very close to the critical level when relatively small levels of Zn had been added. Therefore, dry matter yield did not increase as much as Zn uptake when Zn rate and reaction zone size were increased.

The influence of phosphorus on Zn utilization by black beans on Lakeland silty clay loam was investigated in a fourth experiment. Without added Zn, application of up to 160 ppm phosphorus did not increase black bean growth. When 8 ppm of Zn were added, shoot dry matter yield increased linearly with increasing phosphorus up to 8 ppm phosphorus and then levelled off. Plant phosphorus and Zn concentrations were inversely related. At both 0 and 8 ppm Zn, 160 ppm phosphorus interfered in Zn uptake or Zn translocation to the shoots. However, high phosphorus aggravated Zn deficiency only when no Zn was added. It was concluded that the 100 ppm phosphorus used in all other experiments did not induce or accentuate Zn deficiency. In fact, that much phosphorus was needed in order to satisfy the phosphorus nutritional requirements of the bean plants.

The effect of method of application of a commercial product, ZnMNS, upon Zn utilization by black beans on Lakeland silty clay loam was investigated in a fifth experiment. Pelleted ZnMNS when banded or mixed throughout the soil did not significantly increase dry matter yield or Zn uptake. Both yield and Zn uptake were substantially increased when the ZnMNS was finely ground and mixed throughout the soil.

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I. INTRODUCTION

Zinc is an essential micronutrient for plant growth. Widespread occurrence of zinc deficiencies especially on calcareous soils have been reported (Thorne, 1957; Navrot and Ravitovitch, 1969). Calcareous soils due to their high pH values reduce the solubility of zinc. Also several studies have shown that heavy applications of phophorous fertilizer can induce zinc deficiencies in plants. Thus greater zinc deficiency problems could be expected in calcareous soils with heavy phosphorus applications.

Due to their geological history, the majority of cultivated Manitoba soils are calcareous (Smith,1977)[1], thus the possibility of zinc deficiencies exist. Indeed earlier works in some Manitoba calcareous and non clacareous soils showed zinc deficiency in wheat and flax plants. Haluschak (1971) in a greenhouse study using some calcareous and noncalcareous Manitoba soils, found that flax yields were significantly increased by zinc applications. He also found that application of phosphorus from 25 to 400 PPM reduced the zinc concentration of wheat and flax, and indicated that zinc-phosphorus antagonism was more pronounced on the calcareous than on the noncalcareous soils. In another study by McGregor (1972) in a greenhouse it was shown that some Manitoba calcareous soils do not supply sufficient quantities of zinc for growth of crops such as flax. He also found that zinc application increased the yield of flax.

It has been noted that annual legumes particularily <u>phaseolus vulgaris</u> are susceptible to zinc deficiencies. There is no information available on the effect of zinc applications on annual legumes in Manitoba

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[1] Personal Communication, Smith, R.E., Canada Manitoba Soil Survey, Department of Soil Science , University of Manitoba.

soils.

A series of growth chamber experiments were conducted therefore, to:

(a) Study the effect of zinc application on dry matter yield and zinc uptake by faba beans, on six Manitoba soils having different $CaCO_3$ contents.

(b) Evaluate the effect of rates and methods of placement of $ZnSO_4$ on the yield, zinc, and phosphorus uptake uptake by black beans on a Manitoba calcareous soil.

(c) Study the influence of added phosphorus on dry matter yield and zinc utilization by black beans.

II. LITERATURE REVIEW

Zinc in the Soil

The zinc content of soil is generally low in comparison with the other essential plant elements. Zinc occurs in soils in primary minerals and in the clay fraction of secondary minerals. Zinc is also tenaciously adsorbed on organic matter and clays and is precipitated as hydroxides, phosphate, carbonates, and silicates under slightly acid to alkaline pH values, (Viets and Boawn, 1965). Thorne (1957) reported that most mineral soils contain between 10 to 300 ppm of total zinc. Navrot and Rarikovitch (1969) found similar Zn levels in some Israel calcareous soils.

Hibbard (1940b) and Thorne et al., (1942) found that zinc was much more concentrated near the surface than below. They concluded that zinc was enriched in the surface soil from vegetative residues. Hibbard (1940b) felt that this may be a major factor in zinc deficiency of deep rooted plants.

Krauskopf (1972) reported that zinc probably exists in soil for the most part as the simple ion adsorbed on fine grained constituents. He found, for example, that 30 to 50% of the zinc in a Tennessee soil was associated with Fe_2O_3 minerals. Kalbasi (1977) found that in eight Manitoba soils the total zinc concentration was highly correlated with total iron and aluminum.

Trieweiller and Lindsay (1969) reported that plant available soil zinc is usually poorly correlated with total zinc. They found that for corn 1.4 ppm of EDTA ammonium carbonate extractable soil zinc separated the Zn-deficient from nondeficient soils.

McGregor (1972) investigated several extractants at varying pH values and found that DPTA was the best extractant for assessing the zinc status of Manitoba soils. He reported that soils containing less than 1.3 ppm DPTA extractable zinc could be suspected of being deficient in zinc for wheat and flax, while soils containing less than 0.8 ppm DPTA extractable were moderately zinc deficient. Brown et al., (1971) reported that for corn the critical level for DPTA extractable soil zinc was 0.5 ppm.

Zinc in the Plant

Zinc plays an important role in auxin formation and in other enzyme systems (Thorne 1957). Presently it is recognized as an essential component in several dehydrogenases, proteinase and peptidases (Lindsay 1972).

Concentration of zinc in the plant varies with species and stage of growth. Zinc concentration is generally highest in very young seedlings and decreases with age (Carrol and Loneragon, 1968). William and Moore (1952) in a greenhouse experiment with 13 Australian soils, reported that the zinc content of whole oat plants decreased from initially high values until flowering. Similar results were obtained in red Mexican beans (*Phaseolus vulgaris*) by Viets et al., (1954b).

Lack of zinc results in distinctive symptoms, most of which are associated with a retardation in growth and decreased chlorophyll levels. Viet et al., (1954a) recorded zinc deficiency symptoms in 26 different crops including the common bean (*Phaseolus vulgaris*). He found that zinc deficient plants grew poorly, exhibited interveinal leaf chlorosis and had necrotic lower leaves.

The recorded plant zinc critical levels vary somewhat. Boawn and Viets (1952) found that the leaves of zinc deficient alfalfa plants in Washington contained 8 ppm zinc. They also found that in the plant zinc concentration range of 15 to 22 ppm there were both normal and deficient plants. Nelson (1956) reported that the zinc concentration in shoots of soybeans grown in a zinc deficient soil was 15 ppm, whereas the zinc concentration in plants grown on a normal soil was 30 ppm. Judy et al., (1964) indicated that if the zinc concentration in pea beans (*Phaseolus vulgaris*) was greater than 25 ppm, there was seldom a response to added zinc. If the bean plant contained 20 to 25 ppm zinc, occasionally a response to zinc occurred. Haluschak (1971) in some Manitoba soils found that seven week old flax plants which contained less than 21 ppm zinc responded to added zinc. Navrot and Ravikovitch (1967) reported that corn plants containing less than 17 ppm zinc usually responded to zinc fertilization. Melton (1968) indicated that the highest yields of *Phaseolus vulgaris* in Michigan were usually obtained when plant zinc concentrations were between 25 and 34 ppm. McGregor (1972) in some Manitoba soils found that eight week old flax containing about 13 ppm zinc could be suspected of being zinc deficient, whereas flax plants containing 9 ppm zinc were moderately zinc deficient.

Zinc toxicity decreased bean yields when plant zinc concentrations were greater than 50 ppm. Boawn and Rasmussen (1971) reported that shoot zinc concentrations associated with a 20% yield decrease ranged from 240 ppm in field beans (*Phaseolus vulgaris*) to 740 ppm for sugar beets.

Zinc deficiency may cause delayed maturity. Boawn et al., (1969) found that the number of days from planting to maturity in field beans was related to zinc concentration. The optimum maturity period was associated with zinc concentrations above 20 ppm. Below 20 ppm the number of days required to reach maturity increased with decreasing zinc concentration.

Factors Affecting the Availability of Soil Zinc to Plants

Factors associated with or contributing to zinc deficiency in plants include pH, organic matter content, calcium carbonate content, soil temperature, soil texture, and available phosphorus content.

pH

An inverse relationship between soil pH and zinc availability has been known for some time (Lott, 1938; Wear, 1956; Judy, 1967). The effect of pH probably results from variation in solubility of the pH dependent forms of zinc occurring in the soil. Wear (1956) found that forms of the zinc which are soluble at lower pH values may be converted to less soluble and less available forms at higher pH values. He also reported that 90% of variation in zinc uptake by sorghum from fertilizer zinc could be attributed to variation in soil pH. Nelson *et al.*, (1959) reported that the high incidence of zinc deficiency in western United States likely resulted from the large number of alkaline soils in that region. Lindsay (1972) stated that the solubility of soil Zn^{++} is highly pH dependent, decreasing 100 fold for each unit increase in pH. Mortvedt and Giordano (1969) found that zinc uptake by corn was greater when $ZnSO_4$ was applied with acid forming nitrogen fertilizers.

This inverse relationship of soil pH and zinc availability can be partially attributed to direct adsorption of zinc onto silicate clays or onto hydrous oxides which may or may not be associated with silicate clays. For example, Kalbasi (1977) postulated that the low availability of soil zinc at high pH may result from the association of zinc with iron and aluminum oxides. On the other hand, Sharpless et al., (1969) felt that the increase in zinc retention with increasing pH resulted from precipitation of zinc by hydroxides and zincates.

Organic Matter

Organic matter is one of the most active fractions of the soil in the immobilization of zinc. Baughman (1956) found that the zinc fixing power of the soil was related to organic matter content. Udo et al., (1970) reported that the organic matter and clay in ten Arizona calcareous soils were primarily responsible for the retention of zinc.

Most work indicates some type of chelation of zinc with organic fraction of soil. Himes and Barber (1957) concluded that organic matter in soil reacted with divalent metal ions (Zn^{++}) in a manner similar to a chelation reaction. They found that removal of organic matter by oxidation with hydrogen peroxide destroyed the availability of soil to chelate zinc. On the other hand, organic matter-zinc complex after being decomposed released zinc. Several studies have shown a high correlation between organic matter and chemically extractable or available zinc (Follet and Lindsay, 1970). Nevertheless, application of organic waste is effective both in correcting zinc deficiencies and in causing deficiencies (Lindsay, 1972).

Calcium Carbonate Content

Calcareous soils are more likely to be deficient in zinc than soils containing no calcium carbonate (Thorne, 1957; Navrot and Ravitovitch, 1969). Calcareous soils generally fall in the pH range of

7.4 or higher. Since the solubility of soil Zn^{++} decreases with pH (Lindsay, 1972) a greater incidence of zinc deficiency would be expected in calcareous soils.

On the other hand, adsorption and precipitation of zinc by carbonates may be partially responsible for the lower zinc availability in calcareous soils. Udo et al., (1970) found a high correlation between the zinc adsorption maxima and the carbonate equivalent suggesting that soil carbonates adsorbed the added Zn^{++}. Navrot and Ravikovitch (1969) found an inverse relationship between the uptake of native soil zinc by tomato plants and soil calcium carbonate content. They also reported that uptake of fertilizer zinc decreased as the particle size of soil calcium carbonate decreased. Ravikovitch et al., (1968) in a greenhouse study with six crops found that plant zinc concentrations tended to decrease as soil calcium carbonate levels increased. Pauli et al., (1968) found in nutrient solution studies that adding calcium carbonate decreased dry matter yield and zinc concentration in navy beans (*Phaseolus vulgaris*). They also reported that calcium carbonate decreased the translocation of phosphorus and zinc from roots to leaves and suggested that excess calcium carbonate influenced phorphorus-zinc relationships within the plant as well as the solubilities of zinc and phosphorus compounds in the growing medium.

Soil Temperature

Zinc deficiencies are usually most prevalent in cold, wet soil during the early part of the growing season (Millikan, 1953, Pumphry and Koehler, 1959). Burleson et al., (1961) concluded that phosphorus induced zinc deficiency is probably enhanced by cold, wet soils, due to restricted root development. Ellis et al., (1964) in a greenhouse experiment with a Michigan calcareous soil found that yield, zinc concentration in plant tissue and total zinc uptake by corn were decreased when soil temperature was decreased. They found a decrease in soil temperature from 23.3°C to 12°C decreased zinc total uptake from 310 to 73 μgm per pot. Wallace et al., (1969) in a greenhouse experiment with controlled root temperature of 14, 20 and 26°C reported that plants responded to zinc only at lowest soil temperature, and that plant zinc concentration tended to increase with soil temperature.

Some workers reported that low soil temperature also resulted in lower zinc solubility. Baurer and Lindsay (1965) concluded that the decreased solubility of soil zinc, rather than a plant physiological effect was the principle cause of increased zinc deficiency in cool weather.

Soil Texture

The clay fraction of soils plays an important role in the availability of soil zinc. Low availability of zinc is believed to be due to adsorption and precipitation of zinc by clay sized particles. Separation of zinc reaction into those of precipitation or adsorption is difficult (Lindsay, 1972). Thorne (1957) reported that the strong adsorption of zinc on soil minerals, often within the clay crystal lattice, offers the best explanation for its low solubility with frequent low availability. Demumbrun and Jackson (1956a) found that montmorillonite was capable of adsorbing zinc beyond its cation exchange capacity particularly at near neutral or alkaline pH levels. Navrot and Ravitovitch (1969) noticed a significant correlation between total zinc and the percentage of clay in some Israel calcareous soils. They concluded that the soil clay fraction was the main carrier of total zinc. They also reported that in calcareous soils in which the carbonate is largely in the clay size fraction zinc occurs as Smithsonite ($ZnCO_3$) and Hydrozincite (2 $ZnCO_3$, 3 $Zn(OH)_2$). These compounds may occur separately or as coatings on the clay sized carbonate particles. Udo et al., (1970) found that the clay size fraction and organic matter were the two soil components primarily responsible for retention of native zinc in some Arizona calcareous soils. Krauskopf (1972) reported that zinc probably exists in soils for the most part as a simple ion adsorbed on fine-grained constituents. He reported that the analysis of a Tennessee soil showed that 30 to 60% of the zinc present was associated with Fe_2O_3 minerals and 20 to 45% with silicate clay minerals, both of which are clay sized. Kalbasi (1977) found that the native zinc content in some Manitoba soils was highly correlated with the concentrations of iron, aluminum and clay sized particles. He stated that the significant correlation between zinc concentration and clay content may have resulted from iron and aluminum oxide coatings on silicate clays and from a large proportion of free iron and aluminum oxides, being clay sized.

Available Phosphorus Content

The effect of phosphorus on zinc availability has received considerable attention in the literature. Usually the interaction is designated as a phosphorus-induced zinc deficiency. Olsen (1972) reported that this disorder was commonly associated with high levels of available phosphorus in soil or with application of high levels of phosphorus, but the mechanism of the interaction was unknown. Thorne (1957) reported that the addition of 896 kg/ha of P_2O_5 decreased zinc concentration in common bean plants 20 to 30% and in corn, 30 to 50%. Judy et al., (1964) found that the application of 780 kg/ha of available phosphorus decreased pea bean yields from 31 to 10 bushels at one location and from 25 to 13 bushels at another location, and often decreased plant zinc uptake. Melton et al., (1970) found that heavy application of phosphorus (500 pp2m) as monoamonium phosphate usually induced zinc deficiency in pea beans on soils containing free calcium carbonate. Haluschak (1971) found that high levels of phosphorus in nutrient solutions decreased zinc uptake by wheat and flax. Lessman (1967) concluded that larger applications of phosphorus to Michigan soils had a marked detrimental effect on zinc utilization by navy beans.

Many workers have shown that reactions external to the plant do not cause the interrelation between phosphorus and zinc. Burleson et al., (1961) reported that applied phosphorus induced zinc deficiency and lowered corn yields. The authors suggested the possibility of phosphorus-zinc antagonism on the root surface. Stückenholtz et al., (1966) concluded that the depressive action of phosphorus on zinc uptake in corn appeared to be largely physiological in nature occurring at root surface and/or in root cells. They found that the translocation of zinc from roots to tops was inhibited by elevated plant phosphorus concentration. The similar results were obtained by Sharma et al., (1968) in corn, wheat and tomatoes.

Other investigators felt that phosphorus interacted with the utilization of zinc within the plant. Boawn and Brown (1968) found phosphorus-induced zinc deficiency in beans and tomatoes. They hypothesized that normal plant metabolism was dependent upon a physiological balance between phosphorus and zinc. Boawn and Leggett (1964) observed a phosphorus-induced growth disorder in potatoes that could be eliminated by an increased supply of zinc. Neither the disorder nor its correction was well correlated with changes in concentration of zinc in stem or leaf tissue. Instead, metabolic upset correlated better with phosphorus/zinc concentration ratios.

Boawn et al., (1954) in contrast to the above literature, reported that phosphorus application did not influence the availability of zinc or its utilization by bean plants. Bingham (1963) found that increased phosphorus application increased zinc concentrations in the roots and leaves of common beans.

Effect of Method and Rate of Application of Zinc Fertilizers on Yield and Zinc Concentration of Plants

Zinc fertilizers can be divided into: (a) inorganic sources and (b) organic sources.

Inorganic Sources :

	Formula	Approximate %Zn
Zinc sulfate monohydrated	$ZnSO_4 \cdot H_2O$	35
Zinc sulfate heptahydrated	$ZnSO_4 \cdot 7H_2O$	23
Basic zinc sulfate	$ZnSO_4 \cdot 4Zn(OH)_2$	55
Zinc carbonate	$ZnCO_3$	52
Zinc oxide	ZnO	78
Zinc sulfide	ZnS	67
Zinc phosphate	$Zn_3(PO_4)_2$	51

Zinc sulfate is a soluble salt. Zinc oxide, zinc sulfide and zinc carbonate are sparingly soluble, whereas zinc phosphate is insoluble.

Zinc sulfate is the most effective inorganic source. Judy et al., (1964) in studies with pea beans, using zinc sulfate, zinc oxide, zinc ammonium sulfate, zinc slag and slag zinc sulfate found that zinc sulfate was the most effective in increasing plant zinc concentration over the entire growing season. Brenkorhoff et al., (1966) reported zinc sulfate was usually more effective in increasing early growth and zinc uptake of beans and corn than other carriers. Some workers however, found that other inorganic zinc compounds were often as effective as zinc sulfate. Boawn et al., (1957) using a noncalcareous soil having a pH = 7.2, found that zinc uptake by corn and beans from zinc oxide zinc ortho phosphate and zinc carbonate was comparable and about the same magnititude as from zinc sulfate when all zinc material was mixed with soil before planting. Shukla (1965) concluded that zinc oxide and zinc sulfate were equally effective in correcting zinc deficiency in corn when they were mixed with the soil. Shaw et al., (1954) reported very little difference in utilization of zinc by oats, corn and orange trees from freshly applied zinc sulfate and zinc carbonate when banded in soil. Giordano and Mortvedt (1966) found that in corn both zinc oxide and zinc sulfate when mixed with soil having pH of 7.3 were much more efficient zinc sources than zinc sulfide applied in the same manner.

Organic Sources:

1 -	Disodium zinc (ethylene diamine tetra acetate)	$Na_2ZnEDTA$
2 -	Sodium zinc (hydroxy ethylene diamine tetra acetate)	NaZnHEDTA
3 -	Sodium zinc nitrilotriacetate	NaZnNTA
4 -	Zinc -(ethylene diamine di-anhydroxyphenyl acetate)	Zn-EDDHA
5 -	Zinc -(hydroxy ethylene diamine triacetate)	Zn-HEDTA

Disodium zinc EDTA has been the most frequently used organic zinc source. Zinc chelates in general are more effective than inorganic sources primarily because of the greater mobility of the chelate in soil. Jurniak and Thorne (1955) and Brown (1965) found that most of the zinc applied in inorganic form to the surface of soil remained where it was placed. Boawn et al. (1957) reported that when zinc at the rate of 2 ppm was mixed with an alkaline silt loam in pots, bean plants took up 3.5 times more zinc from zinc disodium EDTA than zinc sulfate, heptahydrated. Judy et al., 1964, reported that zinc chelates were usually five times more effective than inorganic materials in increasing the zinc uptake and yield in corn, pea beans and sugar beets. Anderson (1964) concluded that clelated zinc sources were generally much more effective at low rates than zinc sulfate fertilizers for corn. Similar results were obtained by Boawn (1973) for common beans. He found that chelates moved into soil sufficiently to be utilized by the plants, whereas inorganic salts were immobilized near the surface and were positionally unavailable.

