THE UNIVERSITY OF MANITOBA

THE EFFECT OF N, P, K, Zn, Cu, AND Fe, ON BLACKBEAN (*Phaseolus vulgaris* (L.) cv. 'Black Turtle') YIELD AND QUALITY.

by

David Bruce McKenzie

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ABSTRACT

The effect of various rates, carriers, and methods of placement of N, P, K, Zn, Cu, and Fe fertilizers on blackbean (Phaseolus vulgaris (L.) cv. 'Black Turtle') yield and quality was examined in field and growth chamber studies. In field trials, nitrogen addition did not generally increase yields when blackbeans were inoculated; however, a yield response indicated that about 100 kg N/ha should be added when soil nitrogen levels are low, spring temperatures are cool, and yield expectations are high. Irrespective of yield response, 100 kg N/ha was found to increase blackbean seed protein content and total N uptake.

Various rates of seed placed, sidebanded, as well as broadcast and incorporated phosphorus generally did not increase blackbean yield or P uptake in field trials. Seed placed P decreased germination and seed yield. Blackbeans yielded extremely well without added P on soils low in available P; therefore, P fertilizer addition is not recommended. Blackbean yields were not increased by potassium addition at three field sites, since soil potassium levels were high to very high. Foliar applications of NPKS during pod formation did not affect seed yield at three sites.

Evidence was found that some Manitoba soils may be low or deficient in plant available zinc, copper, and/or iron. Zn addition increased forage yields at two field sites and seed

yield at one field site. Zinc chelates were more effective than inorganic carriers in increasing blackbean Zn concentrations and uptake. Zinc sulfate was more effective than the other inorganic zinc carriers, but only when zinc sulfate solution was sprayed on the soil and incorporated. Banded or incorporated Zn M-N-S was ineffective in increasing blackbean yield, Zn content, or Zn uptake in the year of application whether it was added in pellet or powdered form. Banded Zink Gro pellets and banded $ZnSO_4 \cdot 7H_2O$ were also ineffective in the year of application. In a growth chamber study, Zink Gro was found to be an effective zinc fertilizer when the pellets were finely ground and thoroughly mixed with the soil. Soil DTPA zinc critical levels determined in small pot experiments were not very helpful in predicting blackbean yield response to zinc fertilizer in the field. Therefore, until further research is conducted plant tissue analysis is recommended. Blackbeans in the early flowering stage were determined to be zinc deficient when tissue concentrations were less than 10 ug Zn/g dry matter. Zinc chelate addition, at a rate of 1 to 2 kg Zn/ha, is recommended when blackbeans are to be grown on a zinc deficient soil. Zinc sulfate solution sprayed on the soil and incorporated, at a rate of 10 to 20 kg Zn/ha, is the second best method of zinc addition. Addition of 2 kg Cu/ha, as Na_2Cu EDTA solution sprayed on the soil and incorporated, increased seed yield at one of two field sites tested. A soil critical level of 0.30 ug Cu/g soil DTPA extractable copper was estimated. Blackbeans in the early pod formation stage with less than 3.8 ug Cu/g dry matter were tentatively considered to be copper deficient. Further research is necessary to establish a precise critical value for copper deficiency. A visual response to foliar application of iron was noted early in the growing season at one field site.

The influence of temperature on P-Zn interactions in blackbeans was investigated in a growth chamber study. Blackbean plants were severely zinc deficient at both 20° c/15° c (day/night) and 28° c/23° c when Zn fertilizer was not added. The plants were P deficient without added P or Zn, and were marginally deficient to deficient at all levels of added P when Zn was added. Without added Zn, increasing rates of added P aggravated plant zinc deficiency and decreased yield at 20° c/15° c but not at 28° c/23° c. The increase in temperature markedly increased soil and fertilizer zinc availability to blackbeans. Much of the increase went to increased dry matter yields, so plant Zn concentrations were similar for each P-Zn treatment. The temperature increase did not appear to affect soil or fertilizer P availability to blackbeans; however, P concentrations required for growth were markedly decreased by the increase in temperature. At 28° c/23° c, Zn addition reduced P uptake by the above ground portion of the plant at high rates of added P, and was thought to be controlling P uptake by the roots and/or translocation into the above ground portion of the plant. At 20° c/15° c, Zn addition increased P uptake because high rates of added P reduced Zn uptake and dry matter yield when Zn was not added.

In two field studies, P and Zn were mixed into the soil at rates designed to give similar P and Zn fertilizer concentrations in the furrow slice as were added to the growth chamber soil. High rates of added P reduced blackbean Zn uptake at the Winkler site, and reduced plant Zn concentrations to marginally deficient levels at both sites. At the Morden site, added Zn increased plant Zn concentrations to sufficiency levels. At the Winkler site, added Zn did not increase plant Zn concentrations over the control treatment, but prevented a P induced reduction in plant Zn uptake when P fertilizer was added. Added Zn appeared to have a regulating effect on the amount of P being translocated within the plant. Although soil P and Zn levels at the Winkler site were similar to P and Zn levels in the growth chamber soil; blackbeans grown at the field site without added P or Zn yielded extremely well and showed no symptoms of either Zn or P deficiency. This indicates that the restricted soil volume was the major factor causing P and Zn deficiencies in pot experiments. Low spring soil temperatures may enhance P or Zn deficiencies in crops grown on some Manitoba soils, but these deficiencies should lessen as the soil increases in temperature.

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I. INTRODUCTION

Field beans have been grown in Manitoba for the past fifteen to twenty years. They are well adapted for production in areas of southern Manitoba with suitable soil types and adequate heat unit accumulation. Traditionally, field beans have been sold to the canning industry to be used in pork and bean production or in soup. Agriculturalists consider field bean production to be a method of crop diversification as well as a valuable cash crop. Machinery for growing beans is specialized and expensive and the risk of crop failure is higher than in cereal production, but the crop has been highly profitable for the farmers growing it.

In 1975, blackbeans were introduced as a commercial crop in Manitoba. The main demand for this type of bean is in the export market because it is a traditional food in many areas of Latin America. Very little research had been done on the nutritional needs of field beans in Manitoba. Therefore, in 1976, the Department of Soil Science at the University of Manitoba commenced a three year study with the purpose of establishing fertilizer recommendations for field grown beans. This thesis represents a portion of the investigation in which the effect of adding N, P, K, Zn, Cu, and Fe on blackbean yield and quality was examined at seven field sites and in two growth chamber studies.

II. LITERATURE REVIEW

A knowledge of crop nutrition is essential in order to maximize yields and control quality in field crops. There are seventeen elements which are essential to the growth of all plants. Carbon, hydrogen, and oxygen are supplied by air and water. Normally, the remaining nutrient elements are supplied by the soil. Nitrogen, phosphorus, potassium, sulfur, calcium, and magnesium are required in large amounts in most plants and are termed macro-nutrients. Copper, manganese, zinc, iron, boron, molybdenum, cobalt, and chlorine are required in small amounts by most plants and are termed micro-nutrients.

Nutrient deficiencies can cause decreases in crop yield and/or quality. To avoid this, soil and plant tests have been developed to predict potential nutrient deficiencies. Each test is often specific to a single nutrient-element, and the test values must be correlated with growth or quality responses on a crop-by-crop basis. Soil tests have the advantage of predicting nutrient deficiencies prior to seeding, allowing the growers to fertilize as they seed. Plant tests can be used along with soil tests, but often do not give the grower enough time to correct a nutrient deficiency.

Soybeans and various other beans have been the subject of numerous nutrition studies. This review considers the nitrogen, phosphorus, potassium, zinc, copper, manganese, and iron nutrition of beans with special reference to Manitoba conditions.

A. Nitrogen.

1. Soil Nitrogen.

More than 95 percent of the total nitrogen in most surface soils is organically combined (Bremner 1965 b). However, only a small fraction of organic nitrogen in the soil becomes available to plants over the growing season and this is by conversion to inorganic forms. Inorganic forms of combined nitrogen, such as ammonium and nitrate, are readily taken up by plants in most soils. An exception is nonexchangeable ammonium which is unavailable to plants. Some subsoils have been reported to contain as much as 30 percent of their total-N in the form of nonexchangeable ammonium.

An estimate of the nitrogen supplying capacity of a soil would be valuable to growers to optimize their crop yields. Many methods of testing soils for plant available nitrogen have been proposed (Dahnke and Vasey 1973). These tests can be divided into tests for nitrogen availability indexes and tests for initial inorganic nitrogen. Nitrogen availability indexes are a measure of the potential of a soil to supply nitrogen to plants. If the amount of residual inorganic nitrogen is variable from year to year, as it is in Manitoba, it becomes necessary to include initial inorganic nitrogen in any nitrogen soil testing program. In Manitoba, the Provincial Soil Testing Lab measures water extractable nitrate-nitrogen to a 61 cm soil depth (Anonymous 1977). Late fall or early spring soil nitrate-nitrogen levels have been correlated with crop yields (Soper *et al*. 1971) as well as yield response to added fertilizer nitrogen for a variety of commercial crops. Nitrogen fertilizer recommendations are made on this basis.

Most plants have to depend completely on the soil or added fertilizer for their supply of inorganic nitrogen. However, legumes living in symbiotic association with certain types of *Rhizobium* bacteria have another source of nitrogen supply. They are supplied with atmospheric nitrogen which has been fixed by the *Rhizobium* bacteria. Ohlrogge (1964) reported that from one-half to two-thirds of a soybean crop's nitrogen requirements may be supplied by N-fixing bacteria with the remainder coming from the soil.

Due to this large supply of atmospheric nitrogen that is available to beans, fertilizer nitrogen addition to legumes is not recommended in Manitoba. Past research with fababeans (Richards 1977) has demonstrated that fertilizer nitrogen did not increase seed yields at any soil nitrate-nitrogen test level. The little nitrogen research done on peas and beans has also indicated a lack of yield response to applied nitrogen (Chubb 1961).

2. Plant Nitrogen.

Plants require nitrogen for their growth, development, and reproduction. Nitrogen is a constituent of all proteins, all enzymes, and many metabolic intermediates involved in synthesis and energy transfer. Worldwide, more crops are deficient in nitrogen than in any other element.

Nitrogen deficiency results in a paling of older leaves which may become yellow and abscise. Nitrogen in older leaves is mobilized and transported to the younger growing parts of the plant. Anthocyanin developement in stems, leaf veins, and petioles is a characteristic symptom, and this may result in red or purple colors. Overabundance of nitrogen often causes a great proliferation of stems and leaves (Bidwell 1974). The sufficiency range for nitrogen in bean leaves prior to flowering is 42.5 to 55.0 mg N/gram dry matter (Vitosh *et al*. 1978).

3. Effect of Nitrogen Additions on Bean Yields.

Whether or not nitrogen additions should be recommended for beans has been a controversial issue (Vincent 1965; De Mooy *et al*. 1973). Bean yield responses to nitrogen fertilizer have been inconsistent. De Mooy *et al*. (1973) attribute sporadic response to nitrogen fertilization to inefficient *Rhizobium* strains or to environmental factors which inhibit the growth of nodules. Molybdenum deficiency, drought, or waterlogging may also lead to poor nodulation and a yield response to added nitrogen.