Effect of Application Method

Type of zinc carrier must be considered when comparing various methods of application. Mobility of soil applied zinc compounds has an implication on the placement of zinc fertilizers. Inorganic zinc fertilizers are immobile in the soil. If they are banded or placed as a point source, a smaller portion of roots comes into contact with the fertilizer reaction zone than if they are mixed well throughout the soil. In addition, inorganic zinc sources are usually more effective when finely ground because this increased contact between the roots and the fertilizers. Morderdt and Giordano (1969) found that forage yield and zinc uptake by corn were highest when finely ground zinc sulfate was mixed with the soil, compared to when zinc sulfate was granulated with macronutrient fertilizers or when zinc oxide was mixed with the soil. Similar results were obtained by Terman and Mortvedt (1965). Brown and Krantz (1966) reported that zinc inorganic fertilizer needs sufficient contact with roots in order to be effective. Brinkerhoff et al., (1966) stated that zinc uptake and yield of pea beans were higher when zinc sulfate was mechanically mixed than when incorporated into macronutrient fertilizer granules. Boawn (1973) found that zinc sulfate banded before planting was less available to common beans than when broadcast and plowed down. Similar observations were made by Shaw et al. (1954) for corn and citrus seedlings.

Application of inorganic zinc sources with acid forming nitrogen fertilizers increases the availability of zinc to plants due to lowering of pH. Boawn et al., (1960) studied the influence of diamonium sulfate, ammonium nitrate and calcium nitrate upon uptake of native soil zinc by sorghum and potatoes from a noncalcareous soil having a pH of 7. Zinc uptake and concentration were greatest when the nitrogen carrier was diammonium sulfate, the most acid forming of the carriers, and least when it was calcium nitrate, an alkaline fertilizer. Giordano et al., (1966) reported that dry matter yields and uptake of zinc by corn grown in greenhouse pots were higher with diammonium sulfate than with urea.

Since zinc chelates are quite mobile in the soil they are equally effective whether mixed with the soil or banded. Brown and Krantz (1966) found that placing disodium zinc EDTA in a point was equivalent to mixing it with the soil for the correction of zinc deficiency in corn. Brown (1965) also found that stable organic sources such as disodium zinc EDTA work equally well whether banded or mixed with the soil.

Rate of Application

The amount of fertilizer zinc required to correct a zinc deficiency in plants depends upon severity of the deficiency, type of crop, type of zinc fertilizer, and method of application. Pumphery et al., (1963) reported that zinc sulfate broadcast and plowed down was as effective in increasing total dry matter and grain yields of corn at 5.5 kg zinc per ha as at 11, 22 and 44 kg zinc/ha, although the higher zinc rates increased zinc uptake more than the lower rates. Brown and Lebaron (1970) recommended the application of 5.5 kg/ha of actual zinc in inorganic form each year in which common beans are grown, providing the inorganic zinc source is mixed throughout the soil before planting. When beans are grown continuously they recommended 11 kg zinc/ha every third year. They suggested that in instances in which zinc deficiency is very severe, 11 kg zinc/ha per year may be necessary.

The amounts of zinc recommended to correct the zinc deficiency varies with the zinc carriers. Vinande et al., (1968) reported that 0.66 kg zinc/ha as chelate and 3.3 kg zinc/ha from zinc sulfate were equally effective for correcting the zinc deficiency in pea beans. Wallace and Romney (1970) concluded that 0.89 kg/ha of zinc as zinc EDTA was as effective in correcting the zinc deficiency in corn as 8.9 kg/ha of zinc as zinc sulfate. It was not clear whether zinc was mixed in solution with the soil or added to the soil surface in dry form. Boawn, (1973) reported that disodium zinc EDTA broadcast and plowed down before planting of common beans was 2 to 2.5 times as effective as zinc sulfate applied in the same manner. He also reported that the minimum rate of chelate source that resulted in an adequate level of zinc in bean plants, varied from 0.9 to 1.7 kg/ha.

III. ANALYTICAL METHODS AND MATERIALS

Special treatments used for individual studies reported in this manuscript are described with the results obtained in the appropriate subsections. The analytical procedures employed in characterizing the soil and the common experimental methods for all growth chamber experiments are outlined below.

(A) Soil Analysis

(1) Soil pH

Duplicate 10 gm soil samples were suspended in 20 ml of 0.01 M $CaCl_2$ and equilibrated for 30 minutes by shaking. pH was measured in the supernatant using a standard combination pH electrode.

(2) Organic Matter

Organic matter was determined as described by Walkley and Black (1943). Excess potassium dichromate was used to oxidize the organic matter and the untreated dichromate back titrated with ferrous sulfate using barium diphenylamine sulfate as an indicator.

(3) Inorganic Carbonate Content

Duplicate one gram soil samples were digested in a solution of 1:9 v/v HCl and H_2O for 10 minutes. The CO_2 evolved was sucked through a drying and adsorption train, then the CO_2 adsorbed by ascarite in a Nesbitt tube. The weight of CO_2 adsorbed on the ascarite was determined and inorganic carbonate content of the soil calculated.

(4) Determination of Water Content at Field Capacity

Air-dried soil was ground and put into a 400 ml beaker. Water was added to each sample until the wetting front had moved half-way down the beaker. The beakers were covered with plastic and equilibriated for 96 hours after which samples were taken from the wetted portion. Soil samples were weighed, the losses in weight were measured and the moisture content of soil calculated.

(5) Determination of DTPA Extractable Zinc in Soil

Zinc was extracted from soil using a solution of 0.005 M DTPA (Diethylenetriamine pentaacetic acid), 0.01 M in $CaCl_2$ and 0.1 M in TEA (Triethanolamine), according to the method described by Lindsay and Norvell (1969). The pH of the extracting solution was adjusted to 7.3 with diluted HCl. Twelve and one half grams of soil were shaken with 25 ml of the solution for two hours.

The suspensions were filtered and zinc concentration in the extractants was determined using a Perkin Elmer Model 303 atomic adsorption spectrophotometer.

(B) Plant Analyses

(1) Zinc Determination

Oven-dried plant samples were finely ground with a small steel mill. Duplicate one gram samples were placed into micro-Kjeldahl flask. Five ml of concentrated HNO_3 were added to each sample. After one hour predigestion two ml of 70% $HClO_4$ were added to each sample. Then the plant material was digested by boiling the mixture until the solution completely cleared. The digest was diluted to 25 ml with dionized water. The zinc concentrations were measured using a Perkin Elmer Model 303 atomic absorption spectrophotometer.

(2) Phosphorus Determination

A suitable aliquot from the digest prepared for the zinc determination was placed into a 50 ml volumetric flask. Total phosphorus concentration of the digest was determined using ammonium molybdate and ascorbic acid method (Murphy and Riley 1962). Total phosphorus content of the plant material was calculated.

(3) Percent Nitrogen

Percent nitrogen was determined by the modified Kjeldahl-Gunning method as described by Jackson (1958). The digestion accelerator used was a Kalpak [1] no. 2. The accelerator contained 0.3 grams of $CuSO_4$ and 10 grams of K_2SO_4.

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[1] Obtained from Canadian Lab Supplier Ltd.

COMMON EXPERIMENTAL METHODS FOR THE GROWTH CHAMBER EXPERIMENTS

The project involved a preliminary (first) experiment with fababean (*Vicia faba*) followed by the four other experiments with black beans (*Phaseolus vulgaris*). The preliminary experiment was conducted with six soil types from which one soil type was selected for the other experiments. A description of the soils used and experimental procedures employed are outlined below.

Six surface soils were selected on the basis of different calcium carbonate contents. The soils, varying in texture, pH, DTPA extractable zinc and organic matter content (Table 1), were collected from various locations in Manitoba.

The soil samples were air-dried, crushed by hand, and thoroughly mixed. Five kilograms soil were used for each pot. Prior to seeding each 5 kg of soil was sprayed separately with a solution of K_2SO_4 to provide to 200 ppm of K and 80 ppm of S on an air-dried soil basis. Then for each experiment every 5 kg of soil received the appropriate zinc and then phosphorus treatments. After the fertilizer treatments, plastic pots of 19 cm high and 20 cm top diameter were uniformly filled with 5 kg of soil.

All the experiments were completely randomized designs with three replicates. Two and one way of analysis of variance were used to analyze the data.

Bean seeds were placed on a wet paper towel for 2 days to germinate. Only well germinated seeds were selected for planting. Four seeds were planted 2.5 cm below the soil surface in each pot and after 2 weeks were thinned to two plants. In all experiments seeds were inoculated

Table 1. Soil Chemical and Physical Characteristics.

Soil Associate	Subgroup	Textural Class	DPTA Extractable Zn (ppm)	Organic Matter Content (%)	pH	$CaCO_3$ Equilivent (%)	Moisture Content at F.C. (%)
Morden	Black	C.L.	3.05	8.2	7.25	1.6	29.0
Winkler	Orthic Black	V.F.siL	1.10	4.9	7.42	0.0	32.0
Tarno	Rego Humic Gleysol	Si.L.	1.05	10.2	7.75	10.0	38.0
Lakeland (A)	Gleyed Carbonated Rego Black	Si.C.L.	0.80	11.2	7.60	11.5	29.5
Portage	Gleyed Rego Black	Si.C.l.	0.75	5.5	7.65	1.30	28.5
Lakeland (B)	Gleyed Carbonated Rego Black	Si.C.L.	0.35	4.6	7.55	23.3	35.5

with a proper nitrogen inoculum[1] before planting. In order to exclude any possible zinc contamination, the pots were washed with 0.1 M EDTA (ethylene diaminetetra acetic acid), and then with a 10% HNO_3 solution and washed with deionized water.

Growth Chamber Conditions

The growth chamber temperature was maintained at 20C for a light period of 15 hours and at 15C for a 9 hour dark period. The relative humidity was 40% and 80% for the light and dark periods respectively. The soil was watered to field capacity with deionized water daily. There was no evidence of wilting. The position of the pots within the growth chamber was changed periodically.

In all experiments the aerial portion of the plants was harvested at 45 to 51 days, washed with 50 ml concentrated HCl in 4 liters of deionized water, dried at 85C for 24 hours and weighed. The roots of the last two experiments were collected as well as possible. The majority of the roots were removed from the soil by cracking and shaking the soil of each pot. The resulting roots were washed several times with deionized water to remove the soil, dried at 85°C for 24 hours and weighed.

[1]Supplier: The Nitrogin Co., Milwaukee, Wisconsin 53209, USA.

IV. RESULTS AND DISCUSSION

Experiment 1

The Effect of Added Zinc Upon Dry Matter Yield and Zinc Utilization by Fababeans on Six Manitoba Soils.

Zinc deficiency more often occurs on calcareous than on noncalcareous soils (Thorne, 1957).

The majority of Manitoba's cultivated soils are calcareous (Smith, 1977). The first experiment was conducted to study the effect of adding Zn to six Manitoba soils, all of which had high pH values and whose calcium carbonate equivalents varied from 0 to 23% (Table 1). Zinc was added as ZnEDTA to each soil at rates of 0 and 2 ppm (Table 2). A water solution of ZnEDTA was sprayed on each 5000 g soil sample separately and mixed thoroughly. After the zinc was added, phosphorus in the form of $Ca(H_2PO_4)_2$, at the rate of 100 ppm was applied to the soil in a similar fashion as zinc before planting. The results of this experiment are given in Tables 2 to 8.

Addition of 2 ppm zinc increased the dry matter yield of fababeans for all except the Morden soil. However, these increases were statistically significant using Tukey's test only for the Lakeland A and statistically significant using the F test (5% level) for the Tarno, Lakeland A and B and Portage soils. These soils all contained less than 1.1 ppm DPTA extractable Zn (Table 1 & 2). These data therefore, indicate that 1.1 ppm DPTA-extractable soil Zn would be the critical level beyond which added Zn would not increase the yield for fababeans under the conditions of this experiment. The results are in good agreement with the findings of McGregor (1972) who reported that wheat and flax responded to Zn fertilizer when DPTA extractable zinc levels in some Manitoba soils were less than 1.3 ppm. Dry matter yield was

Table 2. Effect of Rate of Zn as ZnEDTA on Dry Matter Yield of Above Ground Portion of Fababeans (comparison among 6 means within each rate)[1]

Zinc \ Soil Type	Morden	Winkler	Tarno	Lakeland A	Portage	Lakeland B
(ppm)			(g/pot)			
0	20.67_{a}	14.26_{b}	11.86_{b}	12.96_{b}	11.47_{b}	9.33_{b}
2	20.19_{a}	16.23_{ab}	15.01_{ab}	19.33_{a}	15.62_{ab}	12.79_{b}

Table 3. Effect of Rate of Zn as ZnEDTA on Dry Matter Yield of Above Ground Portion of Fababeans (comparison between the 2 means within each soil)[1]

Zinc \ Soil Type	Morden	Winkler	Tarno	Lakeland A	Portage	Lakeland B
(ppm)			(g/pot)			
0	20.67_{a}	14.26_{a}	11.86_{a}	12.96_{a}	11.47_{a}	9.23_{a}
2	20.19_{a}	16.23_{a}	15.01_{a}	19.33_{b}	15.62_{a}	12.79_{a}

[1] Tukey's test at 5% level used. Treatment means are not significantly different when followed by the same letter.

positively correlated with DPTA extractable soil Zn for both Zn treated and untreated soils (Tables 6 and 7). This indicates that either not enough zinc was added or there were other limiting factors which were related to DPTA extractable Zn. Dry matter yield was negatively correlated to soil pH when no Zn was added (Table 7). This possibly was due to the effect of pH on Zn availability to plants. When zinc was added dry matter yield was not significantly correlated with pH. Among soils which did not receive Zn, Morden had the highest dry matter yield, most likely because it had the highest DPTA extractable Zn level (Table 1). Dry matter yields on soil receiving Zn were not equal, indicating that there were other limiting factors, or that not enough Zn was added.

Addition of 2 ppm Zn increased significantly the Zn concentration of plants grown on all six soils (Table 5). This increase was not always associated with an increase in dry matter yield. Zinc concentration in plants was positively correlated to soil DPTA extractable Zn and negatively correlated to soil pH after addition of 2 ppm Zn (Table 6). These correlations, however, were not significant on soils where no zinc was added (Table 7). When Zn was added, Zn concentrations in plants grown on Morden, Winkler and Lakeland A soil were significantly higher than those plants grown on other soils (Table 4).

However, concentration of Zn in the plant could not be used to separate out Zn deficient plants or to determine a plant Zn critical level, since there was not a clear cut beyond which no response occurred. Therefore it would appear that soil analysis was a better indication of Zn deficiency in plants.

Application of 2 ppm of zinc increased the total zinc uptake approximately 3 fold in all soils (Table 9). Those increases were

Table 4. Effect of Rate of Zn as ZnEDTA on Zn Concentration in Above Ground Portion of Fababeans (comparison among 6 means within each rate)[1]

Soil Type / Zinc (ppm)	Morden	Winkler	Tarno	Lakeland A	Portage	Lakeland B
	(ppm)					
0	11.9 a	12.25 a	7.68 a	17.9 a	8.17 a	8.8 a
2	39.9 a	34.8 a	20.8 b	33.3 a	18.8 b	23.0 b

Table 5. Effect of Rate of Zn as ZnEDTA on Zn Concentration of Above Ground Portion of Fababeans (comparison between the 2 means within each soil)[1]

Soil Type / Zinc (ppm)	Morden	Winkler	Tarno	Lakeland A	Portage	Lakeland B
	(ppm)					
0	11.9 a	12.2 a	7.6 a	17.9 a	8.1 a	8.8 a
2	39.92 b	34.8 b	20.8 b	33.3 b	18.8 a	23.0 b

[1] Tukey's test at 5% level used. Treatment means are not significantly different when followed by the same letter.

Table 6. Simple Correlation Among Various Parameters in Experiment 1 for Those Treatments Receiving Zn.

	D.M.	Zn Conc.	Total Zn Uptake	DTPA Extractable Zn	$CaCO_3$ Equivalent	pH
D.M.		0.79**	0.91**	0.72*	-0.53	-0.53
Zn Conc.			0.97**	0.70*	-0.37	-0.84**
Total Zn Uptake				0.76*	-0.43	-0.79*
DTPA Extractable Zn					-0.53	-0.75*
$CaCO_3$ Equivalent						0.36
pH						

Table 7. Simple Correlation Among Various Parameters in Experiment 1 for Those Treatments Receiving No Zn.

	D.M.	Zn Conc.	Total Zn Uptake	DTPA Extractable Zn	$CaCO_3$ Equivalent	pH
D.M.		0.67*	0.58	0.94**	-0.41	-0.75*
Zn Conc.			0.83**	0.13	-0.07	-0.29
Total Zn Uptake				0.66*	-0.39	-0.68*
DTPA Extractable Zn					-0.53	-0.75*
$CaCO_3$ Equivalent						0.36
pH						

* - R value significant at 5% level.
** - R value significant at 1% level.

Table 8. Effect of Rate of Zn as ZnEDTA on Total Zn Uptake of Above Ground Portion of Fababeans (comparison among 6 means within each rate)[1]

Zinc \ Soil Type	Morden	Winkler	Tarno	Lakeland A	Portage	Lakeland B
(ppm)	(μg)					
0	246 a	176 a	91.2 a	233 a	92.8 a	83.5 a
2	800 a	567 b	310 c	642 ba	300 c	294 c

Table 9. Effect of Rate of Zn as ZnEDTA on Total Zn Uptake of Above Ground Portion of Fababeans (comparison between the 2 means within each soil)[1]

Zinc \ Soil Type	Morden	Winkler	Tarno	Lakeland A	Portage	Lakeland B
(ppm)	(μg)					
0	246 a	176 a	91.2 a	233 a	92.8 a	83.3 a
2	800 b	567 b	310 b	642 b	300 b	294 a

[1] Tukey's test at 5% level used. Treatment means followed by the same letter are not statistically significant.

statistically significant except in Lakeland B soil. There were positive correlations between total zinc uptake by the plant and DPTA extractable Zn for both zinc treated and untreated soils (Tables 6 and 7). Total zinc uptake was negatively correlated with soil pH both for zinc treated and untreated soil (Tables 6 and 7). These data indicate that DPTA extractable Zn is a good indication of zinc availability to fababean plants for some Manitoba soils. They also indicate crops McGregor used which effect the native zinc availability had the same effect on added zinc. McGregor (1972) found that DPTA at pH = 8 was the best extractant to use in assessing the zinc status of Manitoba soils.

Experiment 2

The Effect of Method and Rate of Zinc Application on Yield and Zinc Utilization by Black Beans in Manitoba Calcareous Soils.

The response of black beans to supplemental zinc was investigated at the same time as the zinc nutrition of fababeans was studied. Black beans responded much more to added zinc (2 ppm zinc as ZnEDTA) on Lakeland soil than fababeans. The increase in dry matter yield was 128% for black beans compared to 68% for fababeans. Because of this large increase response in yield, black beans were selected as the test crop in subsequent growth chamber experiments.