Generally, in the literature, bean yield responses to added nitrogen are not common. Welch *et al*. (1973) studied soybean yield responses to added nitrogen at ten locations over several years in Illinois. Yields were significantly increased in only 3 out of 133 instances and these occured at high, uneconomical rates of nitrogen fertilizer. In Manitoba, Richards (1977) found that effectively nodulated fababeans did not respond to nitrogen additions even on soils low in nitrate-nitrogen.

Other authors have reported yield responses to applied nitrogen in soybeans (Bhangoo and Albritton 1972; 1976; Bishop *et al*. 1976) and in peas (Sosulski and Buchan 1978), but yield increases have usually been in the 10 to 20 % range. Sorensen and Penas (1978) suggested that soybean yield responses to added nitrogen fertilizer could occur in soils with low pH values or in soils with low levels of nitrate-nitrogen.

B. Phosphorus.

1. Soil Phosphorus.

Phosphorus exists in both inorganic and organic forms in the soil. Organic phosphorus is not directly available to plants but portions of it may become available to plants over the growing season through mineralization. Plants feed on inorganic phosphorus in the soil solution which at any one time contains only very small amounts of phosphorus. The soil solution is in dynamic equilibrium with sparingly soluble Al-, Fe-, Ca-, along with other phosphorus compounds which constantly renew soil solution phosphorus near plant roots (Thomas and Peaslee 1973).

An estimate of the phosphorus supplying capacity of a soil would be valuable in assisting growers to optimize their crop yields. In Manitoba, Olsen's sodium bicarbonate extractable phosphorus test (Olsen et al. 1954) has been found to be reasonably reliable for predicting yield responses of crops to added phosphorus fertilizer.

2. Plant Phosphorus.

Phosphorus plays an indispensable role in the energy metabolism of the plant. Phosphorus is important in photosynthesis, the electron transport chain, glycolysis, the pentose phosphate pathway, and is an integral part of the structure of organic compounds such as deoxyribonucleic acid (DNA), ribonucleic acid (RNA), and phytin (Bidwell 1974; Wallingford 1978).

As might be expected, phosphorus deficiency affects all aspects of plant metabolism and growth. Symptoms of phosphorus deficiency are loss of older leaves, anthocyanin development in stems and leaf veins, and an accumulation of soluble carbohydrates (Bidwell 1974). The range of phosphorus sufficiency in beans has been reported to be 2.5 to 6.0 mg P/gram dry matter (Vitosh et al. 1978). Melsted et al. (1969) reported the critical composition value of soybean leaves and petioles after first pod formation to be 3.5 mg P/gram dry matter.

3. Effect of Phosphorus Additions on Bean Yields.

Soybeans are considered less responsive to phosphorus fertilizers than other row crops (De Mooy *et al.* 1973). The fact that soybeans absorb most of the fertilizer phosphorus during the second and third months after planting forms a contrast to corn, which is characterized by very high rates of phosphorus uptake in the early stages of growth (Ohlrogge 1960). There have been reports that soybeans respond to phosphorus fertilizer only on soils low or very low in available P or under environmental conditions condusive to high yields (Ham *et al.* 1973; Ham and Caldwell 1978). The higher yielding soybean varieties have also been found to be responsive to phosphorus fertilizer applications, although only on soils with low levels of available phosphorus (Dunphy *et al.* 1966).

Various bean varieties have shown moderate yield increases when phosphorus fertilizers were applied. Field applications of 100 to 200 kg /ha of superphosphate were recommended for cowpeas (Rachie and Roberts 1974). Twenty-five percent yield increases have been reported for mung beans with 15 to 40 kg P_2O_5/ha fertilizer applications. Fababeans (Rogalsky 1972) and snapbeans (Mack *et al.* 1966) have also responded to added phosphorus when soil phosphorus levels were low. Oruc (1970) added phosphorus to field beans at rates up to 800 kg P_2O_5/ha and obtained moderate yield increases with each increase in added phosphorus. This may indicate that maximizing bean yields would require extremely large amounts of added phosphorus fertilizer.

Since the world's natural phosphate resources are limited, it would be desirable to use the most efficient method of phosphorus placement when fertilizing field crops. In soybeans, seed drilled "pop-up" phosphorus applications have been found to improve early plant growth (Ham *et al*. 1973). In Manitoba, Bailey (1976) reported that both soybeans and fababeans responded to 20 kg/ha of phosphorus placed with the seed, although higher rates of seed placed phosphorus resulted in decreased germination and restricted yield. Papanicolaou *et al*. (1977) added phosphorus to *Phaseolus vulgaris* and soybeans, and concluded that sidebanded phosphorus was far more efficient than broadcast and incorporated phosphorus.

C. Potassium.

1. Soil Potassium.

Most of the potassium that is readily available to plants exists as exchangeable ions principally on clay mineral surfaces (Rich 1968). This potassium is in dynamic equilibrium with potassium in the soil solution, and is exchanged when plants deplete the potassium levels in the soil solution. As the exchangeable potassium is removed, it is slowly replaced by non-exchangeable potassium from potassium-bearing minerals present in the soil. In general, sandy and sandy loam soils are low in plant available potassium.

A common measure of plant available potassium is the ammonium acetate soil test. Ammonium acetate extractable potassium has been reported to correlate well with bean yields (Vitosh et al. 1978). In Manitoba, application of potassium fertilizer to annual legumes is recommended when extractable potassium is less than 190 kg K/ha (0-15 cm) (Anonymous 1977).

2. Plant Potassium.

The function of potassium in plants is not clearly defined. Potassium appears to have no structural role in plants. However, it has been proposed that the key metabolic role of potassium may involve its capacity to activate a number of enzyme systems (Wilson and Evans 1968; Bidwell 1974).

Potassium deficiency usually begins to show with a characteristic mottled chlorosis of older leaves. Yellowing appears first at the tip and edges of the leaf and gradually spreads toward the center and base (Bidwell 1974; Vitosh et al. 1978).

Sufficiency levels range from 17.0 to 30.0 mg/gram dry matter in bean leaves prior to initial flowering (Vitosh et al. 1978). Melsted et al. (1969) reported a 22.0 mg K/gram dry matter critical concentration level in soybean leaves and petioles after first pod formation, while Tremblay and Baur (1948) report a 13.0 mg K/gram dry matter critical level in pea leaves at the pre-bloom stage.

3. Effect of Potassium Additions on Bean Yields.

Potassium fertilization has resulted in some of the most striking soybean yield responses of any of the fertilizer nutrients (Ohlrogge 1960). Yield increases have been most consistent on potassium-deficient soils in the southeast United States. In the midwest, soybeans have not responded consistently to potassium applications even when potassium deficiency symptoms were prevalent.

Many workers have observed only relatively small yield responses to applications of potassium fertilizers. In Iowa, Hanway and Weber (1971) reported a 10 to 15 percent soybean yield response on a soil containing 120 kg NH_4O Ac extractable K/ha (0-15 cm). Bhangoo and Albritton (1972) reported a 9 to 19 percent yield increase to 75 kg K/ha on a soil containing 100 kg/ha available K. De Mooy et al. (1973) recorded only marginal soybean yield increases on a soil which contained low levels of available potassium. They speculated that soybeans were less responsive to added fertilizer than other crops due to a relatively high nutrient absorption efficiency.

Other workers have observed large yield responses to high rates of potassium application. Miller et al. (1961; 1964) reported seed yield responses of up to 1800 kg/ha when 178 kg K/ha was added in the presence of adequate phosphorus. Dunphy et al. (1966) measured yield response of fifty-four varieties and lines of soybeans to very high rates of added P and K fertilizer. Yield responses ranged from 70 to 1500 kg/ha. The high yielding varieties under low fertility usually responded to fertilizer better than the low yielding varieties. Jones et al. (1977) reported soybean seed yield increases of up to 2400 kg/ha to 112 kg K/ha on a kaolinitic clay loam in Vermont which tested low in available K.

In Manitoba, fababeans grown on very low potassium soils responded linearly to added potassium up to 240 kg K/ha. Yield increased from 1700 to 2790 kg/ha(Bailey 1975).

Yield responses to potassium fertilizer may be quite dramatic when potassium is the most limiting nutrient. Work by Miller et al. (1961) has emphasized this. The NH_4OAc soil test has proven to be a reliable test for measuring plant available potassium in many areas of the continent, including Manitoba (Soper 1971; Vitosh et al. 1978). Therefore, lack of a yield response to added potassium, when available soil potassium tests low, may indicate that other nutrients are also limiting yield.

D. Zinc

1. Soil Zinc.

Most of the zinc in soils is in combined forms which are not readily available to plants. However, these combined forms are in equilibrium with soil solution zinc, which is readily available to plants. Zn^{2+} is the dominant zinc species in the soil solution of acid and neutral soils. Its concentration is strongly pH dependent, decreasing 100 fold for each unit increase in pH. In alkaline soils, $Zn(OH)_2$ is the dominant zinc species in the soil solution since its concentration in soil solution is unaffected by pH. The occurrence of zinc deficiencies in crops grown on alkaline soils is due to the decreasing presence of Zn^{2+} in solution at high pH (Lindsay 1972a).

Several types of extraction reagents have been used to test the availability of soil zinc to plants (Aubert 1977). Dilute strong acids, weak acids, salt solutions, and organic complexing agents have been tried in various parts of the world. In Manitoba, a DTPA (Lindsay and Norvell 1969) soil test was found to correlate well with yield response of flax and wheat to zinc fertilizer in a growth chamber study (McGregor 1972). Similarly, Brown et al. (1971) examined 92 California soils in the green house for extractable zinc and used corn to test each soil for plant response to zinc fertilization. Using a critical level of 0.5 ppm of extractable zinc, the DTPA soil test was 83% effective in identifying soils on which corn responded to zinc fertilization. Beans, like corn, are sensitive to zinc deficiency (Cox and Kamprath 1972). Cox and Kamprath have suggested zinc fertilization for sensitive crops when DTPA extractable soil zinc is less than 0.5 ppm, or when it is less than 1.0 ppm for soils with high phosphorus levels.

2. Plant Zinc.

Zinc is recognized as an essential component in several dehydrogenases, proteinases, and peptidases in plant systems

(Lindsay 1972 a). One of the earliest effects of zinc deficiency is a sharp decrease in the levels of RNA and the ribosome contents of cells (Price et al. 1972). Visible symptoms of zinc deficiency are elongated leaves with leaf margins curling upward and shortened leaf petioles (Burleson et al. 1961). In the field, zinc deficiency in beans has delayed ripening, making it impossible to harvest the entire crop at optimum maturity (Boawn et al. 1969).