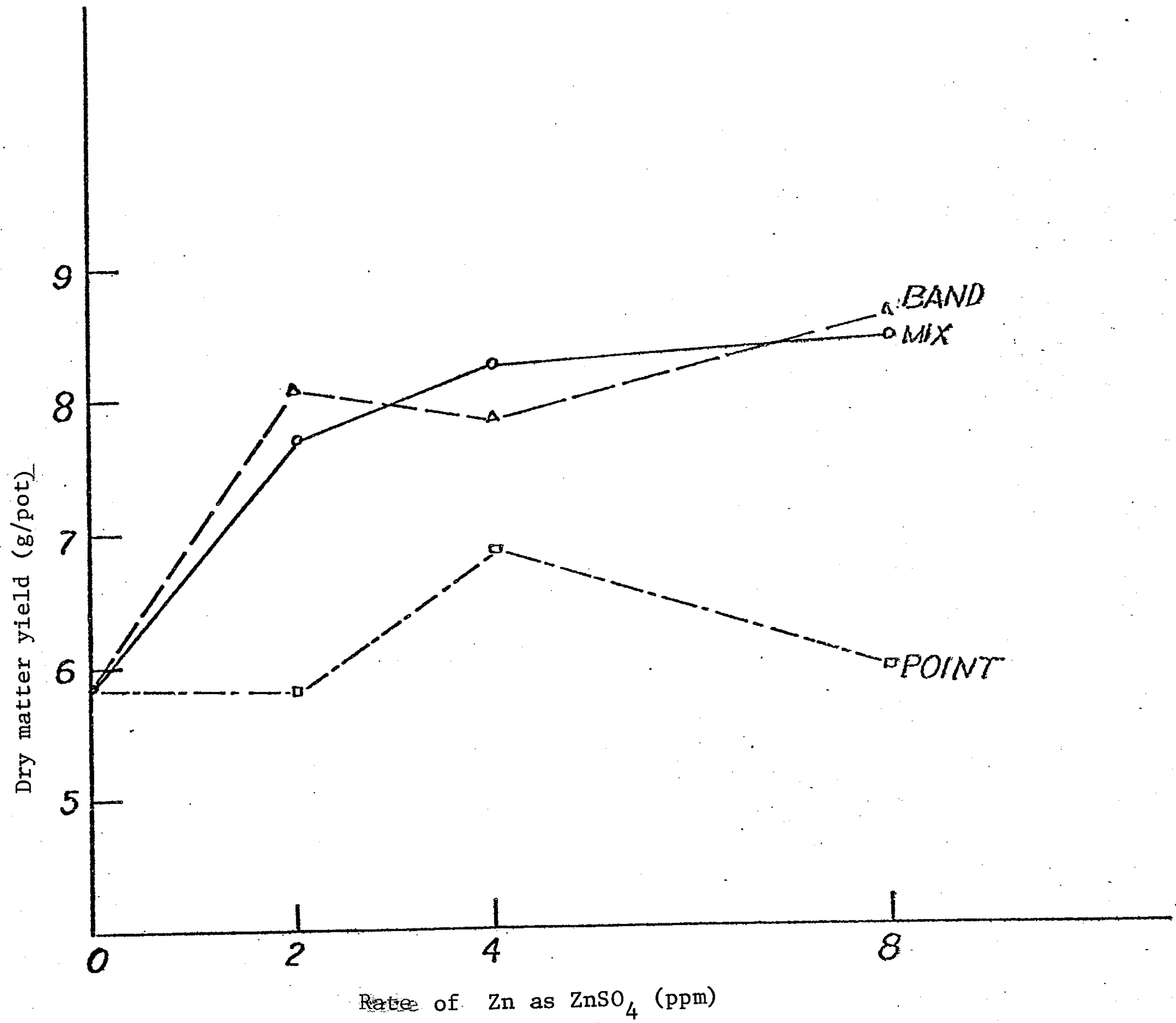
Many investigators have reported that method of application of $ZnSO_4$ to soil is an important factor contributing to variation in the uptake of zinc by plants (Shaw et al. (1954), Mordvedt and Giordano (1969) and Boawn (1973). The second experiment was therefore conducted to study the effects of method and rate of $ZnSO_4$ application to black beans.

The placement treatments consisted of (1) mixing throughout, in which $ZnSO_4$ was thoroughly mixed with the 5000 g of soil for each pot; (2) banding in which 500 g (10% of soil weight) was mixed with $ZnSO_4$ and banded 1.5 cm below the seed level or 4 cm below the soil surface; (3) and point application in which $ZnSO_4$ was placed in a small hole 1.5 cm below the seed level in the centre of each pot. The appropriate amount of reagent-grade $ZnSO_4$ was dissolved in deionized water and sprayed onto the soil with constant mixing for the mixed and band applications and was applied to the soil in a powdered form for the point application. Zinc was added at a rate of 0, 2, 4 and 8 ppm. After the zinc treatment, phosphorus at the rate 100 ppm was sprayed in solution onto the soil and throughly mixed with the entire soil mass. The results of this experiment are given in Tables 10 to 20 and in Figures 1 to 4.

A response in yield of dry matter occurred with addition of zinc only for those treatments in which zinc was either mixed or banded in the soil. This indicated that the method of application of $ZnSO_4$ to soil was important (Table 10, Figure 1).

Application of more than 2 ppm zinc did not further significantly increase dry matter yield when zinc was mixed or banded in the soil (Table 11, Figure 1). When zinc was applied in a point source, dry matter yield did not respond to zinc at any rate of addition. The latter result was most likely due to the fact that a smaller portion of roots was in contact with the zinc fertilizer reaction zone rather than a lower chemical availability of the zinc reaction product.

Zinc concentration in the plants was significantly higher than the control treatment only when $Zn\ SO_4$ was mixed with the soil (Table 12, Figure 2). There was an apparent near linear relationship between rates of zinc application and zinc concentration in the plant when zinc was mixed throughout the soil (Figure 2). With band application there appeared to be an increase in zinc concentration only for the highest rate, however this increase was not significant. These results are in contrast with those of dry matter yield where an increase in dry matter similar to that of the mixed application occurred. When zinc was applied to the soil in a point source, there was no increase in zinc concentration in the plants (Table 12, Figure 2). It would appear from these results that the rate of zinc application need not be large to obtain the maximum yield. However, the results do strongly indicate that mixing the zinc as uniformly as possible with the soil is the most effective method of increasing zinc concentration in plants. The above findings are in agreement with those of several other workers



(Fig. 1) Influence of zinc placement and rate on dry matter yield of the above ground portion of black beans.

Table 10. Effect of Zinc Placement and Rate on Dry Matter Yield of the Above Ground Portion of Black Beans (comparison among placement methods within each rate).[1]

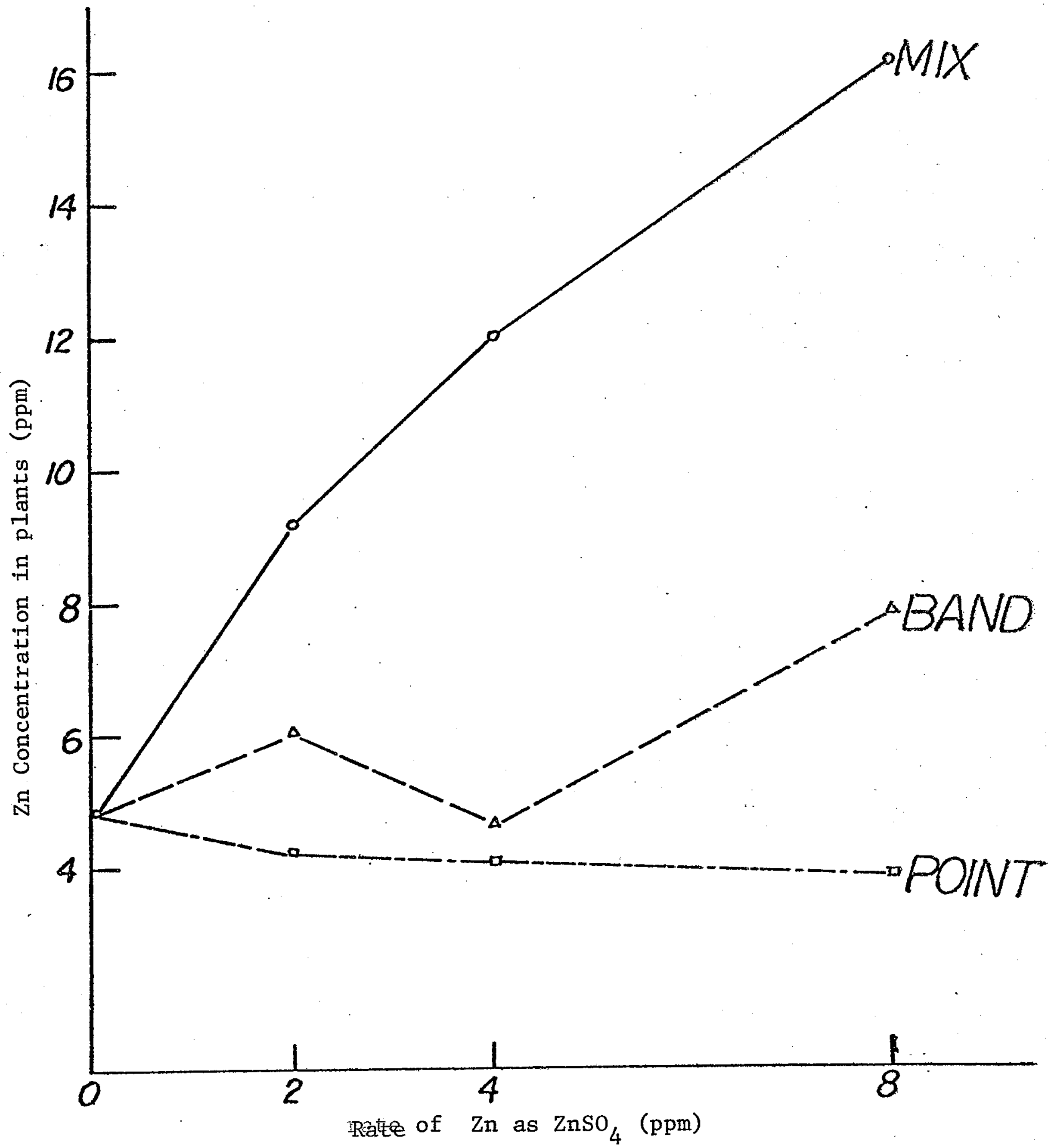
Zinc \ Placement	Mix	Band	Point
(ppm)	(g/pot)		
2	7.70_a*	8.07_a*	5.80_b
4	8.23_a*	7.83_a*	6.87_a
8	8.42_a*	8.60_a*	5.90_b
Control	5.83		

Table 11. Effect of Zinc Placement and Rate on Dry Matter Yield of the Above Ground Portion of Black Beans. (comparison among rates within each placement method)[1]

Zinc \ Placement	Mix	Band	Point
(ppm)	(g/pot)		
2	7.70_a*	8.07_a*	5.80_a
4	8.23_a*	7.83_a*	6.87_a
8	8.42_a*	8.60_a*	5.90_a
Control	5.83		

[1]Tukey's test at 5% level used. Treatment means are not significantly different when followed by the same letter.

* : significantly higher than the control at 5% level.



(Fig.2) Influence of zinc placement and rate on zinc concentration of the above ground portion of black beans.

Table 12. Effect of Zn Placement and Rate on Zinc Concentration of the Above Ground Portion of Black Beans. (comparison among placement methods within each rate)[1]

Zinc \ Placement	Mix	Band	Point
(ppm)		(ppm)	
2	9.25_{a}*	6.00_{ab}	4.25_{b}
4	$12.0*_{a}$	4.67_{b}	4.17_{b}
8	$16.1*_{a}$	7.93_{b}	3.92_{b}
Control	4.94		

Table 13. Effect of Zinc Placement and Rate on Zinc Concentration of the Ground Portion of Black Beans (comparison among rates within each placement method)[1]

Zinc \ Placement	Mix	Band	Point
(ppm)		(ppm)	
2	9.25_{a}*	6.00_{a}	4.25_{a}
4	12.0_{ab}*	4.67_{a}	4.17_{a}
8	16.1_{b}*	7.93_{a}	3.92_{a}
Control	4.94		

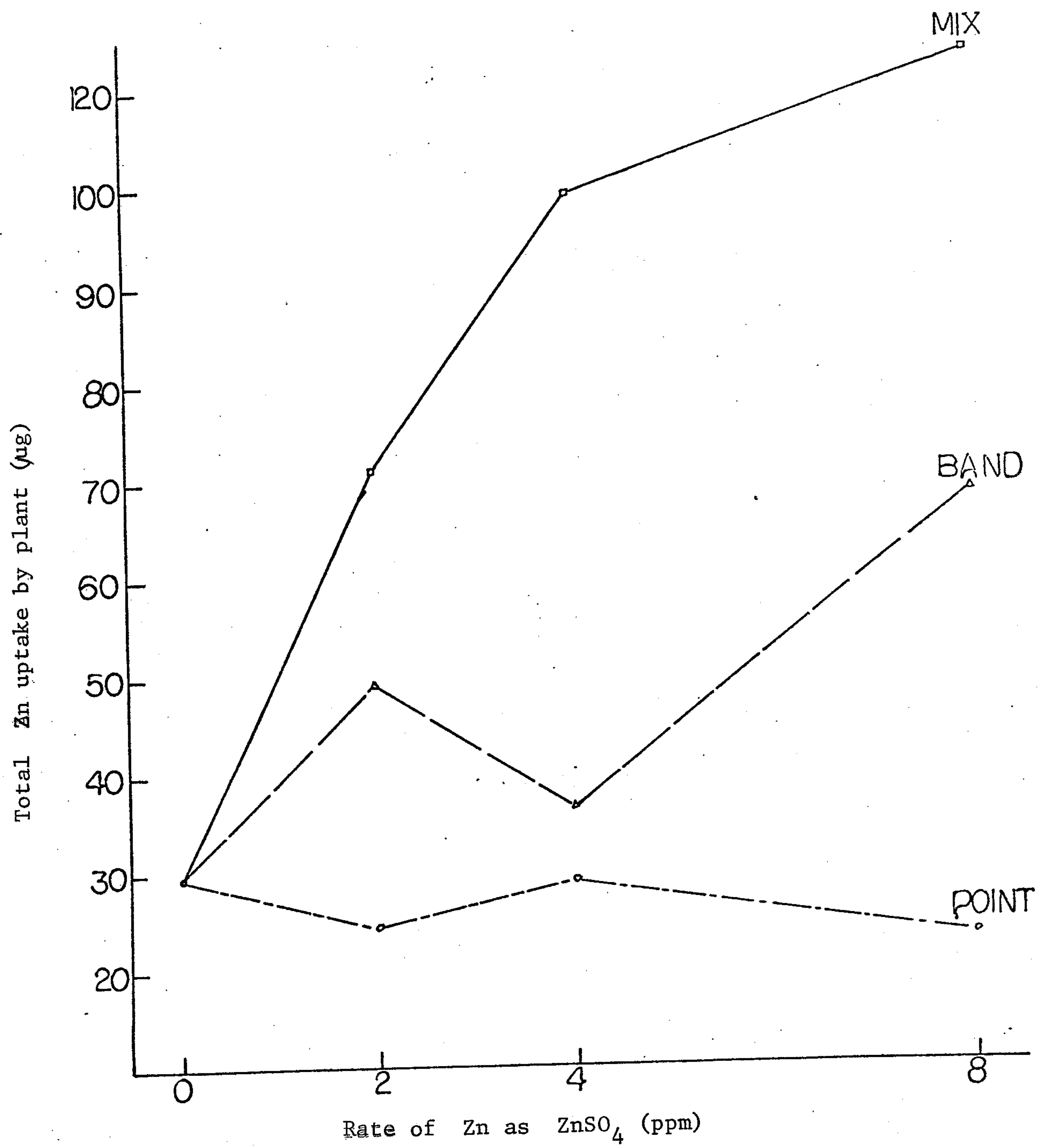
[1]Tukey's test at 5% level used. Treatment means are not significantly different when followed by the same letter.

* : significantly higher than the control at 5% level.

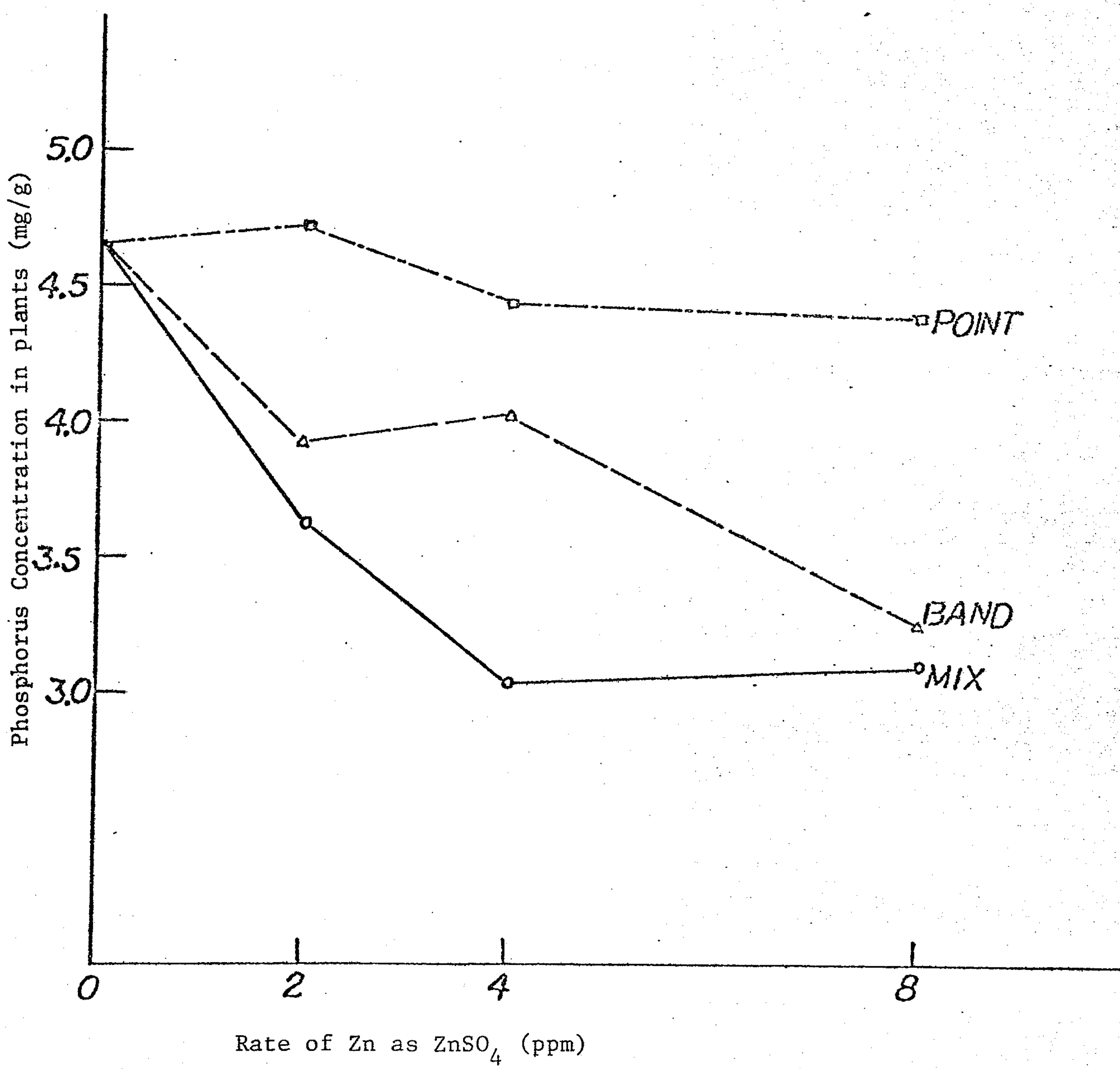
(Neff and Burrow, 1954, Shaw et al., 1954, Mordvedt and Giordano, 1969) who found that mixing $ZnSO_4$ with soil was more effective in increasing zinc concentration in plant than applying it on the surface or in a band.