Adequate zinc in soybean leaves at early pod set has been reported to range from 20 to 75 ppm (Jones 1972). Below 20 ppm, the number of days required to reach maturity in field beans increased rapidly (Boawn et al. 1969). With zinc levels below 15 ppm there was an increase of up to thirty days in the time required to reach maturity. Melsted et al. (1969) reported the zinc critical level in soybean leaves at pod set to be 15 ppm. Ohki (1977) reported the critical nutrient deficient levels to be 15 ppm for a young developing leaf and 14 ppm for a recently matured leaf in soybeans. Hedayat (1977) estimated the critical level of zinc in seven week old blackbean shoots to be 13.5 ppm.

3. Effect of Zinc Additions on Bean Yields.

Responses to zinc addition are most likely to occur on calcareous, coarse textured soils or where the subsoil has been exposed due to erosion or land leveling. A common recommendation for growing beans on zinc deficient soils has been 10 kg Zn/ha applied as broadcast zinc sulfate.

Murphy and Walsh (1972) list thirteen sources of fertilizer zinc that are available for application to field crops.

For water insoluble inorganic carriers it has been established that zinc availability to plants increases as particle size decreases(Ellis 1965; Terman and Mortvedt 1965). Zinc sulfate is a common soluble inorganic carrier which has been reported to be more effective in increasing early plant growth and zinc uptake than other inorganic carriers. Zn-M-N-S (Zinc ammonium sulfite), manufactured by Cominco, was less soluble than zinc sulfate but was suitable for soil application when mixed well with the soil (Brown and LeBaron 1970). Hedayat (1977) reported that pelleted ZnMNS was ineffective in increasing blackbean dry matter yield or zinc uptake when banded or mixed throughout the soil. However, powdered ZnMNS mixed throughout the soil resulted in substantial increases in blackbean yield and uptake of zinc. Organic zinc carriers are more efficient than inorganic carriers but are not widely used because of their high cost. In Michigan, zinc chelates were reported to be five times as effective as inorganic sources (Judy, Lessman, Rozycka, Robertson, and Ellis 1964; Judy, Melton, Lessman, Ellis, and Davis 1964). Holden and Brown (1965) reported that Zn EDTA (zinc ethylenediamine-tetraacetic acid) was twice as efficient as zinc sulfate in neutral soils and up to six times as efficient in calcareous soils.

Placement of the zinc carriers is also an important factor. Inorganic zinc sources have been reported to be most effective when powdered and thoroughly mixed with the soil (Hedayat 1977) while placement is not so important when organic zinc sources are used (Brown and LeBaron 1970). Boawn (1973) reported that when zinc sources were surface broadcast and leached with sprinkler irrigation, zinc sulfate was entirely ineffective while ZnEDTA was still a highly effective source of zinc. Foliar applications of ZnEDTA and zinc sulfate were equivalent in correcting zinc deficiency in beans (Vinande et al. 1968).

4. Phosphorus-Zinc Interactions.

Macro-nutrient fertilization of field crops has steadily increased over the years as farmers have tried to increase their crop yields. This has gradually been increasing the incidence of plant nutritional disorders due to deficiencies in one or more essential micro-nutrients.

A disorder in plant growth which shows symptoms of zinc deficiency has been associated with high levels of available P or with applications of P to the soil. This plant disorder is thought to be due to a phosphorus-zinc interaction.

Some early workers thought the cause of this phosphorus-zinc interaction to be the formation of insoluble $Zn_3(PO_4)_2$ in the soil (Olsen 1972). This would supposedly reduce the concentration of zinc in the soil solution to deficiency levels.

Other workers believed that plant zinc deficiencies resulting from phosphorus addition are purely dilution effects (Christensen 1971). Accordingly, the addition of phosphorus would correct a phosphorus deficiency in the plant and result in a yield increase. If the plant was marginally zinc sufficient, the yield increase would dilute the plant zinc concentration and the plant would become zinc deficient.

Many researchers have written of a "phosphorus-induced zinc deficiency" in plants. They have indicated that phosphorus actively interferes with zinc uptake and/or utilization by the plant.

Several workers thought that phosphorus reduced the rate of zinc entry into the roots (Stukenholtz et al. 1966; Soltanpour 1969; Racz and Haluschak 1974; Takkar et al. 1976). Safaya (1978) thought that phosphate had an initial stimulatory effect on zinc movement into the root, but later it decreased zinc movement into the root. Wallace et al. (1978) observed in solution cultures that at low pH values, increased phosphorus levels increased zinc in leaves, stems, and roots. At high pH, they concluded that phosphorus inhibited zinc uptake through the roots, causing decreased zinc concentrations in leaves, stems, and roots. Burleson et al. (1961) thought the phosphorus-zinc antagonism was within the root. Hedayat (1977) attributed the reduction in zinc concentration to the effect of phosphorus on zinc uptake and/or translocation within the plant. Youngdahl et al. (1977) found that high phosphorus levels increased the amount of zinc binding to root cell walls. This would reduce the amount of zinc available for transport out of the roots.

Safaya (1976) stated that at relatively low phosphate levels, zinc deficiency was induced by impedment of zinc translocation from roots to shoots. At high phosphorus levels, zinc deficiency was also induced but in this case it was due to a decrease in zinc absorption at the root surface. Several workers felt that impedment of zinc translocation within the plant was the main effect of high levels of phosphorus on zinc (Sharma et al. 1968; Paulsen and Rotimi 1968; Warnock 1970). Nair and Babu (1975) thought that the amount of phosphate applied to the soil was directly related to the level of impedment of zinc translocation in the plant. Therefore, the amount of zinc needed to correct the deficiency was proportional to the applied phosphate.