Total zinc uptake into black beans shoots was significantly increased over that of control only when 4 and 8 ppm of zinc were mixed with soil (Table 15). These increases resulted from increases in yield as well as in zinc concentration in the plants. The results for zinc uptake were quite variable. Thus increases in zinc concentration and total zinc uptake due to banding zinc in the soil appeared to be real, but were not statistically significant. When zinc was applied as a point source there was no increase in total zinc uptake. These results show that mixing zinc as uniformly as possible in the soil results in larger increases in plant uptake for any given rate of zinc application compared to band or point application. Increasing the rate of zinc application appeared to increase the amount zinc taken up in most mixed and band treatments. But, due to variability among the replicates, the increases were only significant for the 4 and 8 ppm rates of the mixed treatment.

The phosphorus concentration in the bean shoot was generally decreased by zinc application. However, this decrease was significant only when zinc was mixed with the soil or when it was banded in the soil at the rate of 2 and 8 ppm of zinc. When zinc was applied in a point, no significant decreases were observed in phosphorus concentration in bean shoots (Table 16, Figure 4). The data in Table 13 show that application beyond 2 ppm of zinc had no significant further effect on plant phosphorus concentration. The decreases in phosphorus concentration in the plant due to zinc applications were most likely due



(Fig. 3) Influence of zinc placement and rates on total zinc uptake by the above ground portion of black beans.



(Fig. 4) Influence of zinc placement and rates on phosphorus concentration of the above ground portion of black beans.

Table 14. Effect of Zinc Placement and Rate on Total Zinc Uptake by the Above Ground Portion of Black Beans. (comparison among placement methods within each rate)[1]

Zinc \ Placement	Mix	Band	Point
(ppm)		(μg)	
2	71.6_a	48.7_a	24.6_b
4	99.5_a*	36.5_{bc}	28.6_c
8	$118._a$*	68.7_b	23.1_b
Control	28.9		

Table 15. Effect of Zinc Placement Method and Rate on Total Zinc Uptake by the Above Ground Portion of Black Beans. (comparison among rates within each placement method).[1]

Zinc \ Placement	Mix	Band	Point
(ppm)		(μg)	
2	71.6_a	48.7_a	24.6_a
4	99.5_a*	36.5_a	28.6_a
8	$118._b$*	68.7_a	23.1_a
Control	28.9		

[1]Tukey's test at 5% level used. Treatment means are not significantly different when followed by the same letter.

* : Significantly higher than the control at 5% level.

Table 16. Effect of Zinc Placement and Rate on Phosphorus Concentration of the Above Ground Portion of Black Beans. (comparison among placement methods within each rate).[1]

Placement / Zinc	Mix	Band	Point
(ppm)	(mg/g)		
2	3.52_a*	3.93_a*	4.72_b
4	3.04_a*	4.03_b	4.47_b
8	3.17_a*	3.24_a*	4.41_b
Control	4.65		

Table 17. Effect of Zinc Placement and Rate on Phosphorus Concentration of the Above Ground Portion of Black Beans. (comparison among rates within each placement methods)[1]

Placement / Zinc	Mix	Band	Point
(ppm)	(mg/g)		
2	3.52_a*	3.93_a*	4.72_a
4	3.04_a*	4.03_a	4.47_a
8	3.17_a*	3.24_b*	4.41_a
Control	4.65		

[1]Tukey's test at 5% level used. Treatment means are not significantly different when followed by the same letter.

* : significantly lower than the control at 5% level.

to dilution, since total phosphorus uptake by the plants was not affected by zinc levels (Table 18).

Percent nitrogen in the plant tended to decrease for these treatments where response to zinc applications occurred, however these decreases were not significant (Table 19). A decrease in percent nitrogen was likely due to the dilution, since total nitrogen uptake was not affected by zinc rate or placement (Table 20).

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Table 18. Effect of Zinc Placement and Rate on Total Phosphorus Uptake by the Above Ground Portion of Black Beans. (no significance of differences among rates or placement methods)

Placement / Zinc	Mix	Band	Point
(ppm)		(mg)	
2	27.2	31.8	27.4
4	30.7	31.6	31.9
8	26.7	27.8	26.0
Control	27.1		

Table 19. Effect of Zinc Placement and Rate on Nitrogen Concentration of the Above Ground Portion of Black Beans. (no significance of differences among rates and placement methods)

Placement / Zinc	Mix	Band	Point
(ppm)		(%)	
2	1.80	1.94	2.37
4	2.01	2.14	2.10
8	1.72	1.99	2.12
Control	2.28		

Table 20. Effect of Zinc Placement and Rate on Total Nitrogen Uptake by the Above Ground Portion of Black Beans (no significance of difference among rates and placements methods)

Zinc \ Placement	Mix	Band	Point
(ppm)		(mg)	
2	139	157	137
4	166	167	143
8	144	169	125
Control	130		

Experiment 3

The Effect of Added Phosphorus on the Absorption of Zinc and Response in Yield to Added Zinc by Black Beans.

There is considerable evidence in the literature which indicates that added phosphorus can induce zinc deficiency in plants. (Thorne, 1957. Judy et al., 1964. Melton, et al., 1970. Takkar et al., 1976). In the previous growth chamber experiment black beans responded to zinc applications; however a rather large amount of phosphorus (100 ppm) had been added to the soil. Therefore, the third experiment was conducted to ensure that the response was due to a true soil deficiency and not due to a phosphorus-induced deficiency.

The phosphorus treatments consisted of 0, 20, 40, 80, and 160 ppm; and zinc treatments were 0 and 8 ppm zinc as $ZnSO_4$ for each level of phosphorus. Both the phosphorus and zinc carriers were dissolved in deionized water, sprayed on the soil and mixed thoroughly thereafter. The results of this experiment are given in Tables 21 to 34 and Figures 5 to 8.

Adding phosphorus to the soil without added zinc appeared to increase the dry matter yield at lower rates followed by a decline at higher rates, however these responses were not significant (Table 21, Figure 5). When 8 ppm of zinc was added to the soil a response in yield to added phosphorus occurred. The response was linear up to 80 ppm of phosphorus and leveled off beyond that point (Table 21, Figure 5). These results indicate that the soil was severely phosphorus deficient and maximum response to added phosphorus would not appear unless sufficient zinc was added. It also indicated that the optimum rate of phosphorus with added zinc was 80 ppm. Dry matter yield at all levels of phosphorus was higher

Table 21. Effect of rate of zinc and phosphorus on dry matter yield of the above ground portion of black beans. (Comparison among five means within each rate of zinc.)[1]

Zinc \ Phosphorus	0	20	40	80	160
(ppm)	(g/pot)				
0	2.60_a	4.75_a	4.31_a	3.96_a	2.73_a
8	3.05_a	5.38_b	6.63_b	10.7_c	10.1_c

Table 22. Effect of rate of zinc and phosphorus on dry matter yield of the above ground portion of black beans. (Comparison between the two means within each rate of phosphorus.)[1]

Zinc \ Phosphorus	0	20	40	80	160
(ppm)	(g/pot)				
0	2.60_a	4.75_a	4.31_a	3.96_a	2.73_a
8	3.05_a	5.38_a	6.63_b	10.7_b	10.1_b

[1]Tukey's test at 5% level used. Treatments means are not significantly different when followed by the same letter.

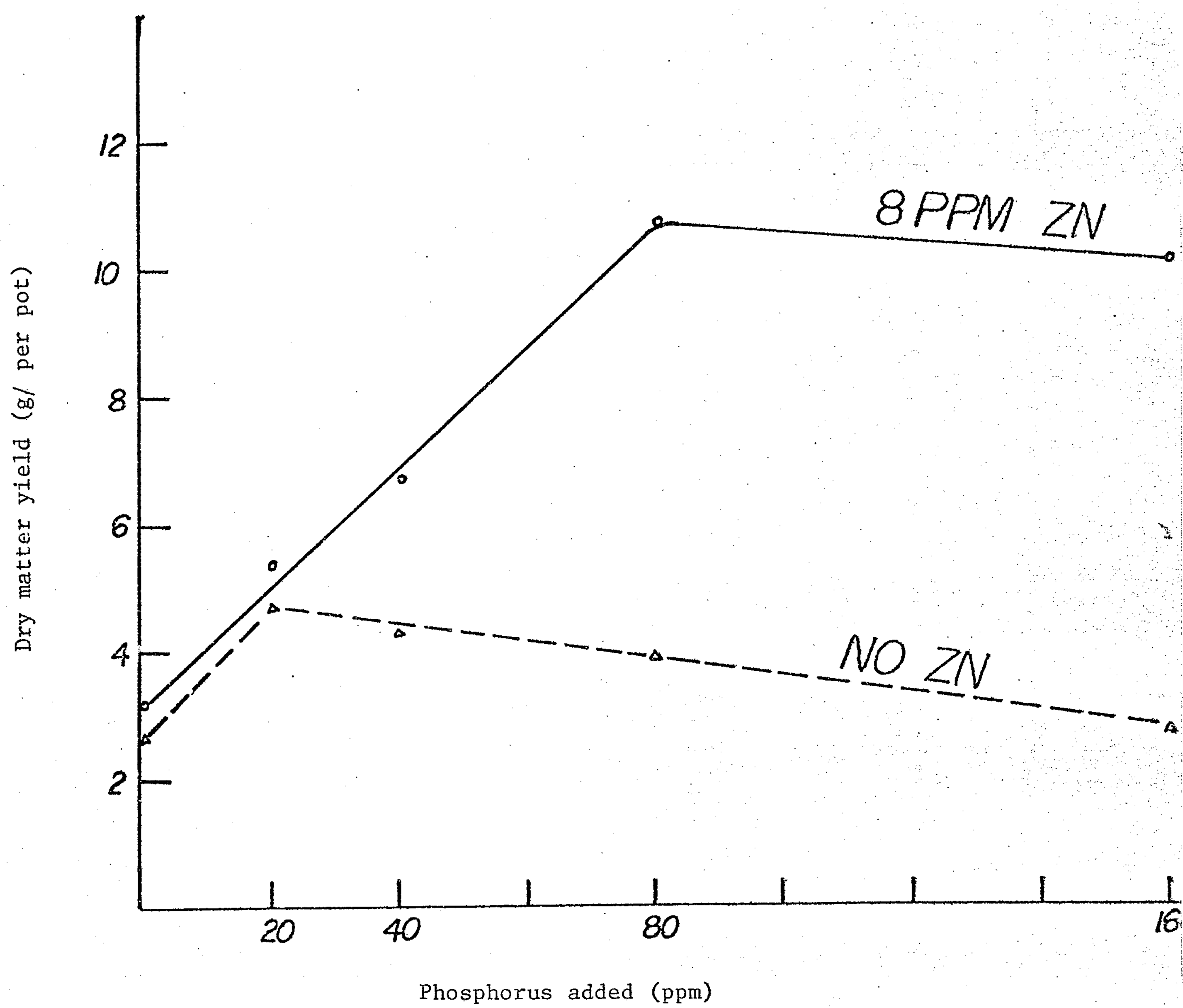


Figure 5. Influence of rate of zinc and phosphorus upon dry matter yield of the above ground portion of black beans.

when 8 ppm of zinc was added than without added zinc, however these increases were significant only at 40, 80, and 160 ppm of added phosphorus (Table 22). The data on dry matter yield shows a strong positive interaction between zinc and phosphorus added to soil (Figure 5).

Zinc concentration in the plant decreased with the addition of phosphorus when zinc was not added to the soil (Table 23, Figure 6), however this decrease was not significant. When 8 ppm of zinc was added to the soil, added phosphorus significantly decreased the zinc concentration in the plant. Both with and without added zinc there was an inverse relationship between added phosphorus and zinc concentration in the plant (Table 23).

Without added zinc the decrease in zinc concentration of plants with increased phosphorus up to 40 ppm was mostly due to dilution but also possibly due to phosphorus interference in zinc uptake. When 80 and 160 ppm of phosphorus were added to the soil without added zinc decreased dry matter yield, and decreased zinc concentration in the plant occurred (Tables 21 and 23). This might indicate that phosphorus aggrevated the already present zinc deficiency either by affecting zinc uptake or translocation within the plant. When 8 ppm zinc was added, the decreases up to 80 ppm phosphorus were most likely due to dilution, but when 160 ppm of phosphorus was added the decrease in zinc concentration in the plant appeared to be due to the effect of phosphorus on zinc uptake and/or translocation (Table 23). It may be concluded that in the previous experiment the addition of 100 pm of phosphorus did not induce zinc deficiency but rather corrected a phosphorus deficiency.

Although none of the means were significantly different, total

Table 23. Effect of rate of zinc and phosphorus on zinc concentration of the above ground portion of black beans. (Comparison among five means within each rate of zinc.)[1]

Zinc \ Phosphorus	0	20	40	80	160
(ppm)	(ppm)				
0	6.83_a	4.50_a	4.41_a	4.22_a	3.87_a
8	26.7_a	22.6_b	19.1_c	16.0_c	12.4_d

Table 24. Effect of rate of zinc and phosphorus on zinc concentration of the above ground portion of black beans. (Comparison between the two means within each rate of phosphorus.)[1]

Zinc \ Phosphorus	0	20	40	80	160
(ppm)	(ppm)				
0	6.83_a	4.50_a	4.41_a	4.22_a	3.87_a
8	26.7_b	22.6_b	19.1_b	16.0_b	12.4_b

[1] Tukey's test at 5% level used. Treatment means are not significantly different when followed by the same letter.

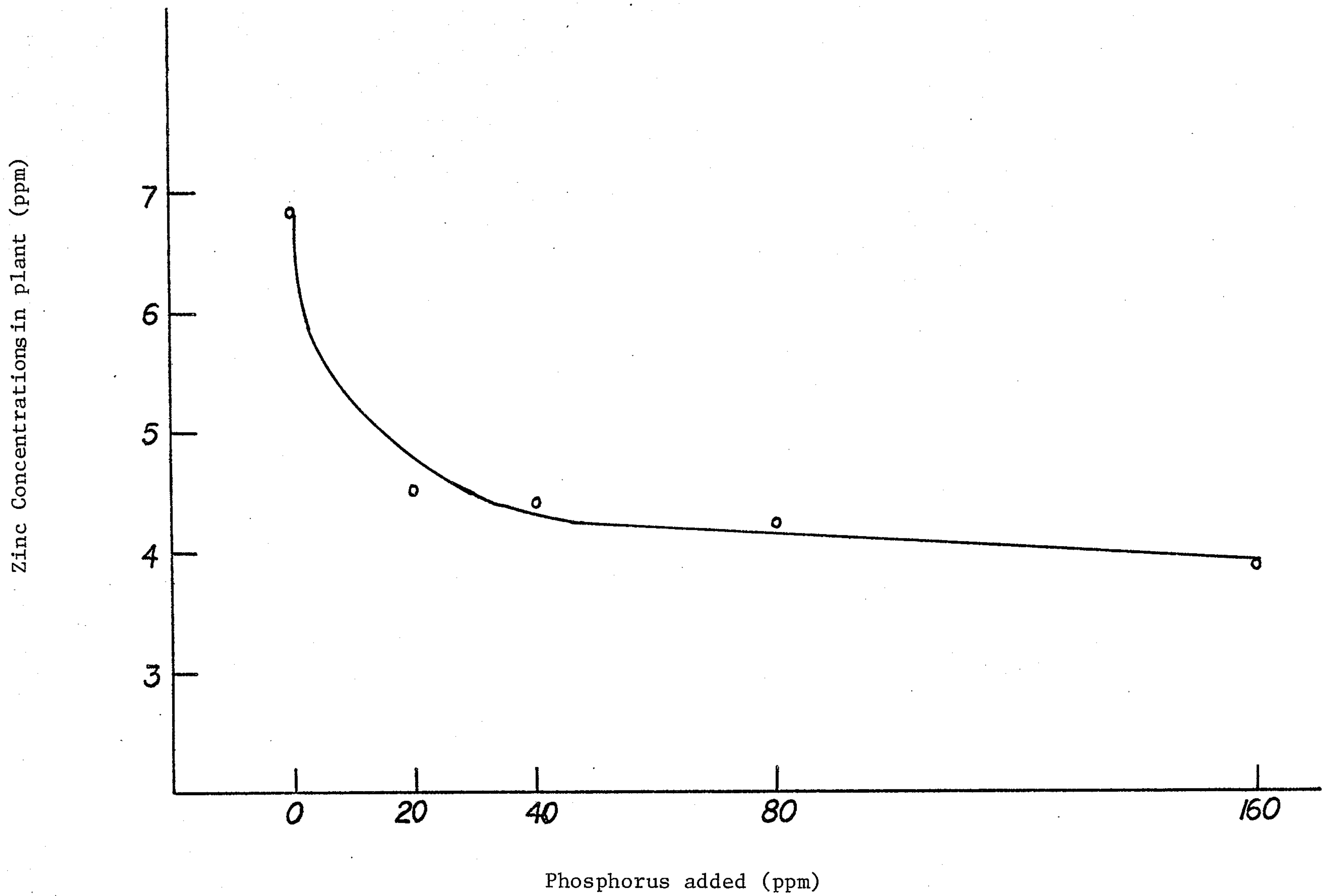


Figure 6. Influence of rate of phosphorus upon zinc concentrations of black beans when no zinc was added.

zinc uptake by the plant without added zinc appeared to be increased by the lower levels of added phosphorus and decreased with the higher levels of added phosphorus (Table 25). The decrease in zinc uptake at the high levels of added phosphorus were most likely due to the interference of phosphorus with zinc uptake. When 8 ppm of zinc was added to the soil, total zinc uptake by the plants increased significantly up to 80 ppm of phosphorus. These increases resulted from increases in dry matter yield. However at a higher rate of phosphorus (160 ppm) total zinc uptake by the plant decreased, which indicates interference in zinc uptake by phosphorus (Table 25). Data in Table 26 shows that total zinc uptake by the plant at all levels of phosphorus was higher with added zinc.

At both levels of zinc minimum zinc concentrations in the plant were obtained at maximum phosphorus rates (Table 26). This reverse relationship between phosphorus and zinc concentrations in plant (Tables 23 and 27, Figure 6, and 7) has been reported by investigators working with beans (Burleson et al., 1961. Judy et al., 1964. Lessman, 1967. Paulsen and Rotimi, 1968. Boawn and Brown, 1968. Wallace et al., 1974) and for other crops (Burleson et al., 1961. Ellis et al., 1964. Stukenholtz et al., 1966. Ganiron et al., 1969. Takka et al., 1976).

Phosphorus concentration in black beans without added zinc increased continuously with increased rate of added phosphorus up to 160 ppm (Table 27). When 8 ppm zinc was added to the soil, phosphorus concentration in the plant increased with 20 ppm of added phosphorus and beyond that nearly leveled off. It would appear that when the plant had zinc in adequate amounts it had the ability to regulate the phosphorus uptake so that the phosphorus concentration in the plant is independent of rate of added phosphorus (Table 27). Paulson and Rotimi (1968) made a similar observation; they

Table 25. Effect of rate of zinc and phosphorus on total zinc uptake by the above ground portion of black beans. (Comparison among five means within each rate of zinc.)[1]

Zinc (ppm) \ Phosphorus	0	20	40	80	160
			(µg)		
0	17.5 a	21.3 a	19.0 a	10.8 a	10.6 a
8	82.4 a	120 bc	125 c	170 d	125 c

Table 26. Effect of rate of zinc and phosphorus on total zinc uptake by the above ground portion of black beans. (Comparison between the two means within each rate of phosphorus.)[1]

Zinc (ppm) \ Phosphorus	0	20	40	80	160
			(µg)		
0	17.5 a	21.3 a	19.0 a	10.8 a	10.6 a
8	82.4 b	120 b	125 b	170 b	125 b

[1]Tukey's test at 5% level used. Treatment means are not significantly different when followed by the same letter.

Table 27. Effect of rate of zinc and phosphorus on the phosphorus concentration of the above ground portion of black beans.[1] (Comparison among five means within each rate of zinc.)