Watanabe et al. (1965) suggested that a proper balance between phosphorus and zinc was necessary for normal growth, since, when zinc is in low supply increasing phosphorus levels may interfere with normal utilization of zinc in the plant. Other workers' data support this assertion (Adriano 1970; Wallace et al. 1974).

Boawn and Brown (1968) speculated on the mechanism of the phosphorus-zinc imbalance. They suggested that an imbalance disrupted the translocation of phosphorus or zinc to metabolic sites and disrupted the formation and degradation of metabolic compounds.

E. Copper.

1. Soil Copper.

In soils, copper availability to plants, like zinc, is strongly pH dependent (Lindsay 1972 b). Plant available copper decreased with increasing pH so that plant copper deficiencies are most likely to occur in alkaline soils. Cu^{+2} and $CuOH^{+}$ are the dominant copper species in the soil solution. In soils with large amounts of organic matter, soil solution copper becomes strongly bound to the organic matter and is highly unavailable to plants. However, in mineral soils, the presence of organic matter is believed to increase the availability of copper to plants. This would be an important factor in explaining why copper deficiencies are not as prevalent as zinc deficiencies on high pH soils, even though both cations show similar decreases in solubility with increase in pH.

A reliable soil copper test would be advantageous for increasing yields on copper deficient soils. Chelating agents have generally been the best extractants for correlating extractable copper with yield response in the growth chamber (Viets and Lindsay 1973). Lindsay and Norvell (1978) have developed a DTPA soil test designed to extract plant available copper in near-neutral and calcareous soils. By examining data from other workers (Follett 1969; Proskovec 1976) along with their own greenhouse data, they tentatively proposed a soil critical level of 0.2 ppm DTPA extractable copper. McGregor (1972) proposed that Na_2DP (ethylediamine di(O-hydroxyphenyl acetic acid) disodium salt) was a suitable extractant for assessing the copper status of Manitoba soils. In greenhouse studies with flax, he found that a soil containing 0.1 ppm Na_2DP extractable copper was severely copper deficient while a soil containing 1.3 ppm Na_2DP extractable copper was suspected of being copper deficient.

2. Plant Copper.

The function of copper in plants is exclusively catalytic. It is part of a number of important enzymes and is an important member of the photosynthetic electron transport system (Bidwell 1974). Deficiency of copper results in necrosis of leaf tips and produces a withered, dark appearance of leaves. Leaves may also be chlorotic or have necrotic spotting (Reuther and Labanauskas 1966; Bidwell 1974).

Copper sufficiency levels in bean leaves prior to initial flowering range from 10 to 30 ppm (Vitosh *et al*. 1978). Melsted *et al*. (1969) reported a 5 ppm copper critical composition value for soybean leaves and petioles on the plant after first pod formation. In general, most crops are deficient in copper when mature leaf concentrations are below 4 ppm copper (Jones 1972). Toxic levels are usually greater than 20 ppm copper in mature leaves.

3. Effect of Copper Additions on Bean Yields.

Responses to copper additions are most likely to occur on leached sandy soils, alkaline and calcareous soils, and organic soils (Reuther and Labanauskas 1966). Fiskel and Younts (1963) recommended 3 to 6 kg Cu/ha broadcast as $CuSO_4.5H_2O$ at seeding time to correct copper deficiency in soybeans. Michigan researchers (Anon. 1966) suggest that no additional copper is needed if a total of 22 kg Cu/ha has been applied to beans or soybeans.

Murphy and Walsh (1972) list sixteen copper compounds that can be used for soil and foliar applications. Copper fertilizers are available in both inorganic and organic forms. Copper sulfate ($CuSO_4.5H_2O$) is the most common inorganic carrier in use. It is a water soluble carrier and can be used as a foliar spray. Water insoluble inorganic copper carriers become more available to plants as their particle size is decreased. Some organic copper sources which are in use are Cu EDTA, Cu ligninsulfonates, and Cu polyflavonoids. Recommended rates range from 1 to 5.5 kg Cu/ha applied broadcast or in a band. Rates for foliar applications are considerably lower.

Organic copper carriers are generally more efficient than inorganic carriers. In pot experiments, Wallace and Mueller (1973) concluded that copper sulfate was only one-tenth as efficient in providing copper to bushbeans as $Na_2CuEDTA$ when both carriers were mixed evenly throughout the soil. For foliar applications, twelve times as much copper in the copper sulfate form is needed to match the effect of copper from copper chelates (Murphy and Walsh 1972).

Recommended methods of placement for copper are similar to that of zinc. Inorganic copper carriers become more available to plants as their particle size is decreased (Murphy and Walsh 1972). Therefore a broadcast powder or solution mixed into the soil would be the best method of application. Organic carriers can be applied in a band or broadcast. Both inorganic and organic carriers are effective when added in foliar applications.

Copper-seed treatments have been reported to increase seed yields, but this method of application is not in common use.

F. Manganese.

1. Soil Manganese.

Manganese in soils exists in several oxidation states and forms nonstoichiometric oxides with mixed valence states. Its oxides also exist in crystalline and amorphous states, as well as in co-precipitates with iron and other oxides (Lindsay 1972 b).

The divalent Mn^{2+} ion is the predominant manganese species in the soil solution. The $MnSO_4(aq)$, $MnHCO_3^+$, and $MnOH^+$ species contribute only slightly to total soluble manganese in soils. Manganese in soil solution is highly pH dependent. In general, the optimum pH for most plants is about 6.0 to 6.8 since there is usually neither an excess nor a deficiency of available manganese (Lindsay 1972 b).