Zinc \ Phosphorus	0	20	40	80	160
(ppm)	(mg/g)				
0	1.5_a	3.5_b	4.0_b	4.6_b	6.6_c
8	2.0_a	2.5_a	2.4_a	2.3_a	2.5_a

Table 28. Effect of rate of zinc and phosphorus on the phosphorus concentration of above ground portion of black beans.[1] (Comparison between the two means within each rate of phosphorus.)

Zinc \ Phosphorus	0	20	40	80	160
(ppm)	(mg/g)				
0	1.5_a	3.5_a	4.0_a	4.6_a	6.6_a
8	2.0_a	2.5_a	2.4_b	2.3_b	2.5_b

[1]Tukey's test at 5% level used. Treatment means are not significantly different when followed by the same letters.

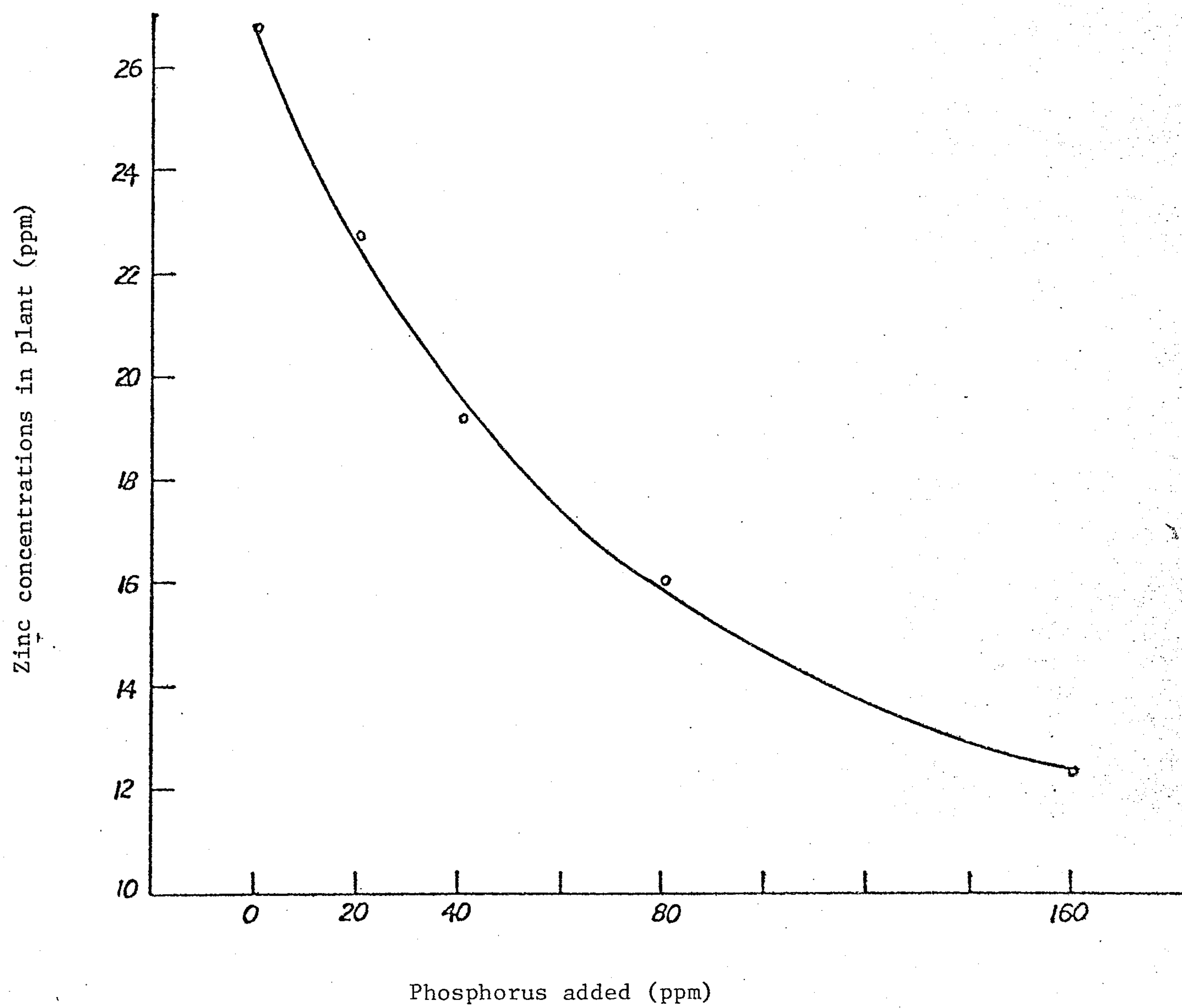


Figure 7. Influence of rate of phosphorus upon zinc concentrations of black beans when 8 ppm of zinc was added.

found using nutrient solutions that phosphorus concentrations in soybean plants decreased by increasing the amount of $ZnSO_4$. Safaya (1976) studied phosphorus-zinc interaction in corn in a loamy sand soil of pH = 8.3, with three phosphorus levels (0, 25, and 75) ppm and two zinc levels (0, 10 ppm). He reported that zinc depressed phosphorus concentration as well as phosphorus flux at almost all the levels of applied phosphorus.

Total phosphorus uptake by the plant increased significantly with application of 20 and 40 ppm of phosphorus without added zinc (Table 29). Beyond 40 ppm phosphorus no significant increase occurred. When 8 ppm zinc was added to the soil, total phosphorus uptake significantly increased up to 80 ppm of phosphorus, and leveled off with the higher rate of phosphorus. These increases resulted from an increase in dry matter yield. The data of Table 30 shows that for all levels of phosphorus except 20 ppm, total phosphorus uptake by the plants was significantly higher when 8 ppm zinc was added.

Percent nitrogen in the plant without added zinc tended to decrease with phosphorus application. The same trend was observed with the application of 8 ppm of zinc (Table 31). The decreases in percent nitrogen with increased rate of phosphorus at 8 ppm of zinc was most likely due to dilution.

Total nitrogen uptake by the plant did not change with the application of phosphorus without zinc added (Table 33). When 8 ppm of zinc was added to the soil, nitrogen uptake increased with increased rate of phosphorus.

Table 29. Effect of rate of zinc and phosphorus on total phosphorus uptake by the above ground portion of black beans. (Comparison among five means within each rate of zinc.)[1]

Zinc \ Phosphorus	0	20	40	80	160
(ppm)	(mg)				
0	3.6_a	16.8_b	17.5_c	18.4_c	18.0_c
8	6.4_a	13.4_b	16.1_c	25.5_d	25.6_d

Table 30. Effect of rate of zinc and phosphorus on total phosphorus uptake by the above ground portion of black beans. (Comparison between the two means within each rate of phosphorus.)[1]

Zinc \ Phosphorus	0	20	40	80	160
(ppm)	(mg)				
0	3.6_a	16.8_a	17.5_a	18.4_a	18.0_a
8	6.4_b	13.4_b	16.1_b	25.5_b	25.6_b

[1] Tukey's test at 5% level used. Treatment means are not significantly different when followed by the same letter.

Table 31. Effect of rate of zinc and phosphorus on per cent nitrogen of the above ground portion of black beans.[1] (Comparison among five means within each rate of zinc.)

Zinc (ppm) \ Phosphorus	0	20	40	80	160
0	2.85_a	1.84_b	1.89_b	2.09_b	2.47_b
8	2.39_a	2.35_a	1.65_b	1.27_b	1.43_b

Table 32. Effect of rate of zinc and phosphorus on per cent nitrogen of the above ground portion of black beans. (Comparison between the two means within each rate of phosphorus.)[1]

Zinc (ppm) \ Phosphorus	0	20	40	80	160
0	2.85_a	1.84_a	1.89_a	2.09_a	2.47_a
8	2.39_a	2.35_a	1.65_a	1.27_a	1.43_b

[1]Tukey's test at 5% level used. Treatment means are not significantly different when followed by the same letter.

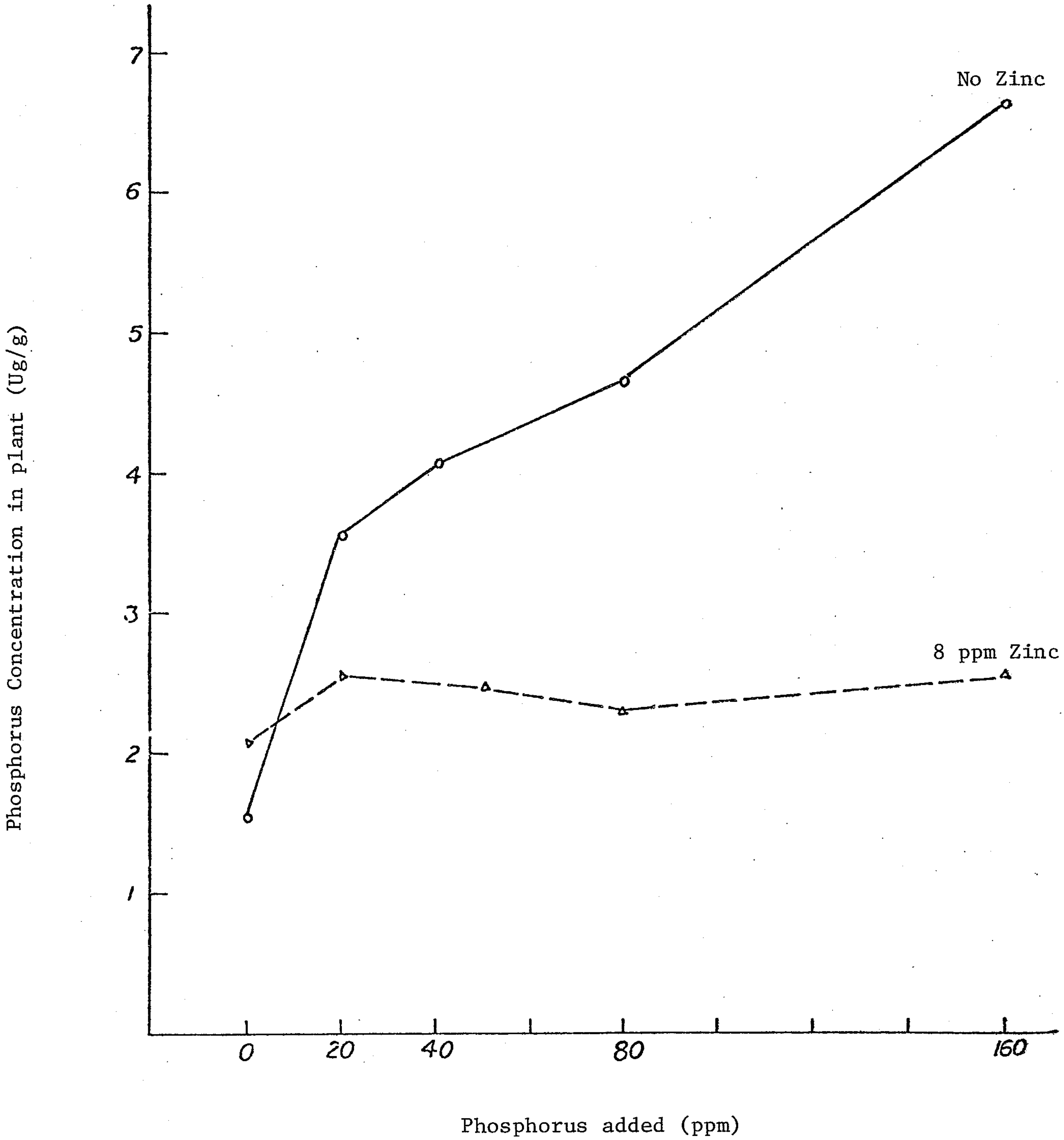


Figure 8. Influence of rate of zinc and phosphorus upon phosphorus concentration of the above ground portion of black beans.

Table 33. Effect of rate of zinc and phosphorus on total nitrogen uptake by the above ground portion of black beans. (Comparison among five means with each rate of zinc.)[1]

Zinc \ Phosphorus	0	20	40	80	160
(ppm)	(mg)				
0	70.3_a	87.1_a	81.1_a	82.4_a	67.3_a
8	73.5_a	124_b	108_a	135_b	144_b

Table 34. Effect of rate of zinc and phosphorus on total nitrogen uptake by the above ground portion of black beans. (Comparison between the two means within each rate of phosphorus.)[1]

Zinc \ Phosphorus	0	20	40	80	160
(ppm)	(mg)				
0	70.3_a	87.1_a	81.1_a	82.4_a	67.3_a
8	73.5_a	124_a	108_a	135_b	144_b

[1]Tukey's test at 5% level. Treatment means are not significantly different when followed by the same letter.

Experiment 4

The Effect of Different Volumes of Soil Treated with Zinc and Rate of Added Zinc on Dry Matter Yield, Zinc Utilization and Nitrogen Uptake by Black Beans.

In the second growth chamber experiment black beans responded to added zinc. The highest zinc uptake occurred when zinc was mixed thoroughly with the soil. The fourth growth chamber experiment was a continuation of the second growth chamber experiment to further study the effect of size of reaction zone and rate of added zinc on dry matter yield and utilization of zinc by the black beans. Rates were designed such that we could compare the effect of different sizes of reaction zone with the same concentration of added zinc within the reaction zone.

The treatments consisted of mixing various amounts of zinc with different portions of 5 kg of soil. Zinc was mixed with: (1) 1% (50 g) of soil (2) 12.5% (625 g) of soil (3) 25% (1250 g) of soil (4) 50% (2500 g) of soil (5) 100% (5000 g) of soil.

The rates of the zinc application were 4, 8, and 16 ppm of zinc as $ZnSO_4$ on a total soil basis. In all five methods of application $ZnSO_4$ was dissolved in deionized water and sprayed on the appropriate amount of soil and mixed thoroughly. After zinc application all pots received 100 ppm of phosphorus as $Ca(H_2PO_4)_2$, which was applied to the soil in a similar fashion as zinc. In all treatments except when zinc was mixed with 100% of the soil, the zinc treated soil was banded 1.5 cm below the seed level or 4 cm below the soil surface.

The results of this experiment are given in Tables 35 to 52 and Figures 9 to 16.

All rates and different sizes of the reaction zone significantly increased the shoot dry matter yield compared to that of the control, except for the lowest rate of zinc mixed with 1% of the soil (Table 35). There was no further significant increase in dry matter yield beyond 4 ppm of zinc (Table 36).

Shoot dry matter yield was increased by increasing the fertilizer reaction zone when 4 ppm zinc was mixed with the soil. For 8 and 16 ppm of zinc increasing the reaction zone beyond 12.5% did not seem to be very effective in increasing the dry matter yield.

Root dry matter yield was increased significantly over that of control with all rates and different sizes of reaction zones, except when 4 and 8 ppm of zinc was mixed with 1% of the soil.

Other workers have found that increasing the volume of soil treated with zinc increased the effectiveness of the zinc application. Brown and Krantz (1960) found that the greater the volume of zinc treated soil, the higher the yield of corn. Mordvedt and Giordano (1969) stated that uniform distribution of applied inorganic zinc in the soil is essential for maximum effectiveness in increasing the yield of corn plants.

Zinc concentration in the aerial portions of the plants were higher than that of the control for all rates and methods of application. However these increases were significant only when zinc was mixed with 100% of the soil, when higher rates were mixed with 50% of the soil and when the highest rate was mixed with 25% of the soil (Table 38).

Increasing the rate of added zinc generally increased the zinc concentration in the aerial portion of the plant. However these increases were only significant for the larger reaction zones.(Tables 39, Figure 11).

Table 35. Effect of volume of soil treated with zinc and rate of zinc on dry matter yield of the above ground portion of black beans. (Comparison among five means within each rate of zinc.)[1]

Zinc (ppm) \ Soil volume treated w/Zn	1%	12%	25%	50%	100%
	(g/pot)				
4	6.05_{a}	8.61_{ab}	9.39_{abc}*	10.6_{bc}*	12.6_{c}*
8	8.11_{a}*	10.5_{a}*	8.94_{a}*	11.4_{a}*	10.3_{a}*
16	7.31_{a}*	10.3_{a}*	9.99_{a}*	10.6_{a}*	9.70_{a}*
Control	3.07				

Table 36. Effect of volume of soil treated with zinc and rate of zinc on dry matter yield of the above ground portion of black beans. (Comparison among three means within each volume of soil treated with zinc.)[1]

Zinc (ppm) \ Soil volume treated w/Zn	1%	12.5%	25%	50%	100%
	(g/pot)				
4	6.05_{a}	8.61_{a}*	9.39_{a}*	10.6_{a}*	12.6_{a}*
8	8.11_{a}*	10.5_{a}*	8.94_{a}*	11.4_{a}*	10.3_{a}*
16	7.31_{a}*	10.3_{a}*	9.99_{a}*	10.6_{a}*	9.70_{a}*
Control	3.07				

[1]Tukey's test at 5% level used. Treatment means are not significantly different when followed by the same letter.

*: significantly higher than the control at 5% level.

Table 37. Effect of volume of soil treated with zinc and rate of zinc on root dry matter yield. (No significance of difference among different volumes of soil treated with zinc or different rates of zinc.)[1]

Zinc \ Soil volume treated w/Zn	1%	12.5%	25%	50%	100%
(ppm)	(g/pot)				
4	2.25_a	2.39_a*	2.38_a*	2.92_a*	3.09_a*
8	1.92_a	3.37_a*	2.43_a*	2.90_a*	2.55_a*
16	2.40_a*	3.09_a*	3.02_a*	3.53_a*	2.59_a*
Control	0.89				

[1]Tukey's test at 5% level used. Treatment means are not significantly different when followed by the same letter.

*: significantly higher than the control at 5% level.

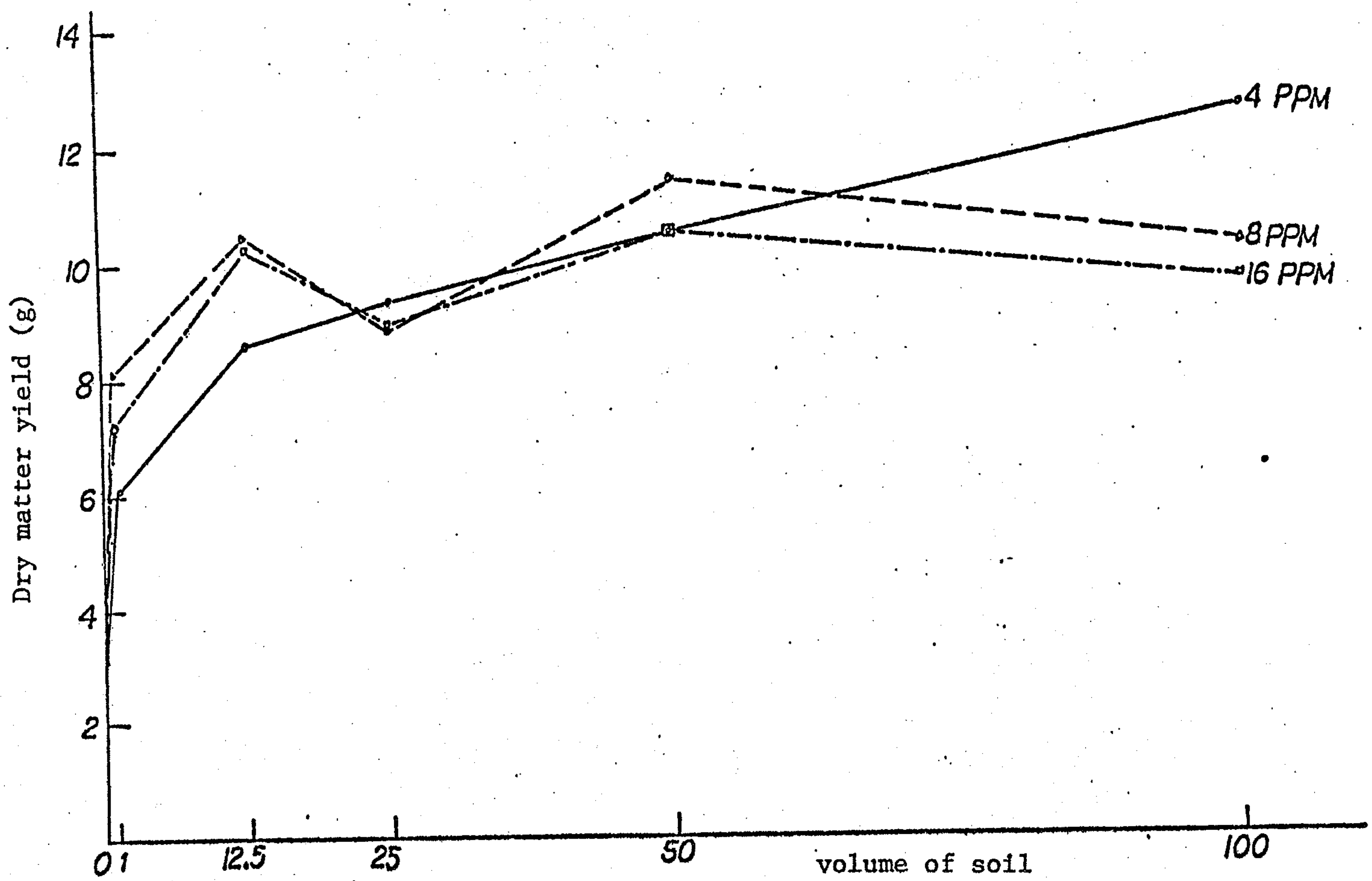


Figure 9. Effect of volume of soil treated with zinc at various zinc rates on the dry matter yield of black beans.

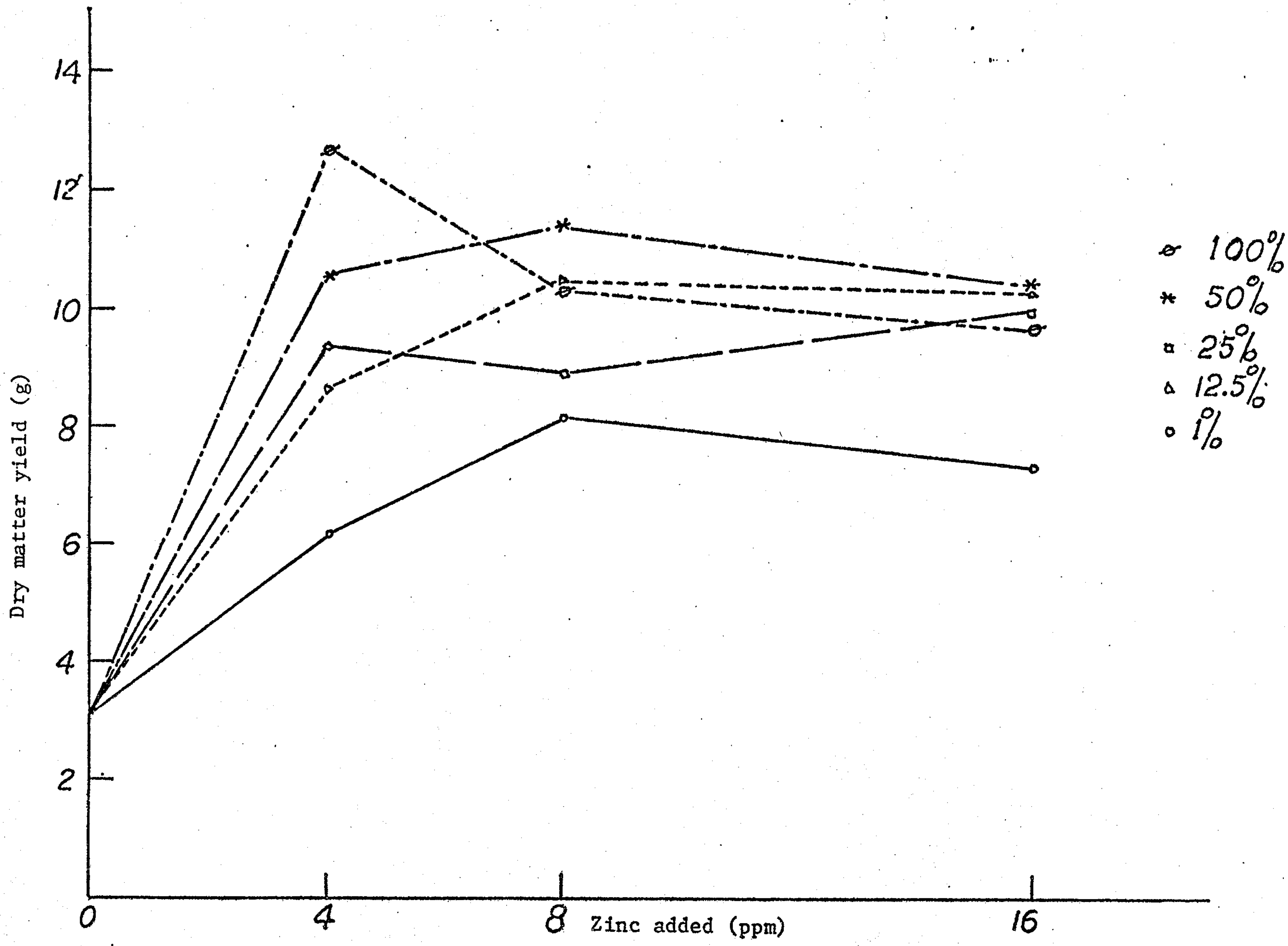


Figure 10. Effect of rate of added zinc at various volumes of zinc treated soil on the dry matter yield of black beans.

Table 38. Effect of volume of soil treated with zinc and rate of zinc on zinc concentration of the above ground portion of black beans. (Comparison among five means within each rate of zinc.)[1]

Soil volume treated w/Zn / Zinc	1%	12.5%	25%	50%	100%
(ppm)	(ppm)				
4	8.46_a	7.40_a	8.22_a	10.7_{ab}	14.2_b*
8	10.0_a	7.80_a	10.6_a	15.7_b*	23.7_c*
16	8.47_a	9.08_a	12.7_a*	18.2_b*	29.3_c*
Control	6.33				

Table 39. Effect of volume of soil treated with zinc and rate of zinc on zinc concentration of the above ground portion of black beans. (Comparison among three means within each volume of soil treated with zinc.)[1]

Soil volume treated w/Zn / Zinc	1%	12.5%	25%	50%	100%
(ppm)	(ppm)				
4	8.46_a	7.40_a	8.22_a	10.67_a	14.2_a*
8	10.0_a	7.80_a	10.6_a	15.7_b*	23.7_b*
16	8.47_a	9.08_a	12.7_a*	18.2_b*	29.3_c*
Control	6.33				

[1]Tukey's test at 5% level used. Treatment means are not significantly different when followed by the same letter.

*: significantly higher than the control at 5% level.

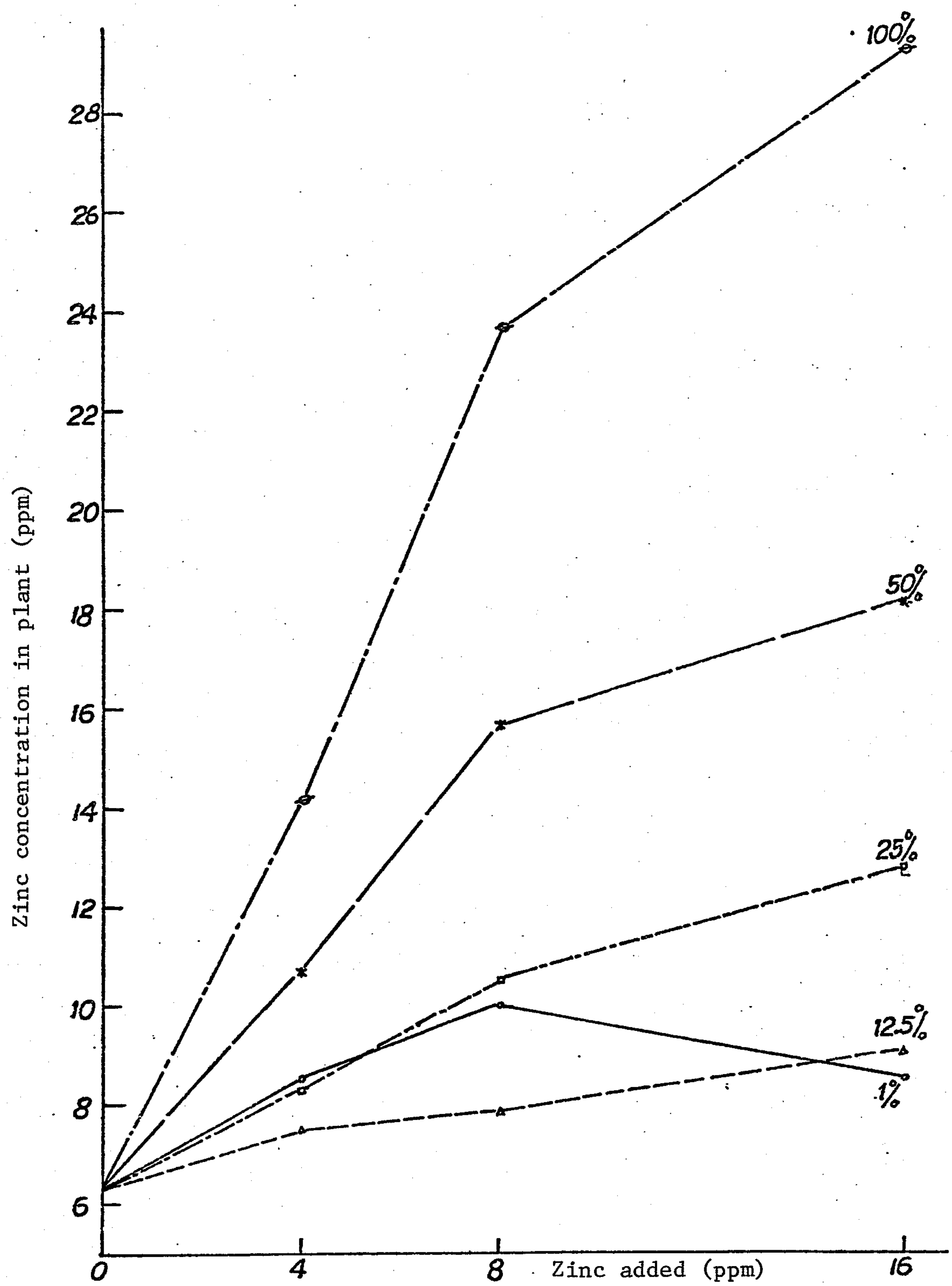


Figure 11. Effect of rate of added zinc at various volumes of zinc treated soil on the zinc concentration of above ground portion of black beans.

There seemed to be a general increase of zinc concentration in the plant with increasing size of reaction zone, but these differences were significant only for the larger reaction zone (Table 38).

Under the experimental conditions of this experiment, using dry matter yield data and zinc concentrations in plants, the critical level of zinc in the plant was found to be about 13.5 ppm (Figure 14). A method proposed by Cate and Nelson (1965) was used. Two perpendicular lines were plotted--one parallel with the x axis and the other with the y axis--so that there was a minimum number of observations in the upper left hand and the lower right-hand quadrants. This critical level of zinc is lower than the findings of other investigators working with beans. (Judy et al., 1964, Melton 1968).

Zinc concentration in the roots was significantly higher than that of the control for all rates and reaction zones, except when 4 ppm of zinc was mixed with 100% of the soil (Table 40). There was no consistent trend in zinc concentration in the root with increasing size of reaction zone (Table 40).

For all rates and methods of application except in the control treatment zinc concentrations in the roots were higher than those of shoots. Paulson and Rotimi (1968) working with nutrient solution and soybeans reported that adding zinc increased zinc concentration in roots more than in shoots.

Addition of zinc regardless of rate of size of reaction zone increased the total zinc uptake by the aerial portion of the black beans compared to that of the control treatment. However, these increases were significant only when zinc was mixed with 100 or 50% of the soil and when

Table 40. Effect of volume of soil treated with zinc and rates of zinc on the zinc concentration of root of black beans. (Comparison among the means within each rate of zinc.)[1]

Zinc (ppm) \ Soil volume treated w/Zn	1%	12.5%	25%	50%	100%
	(ppm)				
4	16.2_a*	17.3_a*	16.7_a*	22.8_a*	15.0_a
8	19.4_a*	18.8_a*	18.0_a*	20.4_a*	23.4_a*
16	19.3_a*	23.2_{ab}*	24.9_{ab}*	29.7_b*	41.5_c*
Control	4.95				

Table 41. Effect of volume of soil treated with zinc and rates of zinc on the zinc concentration of root of black beans. (Comparison among three means within each volume of soil treated with zinc.)[1]

Zinc (ppm) \ Soil volume treated w/Zn	1%	12.5%	25%	50%	100%
	(ppm)				
4	16.2_a*	17.3_a*	16.7_a*	22.8_a*	15.0_a
8	19.4_a*	18.8_a*	18.0_a*	20.4_a*	23.4_a*
16	19.3_a*	23.2_a*	24.9_a*	29.7_a*	41.5_b*
Control	4.95				

[1] Tukey's test at 5% level used. Treatment means are not significantly different when followed by the same letter.

*: significantly higher than the control at 5% level.

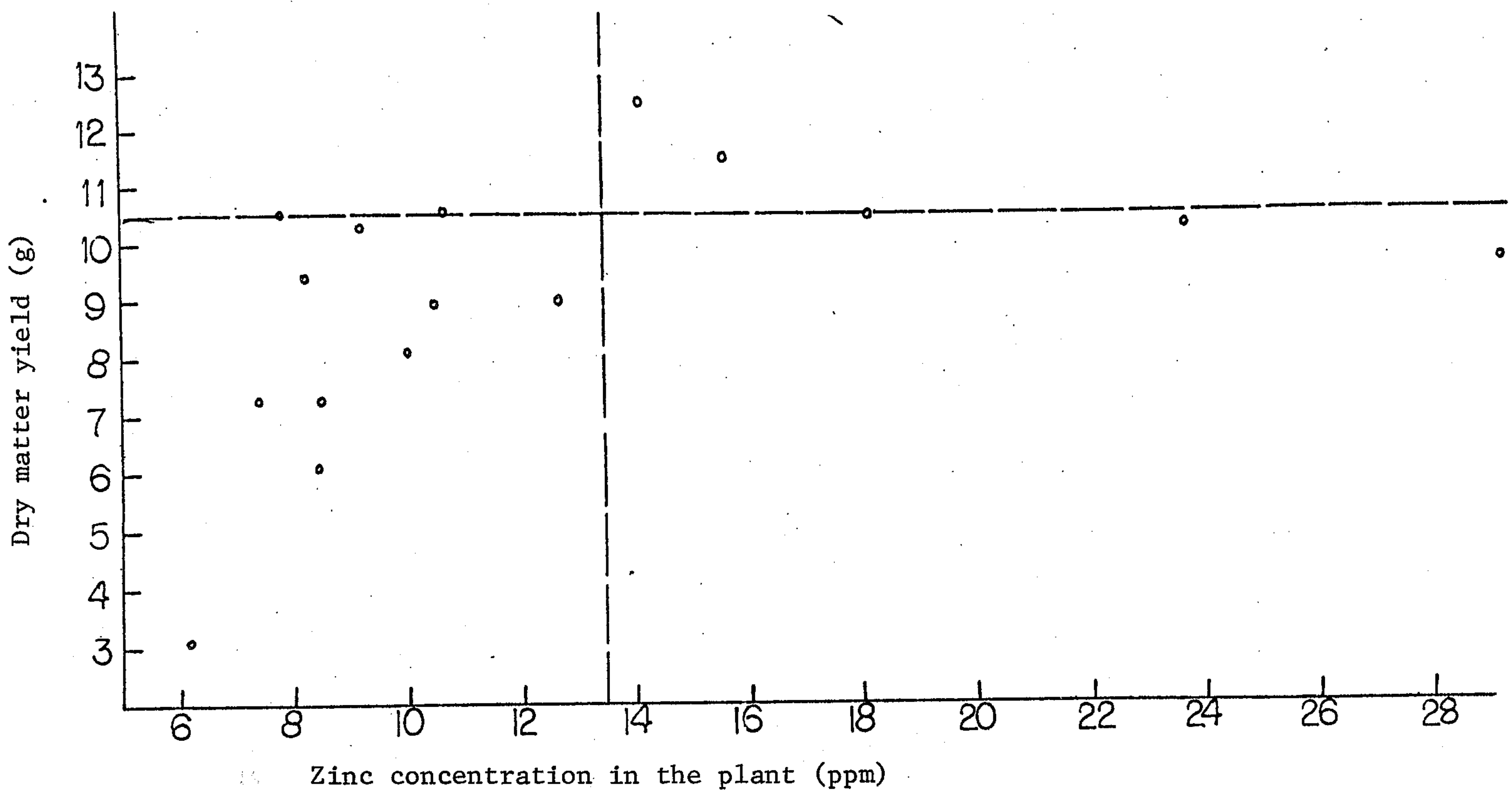


Figure 14. Critical level of zinc in black bean plants.

higher rates of zinc were mixed with 25 or 12.5% of the soil (Table 42). There was a progressive and quite large increase in total zinc uptake with either an increased reaction zone or an increased rate, the only exception being 8 ppm of zinc mixed with 1% of the soil. Due to variability among the pots, these increases were significant only for higher rates and larger reaction zones (Table 42 and 43). These increases resulted from increases in zinc concentrations of the plant as well as increases in dry matter yield.