The divalent manganese ion is the species that is available to plants in the soil (Devlin 1975). It may be found dissolved in the soil solution or as an exchangeable ion adsorbed to the soil colloids and is available to the plant in both forms. As well as being strongly pH dependent, its concentration may fluctuate widely due to soil aeration (Lindsay 1972 b). Soil manganese deficiency conditions can be corrected by flooding, which decreases soil aeration. In waterlogged soils the lack of oxygen promotes the growth of anaerobic microorganisms which can convert plant unavailable forms of manganese to the divalent manganese species. Surveys of Manitoba have found low Mn levels in plant tissue collected from a wide range of soil types, including many high lime soils in the Interlake and the heavy clays and loams of the lower Red-Assiniboine River basins (Martens et al. 1977).

Considerable work has been done on evaluating the status of various fractions of manganese in the soil (Cox and Kamprath 1972). Reducing agents, phosphate solutions, chelating agents, and water have been used in an attempt to correlate extractable soil manganese with plant response to added manganese fertilizer. In Manitoba, a DTPA soil test (Lindsay and Norvell 1969) is in use. The DTPA soil test was developed to identify near neutral and calcareous soils with insufficient available zinc, iron, manganese, and copper for maximum yields of crops (Lindsay and Norvell 1978). In Colorado, 35 soils were tested in the greenhouse for sorghum yield response to applied manganese fertilizer. None of the soils showed a response. Since the DTPA-extractable manganese in these soils ranged from 1.2 to 32 ppm, Lindsay and Norvell suggested that the critical level was possibly near 1.0 ppm. However, recent work by Shuman et al. (1979) indicated a soil critical level of 0.3 ppm DTPA extractable manganese in soybean field studies.

2. Plant Manganese.

Manganese functions in the plant are usually restricted to catalysts. Manganese is the predominant enzyme-activating metal of the Krebs cycle and is required in other respiratory enzymes, nitrogen metabolism, and photosynthesis. Symptoms of manganese deficiency are the formation of small necrotic spots on leaves and the necrosis of cotyledons in leguminous seedlings (Bidwell 1974). Pale green irregular areas between the main veins of leaves may indicate a mild deficiency (Sauchelli 1969). Sufficiency levels in bean leaves prior to flowering range from 20 to 100 ppm manganese (Vitosh *et al.* 1978). Melsted *et al.* (1969) reported a critical composition value of 20 ppm manganese in soybean leaves and petioles after first pod formation.

3. Effect of Manganese Additions on Bean Yields.

Responses to manganese addition are most likely to occur on poorly drained calcareous clay soils and organic soils (Labanauskas 1966). A common method of correcting manganese deficiency in alkaline soils is by applying 100 to 200 kg $MnSO_4$/ha (Sauchelli 1969). Soybeans and beans in general are highly responsive to manganese additions on deficient soils (Lucas and Knezek 1972). Chelated forms of manganese have not been effective when applied to soils due to substitution of iron for manganese in the chelate molecule and a subsequent increase in the uptake of iron and a reduction in the uptake of manganese (Knezek and

Greinert 1971). Residual effects of soil applied manganese fertilizers have seldom been noted because the rate of manganese applied in the field is not high enough to result in significant carryover into succeeding crops (Murphy and Walsh 1972).

Proper placement of manganese fertilizers can greatly improve the efficiency of manganese uptake. Randall *et al.* (1975 a), in soybean field studies, found that manganese sulfate was more effective when placed with the seed than when broadcast and incorporated; although germination damage occured on a coarse textured soil during a dry year. However, foliar manganese applications were more efficient than the soil applied manganese. Foliar applications were most effective when applied at early blossom or early pod set stages. Large single spray applications tended to cause burning in the foliage, so multiple times of spraying were recommended.

G. Iron.

1. Soil Iron.

Of all the trace elements, iron is one of the most abundant elements in the soils and plants (Sauchelli 1969). In soils, the amounts range from 200 ppm to at least ten percent.

The solubility of iron in soils is largely controlled by the solubility of hydrous Fe (III) oxides (Lindsay 1972 b). Total inorganic Fe (III) in solution varies with pH and reaches a minimum in the pH range of 6.5 to 8.0. Iron that has been released from soil minerals may be subject to rapid oxidation or may react with phosphates to form precipitates which are attracted to the surfaces of soil particles (Beeson and Matrone 1976). The rest of iron in soil solution may be quickly complexed with organic matter (Olomu 1971) but some of this may be available to plants since some organic ferric compounds are soluble (Fried and Broeshart 1967). Part of the iron in oxidized soils is adsorbed as $Fe(OH)_2^+$ or $Fe\ OH^{2+}$. Under reduced conditions in submerged soils the concentration of the ferrous ion (Fe^{2+}) in the soil solution increases rapidly.

Iron is most available to the plant in the ferrous form, but significant quantities of the ferric ion may also be absorbed (Devlin 1975). Soils generally are not low in total iron but may be deficient in exchangeable and soluble forms of iron. The optimum pH for iron availability to most plants is about 6.0 to 6.8 since there is usually neither an excess nor a deficiency of iron (Lindsay 1972 b).

The availability of iron to plants seems to be dependent on many factors that are difficult to correlate with an extractable amount in the soil (Cox and Kamprath 1972). Various attempts have been made to measure soil exchangeable iron. Chelating agents seem to have met with the best success. In Manitoba, a DTPA-extractable iron test (Lindsay and Norvell 1969) is in use. It was developed in Colorado to identify near-neutral and calcareous soils with insufficient available zinc, iron, manganese or copper for maximum yields of crops (Lindsay and Norvell 1978). In greenhouse studies with sorghum, a critical level of 4.5 ppm

DTPA- extractable iron separated the responsive from the non-responsive soils. Soils with less than 2.5 ppm DTPA-extractable iron would be expected to cause iron deficiency in sorghum while soils between 2.5 and 4.5 ppm were described as being borderline. Visual symptoms of iron deficiency in the field appeared to correlate with soil test results. Beans, like sorghum, are highly responsive to iron fertilization on iron deficient soils (Lucas and Knezek 1972). Therefore, it appears probable that the soil critical level for field beans would be close to 4.5 ppm DTPA-extractable iron.