There was a curvilinear relationship between total zinc uptake by the aerial portion of black beans and the rate of added zinc in all sizes of reaction zones (Figure 13). There was also a curvilinear relationship between percent utilization of added zinc and the concentration of added zinc within the reaction zone regardless of size of the reaction zone (Table 58 and Figure 15). The above results are in agreement with those of Brown et al., (1960) who found in a non calcareous soil P_H = 7.3 that zinc uptake by tomato, sorghum and sugar beet plants was a curvilinear function of the rate of zinc application. They reported that each succeeding increment of $ZnSO_4$ had a smaller effect on the amount of zinc taken up. Shaw et al., (1954) in a green house experiment using $ZnSO_4$ found that in corn and oat plants the percentage utilization of zinc fertilizer was inversely related to rate of application. The reason for curvilinear relationships between zinc uptake and rate of added zinc and between percent utilization of added zinc and concentration of added zinc in the reaction zone could be due to several factors including the ability of the plant root to take up zinc and/or the chemical availability of the added zinc. Akinyede (1977) in an incubation experiment with the same soil

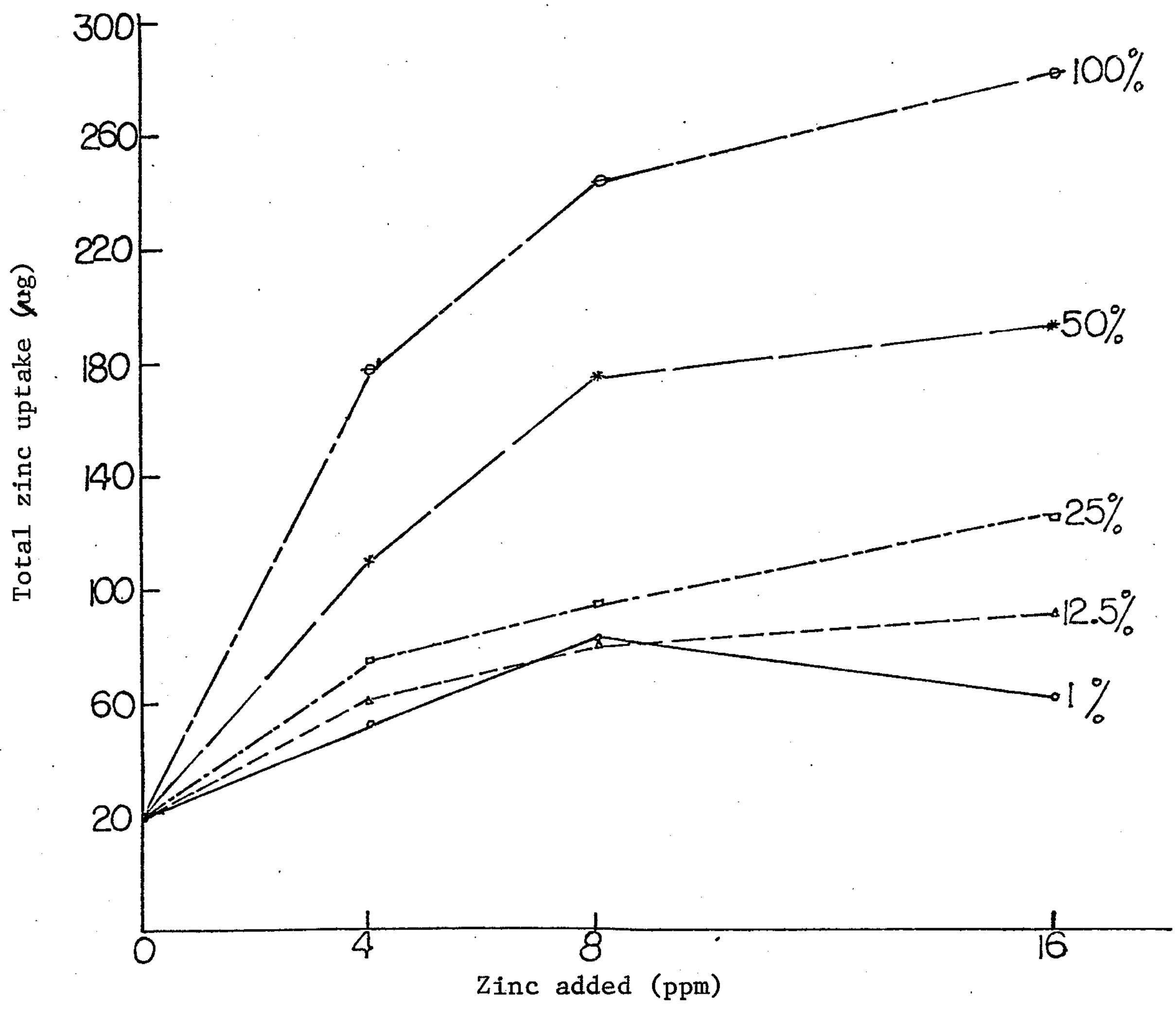
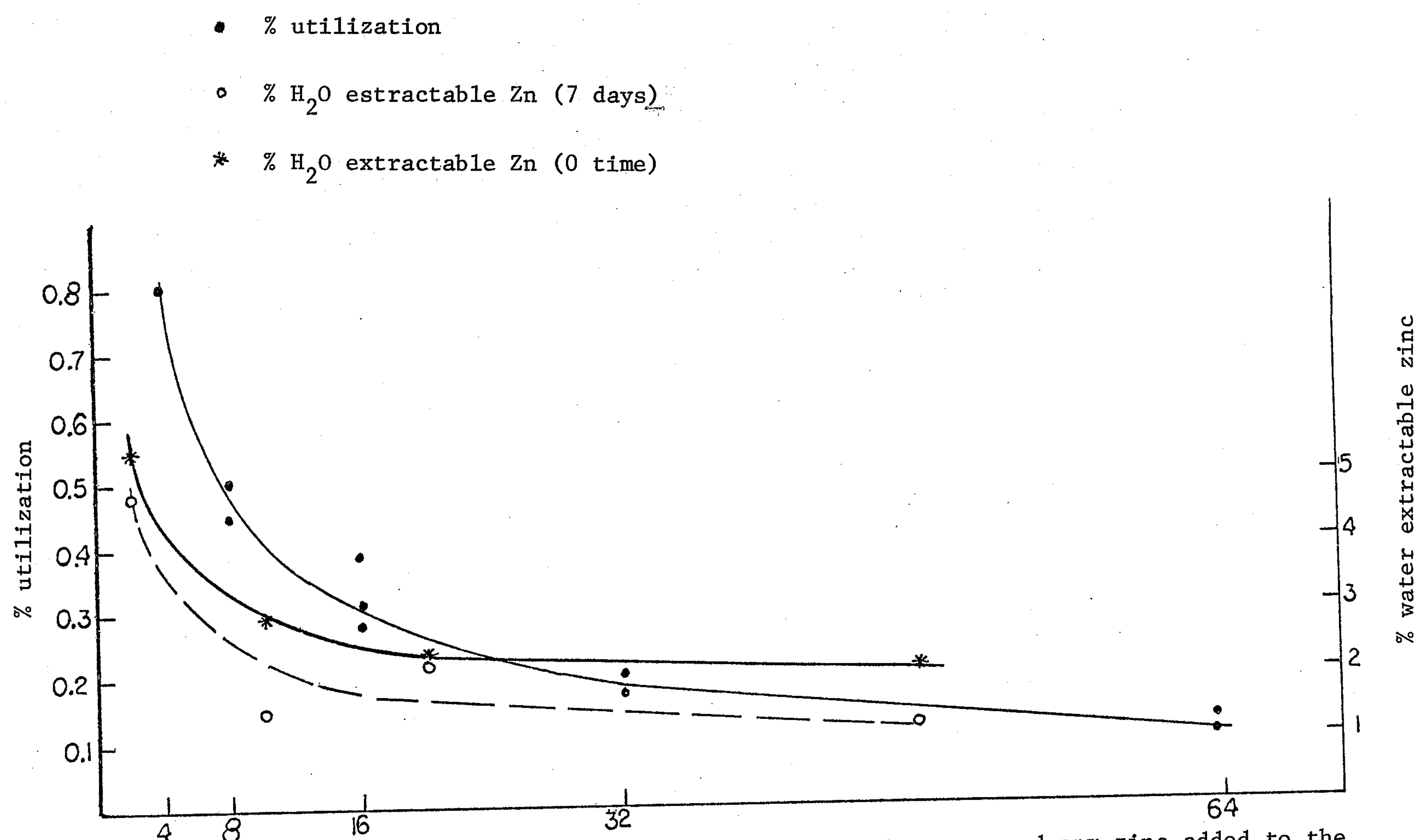


Figure 13. Effect of rate of added zinc at various volumes of zinc treated soil on the total zinc uptake by the above ground portion of black beans.



ppm zinc concentration in the fertilizer reaction zone and ppm zinc added to the soil in incubation Experiment[1]

Figure 15. Effect of zinc concentration in fertilizer reaction zone on percent utilization of added zinc by black beans and effect rate of added zinc (incubation exp.) on percent water extractable Zn.

[1]Akinyede, F. (1977), Master thesis submitted to Faculty of Graduate Studies and Research, Univ. of Manitoba

Table 42. Effect of volume of soil treated with zinc and rate of zinc on total zinc uptake by the above ground portion of black beans. (Comparison among five means within each rate of zinc.)[1]

Zinc (ppm) \ Soil volume treated w/Zn	1%	12.5%	25%	50%	100%
	(µg)				
4	51.4_a	63.0_a	77.1_a	111_a*	180_b*
8	82.8_a	81.6_a	94.6_a*	179_b*	245_b*
16	61.7_a	93.9_{ab}*	126_b*	192_b*	281_c*
Control	19.3				

Table 43. Effect of volume of soil treated with zinc and rate of zinc on total zinc uptake by the above ground portion of black beans. (Comparison among three means within each volume of soil treated with zinc.)[1]

Zinc (ppm) \ Soil volume treated w/Zn	1%	12.5%	25%	50%	100%
	(µg)				
4	51.4_a	63.0_a	77.1_a	111_a*	180_a*
8	82.8_a	81.6_a	94.6_a*	179_{ab}*	245_{ab}*
16	61.7_a	93.9_a*	126_a*	192_b*	281_b*
Control	19.34				

[1]Tukey's test at 5% level used. Treatment means are not significantly different when followed by the same letter.

*: significantly higher than the control at 5% level.

used for this experiment (Lakeland A) found that the percent recovery of water extractable zinc decreased with increasing rate of added $ZnSO_4$ both after seven days and zero time. Plotting this data in the same figure with percent utilization of zinc by black beans versus added zinc in the reaction zone shows that both percent utilization of zinc by black beans from fertilizer reaction zone and percent water extractable zinc diminish with concentration of added zinc. The trend for both percent utilization and water extractable zinc were quite similar (Figure 15). Thus it would appear that the availability of added zinc to black beans was closely related to water extractable zinc.

In general it would appear that increasing the size of the reaction zone and keeping the amount of zinc added to soil constant resulted in an increase in zinc uptake (Table 42). When 4 and 16 ppm of zinc were added to the soil there were positive linear relationships between total zinc uptake and size of the reaction zone (Figure 12). However with the 8 ppm of zinc treatment there was only a small increase in zinc uptake when the reaction zone increased from 1 to 25%; beyond that point there was a general increase in zinc uptake with size of the reaction zone (Figure 12).

To summarize then the data indicate that when the volume of zinc reaction zone was constant, a curvilinear relationship between zinc application rate and zinc uptake into black beans existed. When rate of zinc application was held constant zinc uptake increased with increasing size of the fertilizer reaction zone. In order to explain these results the following hypothesis is proposed:

Within reasonable limits the amount of zinc taken up from added zinc is proportional to the mass of roots in the fertilizer reaction zone times

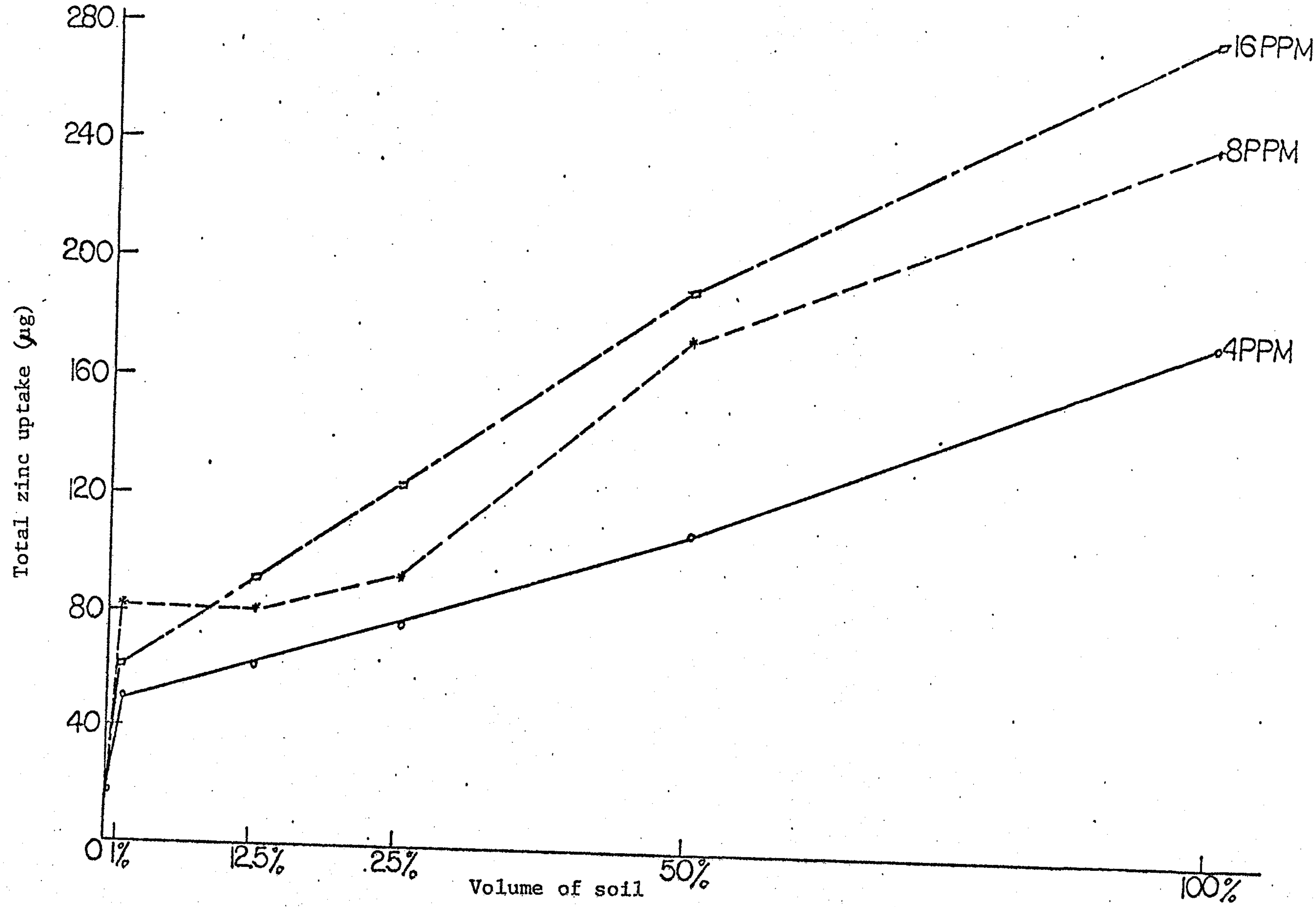


Figure 12. Effect of volume of soil treated with Zinc at various zinc rates on the total zinc uptake by the above ground portion of black beans.

the concentration of zinc in the soil solution of the reaction zone. For reasonably sized reaction zones, doubling the size of the reaction zone, most likely double the root mass in the reaction zone and thus the potential for absorbing zinc is doubled. The validity of this statement is demonstrated in Figure 16, where uptake of fertilizer zinc (zinc taken up by plants in zinc treated soil minus zinc taken up by plants in control treatments) was plotted versus the size of reaction zone. The concentration of zinc in the reaction zones were 4, 8, 16, 32, 64, and 128 ppm. These concentrations were obtained by adding 4, 8, and 16 ppm of zinc (based on 5000 g soil) to 12.5, 25, 50, and 100% of soil mass. This Figure shows a linear relationship between zinc uptake by black beans and size of the reaction zone existed, when concentration of zinc within the reaction zone was held constant. It would appear that doubling the size of the zinc reaction zone, most likely doubled the mass of roots in contact with the fertilizer zinc, and hence doubled fertilizer zinc uptake by black beans. These results appear to confirm the first part of the proposed hypothesis.

When the amount of zinc added to the soil is kept constant, doubling the reaction zone will halve the concentration of added zinc. If the concentration of zinc in the soil solution is directly related to the amount of zinc added, the concentration of zinc in soil solution should also be halved; doubling the size of the reaction zone and keeping the amount of zinc added constant, should therefore, have no affect on zinc utilization by the plant. However, it was shown that the uptake of zinc actually increased by increasing the size of the reaction zone (Figure 12). There are two possible explanations for this happening;

either the concentration of zinc in the soil solution was not reduced to one half but something less than that or the uptake of zinc by the roots was not directly related to the concentration zinc in the soil solution. The second explanation does not seem plausible since some workers have reported that zinc concentration in plants increases directly proportional to the concentration of zinc in solution (Paulsen and Rotimi, 1968). Hence it would appear that zinc concentration of soil solution in the reaction zone is most likely not reduced to one half when we double the size of the reaction zone. Results obtained by Akinyede (1977) showed that percent water soluble zinc decreased with increased amount of added zinc. Which is also in agreement with the second part of the proposed hypothesis.

Thus it may be concluded for fertilizer reaction zone of reasonable size, that the curvilinear relationship of zinc utilization by the plant with an increasing rate of added zinc (keeping the size of reaction zone constant); and the increase in zinc uptake by the plant with an increasing size of the reaction zone (keeping the concentration reaction zone constant) can both be explained by the fact that the amount of zinc in soil solution arising from added zinc is not directly proportional to the amount of zinc added.

Phosphorus concentrations in the shoots were not greatly effected by the addition of zinc. However, decreases were observed when higher rates of zinc were mixed with 50 or 100% of the soil (Table 46). The above data may indicate that black bean plants had a luxury consumption of phosphorus when zinc concentrations in the plant were inadequate.

In contrast with those of the shoots, phosphorus concentrations

Table 44. Effect of volume of soil treated with zinc and rate of zinc on total zinc uptake by the root of black beans. (Comparison among five means within each rate of zinc.)[1]

Soil volume treated w/Zn / Zinc (ppm)	1%	12.5%	25%	50%	100%
	(μg)				
4	36.1_a	40.9_a	39.4_a	66.2_a*	46.1_a
8	37.0_a	63.1_a*	43.5_a	58.1_a*	59.5_a*
16	46.9_a	71.0_{ab}*	73.7_{ab}*	105_b*	108_b*
Control	4.43				

Table 45. Effect of volume of soil treated with zinc and rate of zinc on total zinc uptake by the root of black beans. (Comparison among three means within each volume of soil treated with zinc.)[1]

Soil volume treated w/Zn / Zinc (ppm)	1%	12.5%	25%	50%	100%
	(μg)				
4	36.1_a	40.9_a	39.4_a	66.2_a*	46.1_a
8	37.0_a	63.1_a*	43.5_a	58.1_a*	59.5_{ab}*
16	46.9_a	71.0_a*	73.7_a*	105_a*	108_b*
Control	4.43				

[1] Tukey's test at 5% level used. Treatment means are not significantly different when followed by the same letter.

*: significantly higher than the control at 5% level.

Table 46. Effect of volume of soil treated with zinc and rate of zinc on phosphorus concentration of the above ground portion of black beans. (No significance of difference among different volumes of soil treated with zinc or different rates of zinc.)

Zinc \ Soil volume treated w/Zn	1%	12.5%	25%	50%	100%
(ppm)	(mg/pot)				
4	6.14	3.08	2.83	2.75	3.30
8	5.06	4.43	3.46	2.83	3.27
16	4.49	3.54	2.94	3.38	2.98
Control	3.36				

Table 47. Effect of volume of soil treated with zinc and rate of zinc on root phosphorus concentration of black beans. (No significance of difference among different volumes of soil treated with zinc or different rates of zinc.)

Zinc \ Soil volume treated w/Zn	1%	12.5%	25%	50%	100%
(ppm)	(mg/pot)				
4	2.30	1.64	2.43	2.40	2.70*
8	3.25*	2.00	2.50	2.72*	2.25
16	1.56	1.85	3.62*	2.04	3.19*
Control	1.15				

*: significantly higher than the control at 5% level.

in the roots were increased with both rate of added zinc and size of the reaction zone compared to that of the control. However these increases were significant only when 4 and 16 ppm of zinc were mixed with 100% of soil, when 8 ppm zinc were mixed with 50% of the soil and when 16 ppm zinc was mixed with 12.5% of the soil (Table 47). None of the increases in phosphorus concentration among treatments was significant (Table 47).

Application of zinc generally increased total phosphorus uptake into shoots of black beans (Table 48). These increases were significant only when 4 ppm of zinc was mixed with the largest reaction zone and when 8 ppm zinc was mixed with 1 or 12.5% of the soil.

Zinc application increased total phosphorus uptake by the roots compared to that of the control treatment. These increases were significant only when 4 and 16 ppm of zinc were mixed with the largest reaction zone (Table 49). In contrast to those of shoots, total phosphorus uptake by the roots generally tended to increase with increase in size of the reaction zone. However none of the increases was significant (Table 49).

Percent nitrogen in the aerial portion of the plant was higher than that of the control for all the treatments. However, these increases were not significant (Table 50).

Application of zinc increased total nitrogen uptake by the plant more than three fold in all treatments compared to that of the control. These increases were statistically significant when the zinc was mixed with 50 or 100% of the soil, when higher rates of zinc were mixed with the 12.5% of the soil, and when 8 ppm zinc was mixed with 1% of the soil (Table 51).

Table 48. Effect of volume of soil treated with zinc and rate of zinc on total phosphorus uptake by the above ground portion of black beans. (No significance of difference among different volumes of soil treated with zinc or rates of zinc.)

Zinc \ Soil volume treated w/Zn	1%	12.5%	25%	50%	100%
(ppm)			(mg)		
4	32.3	26.4	26.5	28.6	42.5*
8	38.2*	46.4*	31.1	32.4	33.8
16	32.9	36.8	29.1	35.7	29.1
Control	10.4				

Table 49. Effect of volume of soil treated with zinc and rate of zinc on total phosphorus uptake by the root of black beans. (No significance of difference among different volumes of soil treated with zinc or rates of zinc.)

Zinc \ Soil volume treated w/Zn	1%	12.5%	25%	50%	100%
(ppm)			(mg)		
4	5.08	4.01	5.83	7.11	8.33*
8	6.24	6.73	6.05	7.60	5.75
16	3.74	5.78	7.12	7.18	8.6*
Control	1.03				

*: significantly higher than the control at 5% level.

Table 52. Percent utilization of zinc added as $ZnSO_4$ as influenced by concentration of zinc in the total soil and in the zinc fertilizer zone and as influenced by proportion of total soil volume treated with zinc.

Proportion of soil volume receiving $ZnSO_4$.

Zn Concentration in entire soil mass (ppm)	12.5		25		50		100	
	Zn Conc. Ferti.zone	% Utilization	Zn Conc. Ferti.zone	% Utilization	Zn Conc. Ferti.zone	% Utilization	Zn Conc. Ferti.zone	% Utilization
4	32	0.21	16	0.28	8	0.45	4	0.80
8	64	0.15	32	0.18	16	0.39	8	0.50
16	128	0.09	64	0.13	32	0.21	16	0.32

Table 50. Effect of volume of soil treated with zinc and rate of zinc on percent nitrogen of the above ground portion of black beans. (No significance of difference among different volumes of soil treated with zinc or rates of zinc.)

Zinc \ Soil volume treated w/Zn	1%	12.5%	25%	50%	100%
(ppm)					
4	2.80	2.24	1.91	2.04	1.76
8	3.00	2.01	2.03	2.41	2.18
16	2.67	1.99	2.01	2.03	2.25
Control	1.80				

Table 51. Effect of volume of soil treated with zinc and rate of zinc on total nitrogen uptake by the above ground portion of black beans. (No significance of difference among different volumes of soil treated with zinc or rates of zinc.)

Zinc \ Soil volume treated w/Zn	1%	12.5%	25%	50%	100%
(ppm)	(mg)				
4	169	190	179	212*	246*
8	236*	207*	181	304*	225*
16	193	204*	198*	215*	210*
Control	50.0				

*: significantly higher than the control at 5% level.

The increase in nitrogen uptake due to zinc application could be related to the effect of zinc on symbiotic nitrogen fixation by black beans. At time of harvesting both numbers and size of the nodules on roots of those plant which were grown in the zinc treated soil were increased over that of the control. This observation is in agreement with the finding of Kapur et al., (1976) who reported that application of 5 to 10 ppm of zinc to soil increased nitrogen fixation, nodules number, nodules weight, and nodules leghemoglobin content of soybeans.

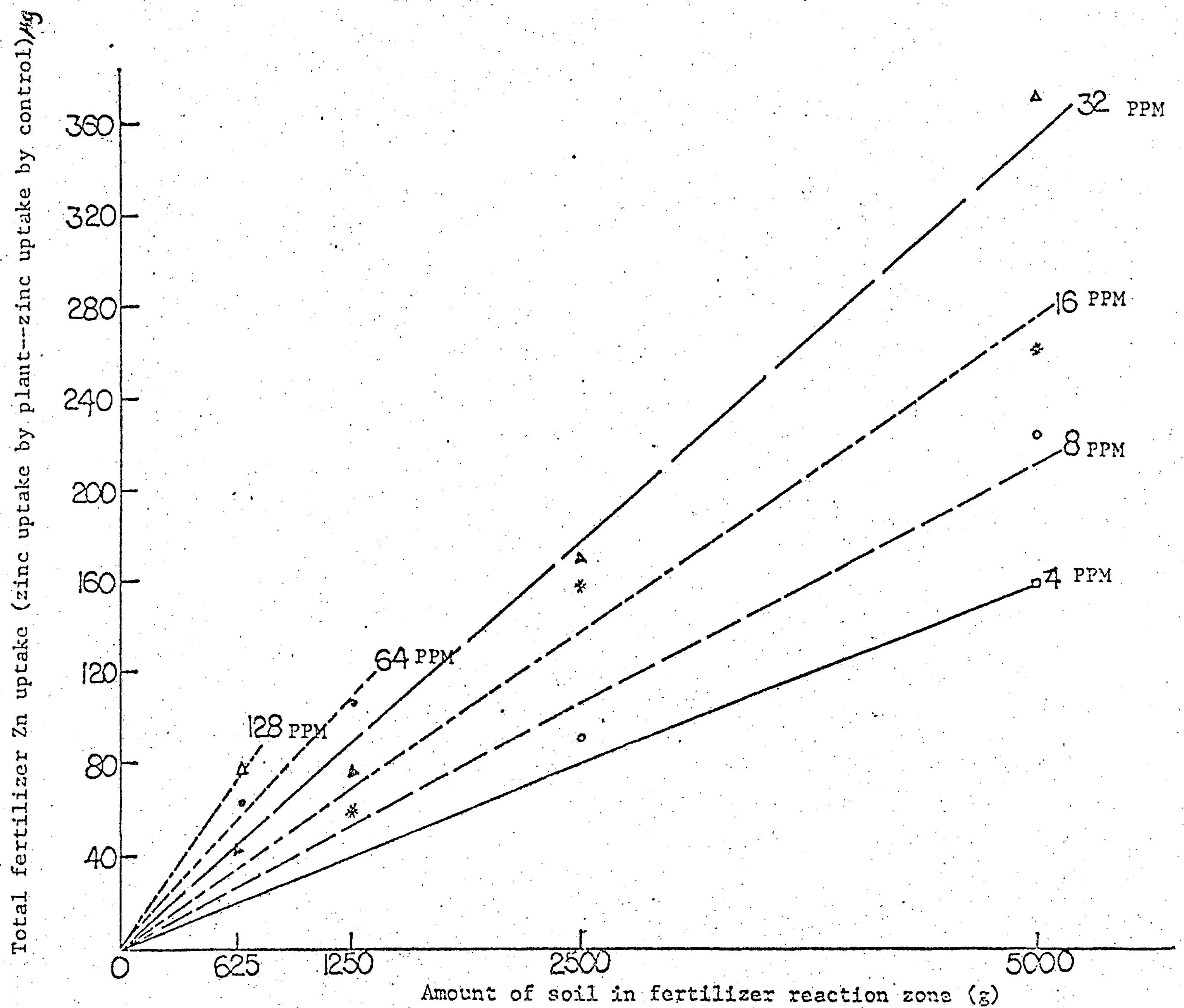


Figure 16. Total uptake of fertilizer zinc at various fertilizer zinc concentration in fertilizer reaction zone as influenced by amount of soil in reaction zone.

Experiment 5

Yield of Black Beans and Utilization of Phosphorus and Zinc as Influenced by Placement of ZnMNS.

In the second growth chamber experiment it was found that the method of application of zinc was very important in zinc utilization by black beans. When zinc was applied as a point source it supplied little or no zinc to black beans and it did not increase yield. When zinc was banded or mixed throughout the soil an increase in dry matter resulted. Therefore, it was thought that the commercial product ZnMNS which has definite pellet size should be looked at with regard to its proper placement. ZnMNS is a readily available zinc source in Manitoba.

ZnMNS fertilizer consists of 9% nitrogen, 20% sulfur, 1.5% manganese and 15% zinc as ammonium sulfate, manganese ammonium sulfite and zinc ammonium sulfite. In a 200 g sample of ZnMNS it was found that 96% of ZnMNS granules were between 2 and 4 mm in size.

Rate treatments consisted of 0 and 8 ppm of zinc based on total weight of soil. Placement treatments consisted of: 1) Banding ZnMNS in two parallel lines 5 cm apart and 3.5 cm below the soil surface of each pot. Black bean seeds were then placed 1 cm above the fertilizer level between the 2 parallel bands. 2) ZnMNS in pellet form was mixed with the soil, to accomplish this, one thousand grams of soil were placed in the pot. Four ZnMNS pellets were placed at each corner of a square (15 cm by 15 cm) on top of this 1000 g layer this was repeated with 3 additional 1000 g layers of soil, and finally the last 1000 g of soil were placed on top of the soil. The squares were rotated such that the pellets were not located in vertical lines directly above one another. 3) ZnMNS was finely ground and thoroughly mixed with the entire soil mass with 50 g of soil, then the 50 g of soil was mixed with 200 g of soil, then was mixed with an additional 1000 g of soil and finally was mixed with the remaining soil of each pot as uniformly as possible.

The third method of application was included so that methods 1 and 2 could be compared with the best treatment in the previous experiment.

The results of this experiment are given in Tables 53 and 54. The dry matter yield of the aerial portion of black beans was increased by both banding and mixing the pellets in the soil, however these increases were not significant (Table 53). An extraordinarily large increase occurred in yield when ZnMNS was finely ground and mixed throughout the soil. The same trend was observed in root dry matter yield (Table 54). These very large increases in yield could be attributed to added zinc, but ZnMNS also contained manganese, nitrogen and sulfur, which could have contributed to an increase in yield. With regard to nitrogen it is reasonably safe to assume that placement had a small or no effect, and therefore the difference among treatments could not be due to nitrogen. Each pot had already received 80 ppm of sulfur as K_2SO_4 which was more than sufficient for plants needs and hence no response to sulfur was expected. Analyses of the plant material for manganese showed that manganese concentration in the plant did not change with any of the three placement methods. Therefore it may be concluded that the large increase in dry matter yield when ZnMNS was finely ground and mixed throughout the soil was mainly due to added zinc.

The above-mentioned results are in agreement with findings of other investigators. Terman and Mordvedt (1965) found that corn plants

Table 53. Yield of Black Bean Shoots and Utilization of Phosphorus and Zinc as Influenced by Placement of ZnMNS. (I)

Treatments: plant variables	No zinc	8(ppm) Zn Banded	8(ppm) Zn Mixed Pellet	8(ppm) Zn Mixed Powdered
Dry Matter (g/pot)	3.0_a	6.5_a	4.5_a	17.2_b
Zn Concentration (ppm)	6.3_a	5.8_a	6.1_a	15.6_b
Total Zn (ug/pot)	19.3_a	38.2_a	28.0_a	279.5_b
P. Concentration (mg/g)	3.3_b	6.2_c	5.8_c	1.2_a
Total P (mg)/pot	10.4_b	41.2_a	27.3_{ab}	21.5_{ab}

Table 54. Yield of Black Bean Roots and Utilization of Phosphorus and Zinc as Influenced by Placement of ZnMNS. (I)

Treatments: plant variables	No zinc	8(ppm) Zn Banded	8(ppm) Zn Mixed Pellet	8(ppm) Zn Mixed Powdered
Dry Matter (g/pot)	0.89_a	2.0_a	1.5_a	4.1_b
Zn Concentration (ppm)	4.9_a	21.4_b	20.6_b	25.0_c
Total Zn (ug/pot)	4.1_c	44.6_b	31.1_{bc}	104.5_a
P. Concentration (mg/g)	1.1_a	2.2_a	4.2_a	1.8_a
Total P. (mg/pot)	1.3_b	4.5_{ab}	5.8_{ab}	7.6_a

(I) Tukey's test at 5% level used. Means of treatments are followed by the same letter are not significantly different.

showed little or no response to inorganic zinc carriers such as zinc oxide or zinc phosphate applied as 1.6 to 0.8 mm granules. But satisfactory response was observed when 0.15 mm granules were added. They concluded that the availability of inorganic zinc to crops from soil application is related to distribution of zinc in the soil and fineness of zinc fertilizer. Mordvedt and Giordano (1967) in a greenhouse study with corn in a sandy loam soil found that when zinc oxide, zinc sulfate or zinc sulfite were incorporated with ammonium nitrate, ammonium polyphosphate or concentrated super phosphate, the response to fertilizer zinc was related to the total number of granules applied per pot.

Zinc concentration in the aerial portion of the plant did not increase with ZnMNS applied as a band or as mixed pellets. However it was increased to 15.6 ppm (Table 53) when ZnMNS was finely ground and mixed throughout the soil. Zinc concentration in the roots was the highest when finely ground zinc was mixed throughout the soil. In all of the treatments zinc concentration in the roots was higher than in the shoots. This higher concentration of zinc in roots was reported by Sharma et al., (1968) for corn plants in a study of zinc phosphorus interaction. Similar results were found by Paulsen and Rotimi (1968) in soybean plants. Zinc concentration in the roots increased significantly by addition of 8 ppm zinc in all treatments compared to that of the control (Table 54). However the highest concentration was obtained when finely powdered ZnMNS was mixed with the soil.

Total zinc uptake for the aerial portion of plant increased with the band and mixed pellet treatment; although the increases were not significant. The trend were similar to those for yield. However they did seem to indicate that the black bean plants were taking up zinc from fertilizer pellets. For the roots these treatments gave considerably higher total zinc values than the control, although these increases were not significant. In contrast to the band and mixed pellets treatments there was a large increase in total zinc uptake by both the aerial portion and the roots of black beans when ZnMNS was finely powdered and mixed with soil, (Tables 53 and 54).

These results clearly indicate again that the most efficient method of adding zinc fertilizer is to mix it with soil as uniformally as possible. The superiority of the powdered mixed treatment in this experiment is probably due to both an increase in the number of roots in contact with zinc as well as the per cent of the material which is soluble. However in this case the number of roots probably played the major role. In band and mixed pellet treatments there were small pockets of highly concentrated zinc which would lead to a very small number of roots being in contact with the fertilizer, thus limiting the ability of root to take up zinc from the fertilizer.

Phosphorus concentration in the aerial portion of the plant increased significantly compared to that of the control when ZnMNS was banded or the pellets were mixed with the soil. However it was significantly reduced when finely ground ZnMNS was mixed throughout the soil. Addition of zinc in all treatments did not significantly change the phosphorus concentration in the roots.

Total phosphorus uptake by aerial portions of the plant were increased by zinc application, however the difference was significant only when ZnMNS was banded in the soil. Although the differences were not significant, total phosphorus uptake by the aerial portion of black beans was higher in banded application than the other treatments, and the reverse was true in the roots. These trends might indicate that high levels of zinc in the plant had a depressive effect on the phosphorus uptake.

SUMMARY AND CONCLUSIONS

Earlier work with some calcareous Manitoba soils indicated that these soils do not supply sufficient quantities of zinc for crops such as flax. It was found that zinc application to these soils increased the yields of flax and wheat. Since 1973 the Soil Science Department of the University of Manitoba have been studying the nutrient requirements of annual legumes. It has been reported that annual legumes grown on calcareous soils, especially Phaseolus vulgaris respond to zinc application. Thus a series of growth chamber experiments on calcareous soils were conducted to determine if these soils are zinc deficient and to determine, if possible, the critical levels of zinc in faba beans and black beans and the best method and rate of application of inorganic zinc carriers.

The first growth chamber experiment was conducted to study the effect of added zinc on yield and zinc utilization by faba beans on six Manitoba soils having 0 to 23% $CaCO_3$. The yield of faba beans significantly responded upon addition of 2 ppm zinc in all soils which had less than 1.1 ppm DTPA extractable Zn. No yield increase was observed in the a soil which had 3.5 ppm DTPA extractable Zn. Zinc concentration in faba bean plants significantly increased in all soils with the application of 2 ppm zinc. Total zinc uptake by faba beans was positively correlated with soil DTPA extractable Zn and negatively correlated with soil pH. Addition of 2 ppm zinc to the soil increased total zinc uptake approximately 3 fold in all soils. Total zinc uptake in treated soil was also positively correlated with soil DTPA extractable Zn and negatively correlated with soil pH. This would indicate that factors affecting native zinc in the soil also affected the added zinc.

The second growth chamber experiment was established to evaluate the effect of method and rate of zinc applied as $ZnSO_4$ on yield and zinc utilization of black beans. When zinc was applied as a point source there was no yield increase, no increase in zinc concentration in plant and of course no increase in total zinc uptake. However when zinc was either banded or mixed with the soil an increase in yield was observed. Application of more than 2 ppm of zinc both in band and mixed treatments, did not give further significant increases in dry matter yield. This would indicate that under the experimental conditions 2 ppm zinc were sufficient. Zinc concentration in plants and total zinc uptake were increased when zinc was mixed throughout the soil. There was an apparent linear relationship between rate of zinc application and zinc concentration in the plant when zinc was mixed with the soil. When zinc was banded in the soil, zinc concentration in the plant was significantly smaller than the mixed treatments. These data strongly indicate that mixing the zinc as uniformally as possible with the soil is the most effective method in increasing the zinc concentration in black bean plants.

The influence of different rates of added phosphorus on zinc utilization and yield of black beans was studied, since there was a possibility that the large response in yield to added zinc in the second experiment was due to the relatively high rate of added phosphorus. Without added zinc no significant response to phosphorus occurred. When 8 ppm of zinc was added to the soil a strong linear response occurred up to 80 ppm of phosphorus. However beyond that no further increase was observed. The data for dry matter yield indicated a strong positive interaction between zinc and phosphorus added to the soil, thus indicating that the soil was both zinc and phosphorus deficient. At both levels of zinc, inverse relationships between zinc and phosphorus concentration in the plant were obtained. Zinc concentration in the plant was decreased with addition of phosphorus for both zinc treated and untreated soil. However, these decreases in zinc concentration were significant only when 8 ppm of zinc was added. The majority of these decreases could be attributed to dilution, however beyond 80 ppm of phosphorus there appeared to be a reduction in zinc concentration which could be attributed to effect of phosphorus on zinc uptake and/or translocation. This would indicate that higher rates of phosphorus aggrevated the already existing zinc deficiency. It can be concluded that in the second growth chamber experiment added phosphorus merely corrected a phosphorus deficiency and did not create the zinc deficiency. The data of phosphorus concentration in the plant indicated that when plants were zinc deficient they took up luxury amount of phosphorus. However when adequate zinc was added the phosphorus concentration in the plant appeared to be independent of rate of added phosphorus.

The fourth growth chamber experiment was a continuation of the second growth chamber experiment to further study the effect of size of reaction zone and rate of added zinc on yield and zinc utilization by black bean. In general black beans yield was increased for low rates of zinc with increasing size of reaction zone. However at higher rates, increasing the size of reaction zone was not as effective.

Generally both increasing the rate of added zinc and size of the reaction zone increased the zinc uptake by black beans. Zinc uptake by the plants was increased with increasing rate of added zinc in all sizes of reaction zones. The relationship between rate of added zinc and zinc uptake by the plant was curvilinear. There was also a curvilinear relationship between per cent utilization of added zinc and concentration of zinc in the reaction zone. These curvilinear relationships could have been due to several factors including the ability of the plant root to take up zinc and/or the chemical availability of added zinc. In general increasing the size of the reaction zone (keeping the amount of zinc added constant) increased zinc uptake by the aerial portion of the plant. From these data and from data of other workers it was hypothesized that within reasonable limits plant zinc uptake from the fertilizer reaction zone is proportional to the mass of the roots in the fertilizer reaction zone times the zinc concentration of soil solution in the reaction zone.

Percent nitrogen in the aerial portion of black beans generally increased with zinc application, but these increases were not significant. With all rates of zinc and size of the reaction zones, total nitrogen uptake by the aerial portion of black beans was increased by zinc application. However the increases were significant only with the larger reaction zones. Since both numbers and size of nodules on the roots of those plants which were grown on the zinc treated soil were increased over that of control, it may be concluded that zinc application had an effect on symbiotic nitrogen fixation by the black beans.

The effect of method of application of ZnMNS on yield and zinc utilization by black beans was studied in the fifth experiment. Data showed that mixing powdered ZnMNS was superior in supplying zinc to black beans than either banding or mixing ZnMNS. These results were most likely due to an increased number of roots being in contact with zinc in powdered and mixed throughout treatment, as well as the greater water solubility of the powdered ZnMNS. In these particular treatments it was concluded that probably the number of roots in contact with fertilizer reaction zone was the major factor determining zinc uptake. These results have a practical significance since farmers would apply this fertilizer in pelleted form either banded or mixed with the soil.

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