2. Plant Iron.

In plants, iron is part of the catalytic site of many important oxidation-reduction enzymes. It is also essential for the formation of chlorophyll (Bidwell 1974) and appears to have a role in the formation of leghaemoglobin in legume nodules (Vincent 1965).

The symptoms of iron deficiency are easily recognized and very specific. Chlorosis developes in the young growing leaves of plants without evident stunting or necrosis (Bidwell 1974).

Sufficiency levels in bean leaves prior to initial flowering range from 50 to 450 ppm iron (Vitosh et al. 1978). Melsted et al. (1969) reported critical composition values in soybean leaves and petioles after first pod formation to be 20 ppm iron.

3. Effect of Iron Additions on Bean Yields.

Iron deficiencies are most commonly found on calcareous and/or poorly drained soils (Wallihan 1966) and most often occur in flax, soybeans, and field beans (Mortvedt and Giordano 1970).

Murphy and Walsh (1972) list fifteen sources of iron fertilizers. Generally, crop response to soil applied carriers have been quite variable. Successful application of inorganic iron sources may require very large applications of iron salts to correct crop deficiencies. Organic iron chelate sources have been recognized for greater efficiency than the inorganic iron sources, but soil applications have not always been feasible or economical. Wallace et al. (1957) suggested that economics favor foliar application of chelates as sources of iron for plants. Sauchelli (1969) noted that recommendations by University of California personnel for grain sorghum call for one foliar spray about 25 days after planting in the case of mild chlorosis, and two or three sprayings in the case of severe chlorosis. Reuss and Lindsay (1963) suggested that a foliar application of a 3% solution of $FeSO_4$ be applied as soon as iron deficiency symptoms are noticed and repeated at two week intervals until the symptoms are no longer apparent.

III. METHODS AND MATERIALS

A. Field Trials.

1. 1976 Blackbean Field Experiments.

a) Soils. Three soils were selected for field studies. One was a gleyed Orthic Black mapped as a Horndean clay loam by Smith and Michalyna (1973). The second was a gleyed carbonated Rego Black mapped as a Reinland fine sandy loam by Smith and Michalyna (1973). The third was a gleyed carbonated Rego Black mapped as a Gnadenthal fine sandy loam by Michalyna and Smith (1972).

b) Experimental Design and Procedure. A randomized block experiment containing four replicates and nineteen treatments was designed with blackbeans (Phaseolus vulgaris (L.) cv. 'Black Turtle') as the test crop. Treatment plots were 7.6 meters long and 2.7 meters wide. Replicates were separated by a 1.5 meter roadway. The four replicates were enclosed by four guard rows of blackbeans.

Treatments in the experiment are listed in Table 1. Nitrogen was added as ammonium nitrate (34-0-0). Phosphorus was added as ammonium phosphate (11-55-0). Potassium was added as potassium chloride (0-0-62). Zinc was added as either zinc chelate or zinc sulfate. The NPKS foliar application was a solution containing urea [$CO(NH_2)_2$], potassium tripolyphosphate [$K_5P_3O_{10}$], and potassium sulfate[K_2SO_4].

There were four main types of fertilizer placement used in this experiment. One was fertilizer placement with the

TABLE 1

TREATMENTS USED IN 1976 BLACKBEAN FIELD EXPERIMENTS

Treat. No.	Amount (Kg P_2O_5/ha) and Method of Phosphate Application	Amount (Kg N/ha) and Method of Nitrogen Application	Other Fertilizers
1	0	30 sidebanded	0
2	20 with seed	30 sidebanded	0
3	40 with seed	30 sidebanded	0
4	80 with seed	30 sidebanded	0
5	20 sidebanded	30 sidebanded	0
6	40 sidebanded	30 sidebanded	0
7	80 sidebanded	30 sidebanded	0
8	80 broadcast	30 sidebanded	0
9	40 sidebanded	8 sidebanded	0
10	40 sidebanded	60 sidebanded	0
11	40 sidebanded	90 sidebanded	0
12	40 sidebanded	120 sidebanded	0
13	40 sidebanded	30 sidebanded	*
14	40 sidebanded	8 sidebanded	No inoculum
15	40 sidebanded	30 sidebanded	30 Kg K/ha
16	40 sidebanded	30 sidebanded	60 Kg K/ha
17	40 sidebanded	30 sidebanded	1 Kg Zn/ha as EDTA sidebanded
18	40 sidebanded	30 sidebanded	5 Kg Zn/ha as $ZnSO_4$ sidebanded
19	40 sidebanded	30 sidebanded	5 Kg Zn/ha as $ZnSO_4$ broadcast

* Three foliar applications of 20 Kg N/ha, 2 Kg P/ha, 6 Kg K/ha and 1 Kg S/ha applied each week during pod formation and filling. Applied as urea, pyrophosphate, and potassium sulfate.

seed. A second method was banding the fertilizer 5 cm. below and 5 cm. to each side of the blackbean seed row. A third method was broadcasting the fertilizer and discing it ten to fifteen centimeters into the soil. The fourth method was foliar application of NPKS. This was accomplished by spraying the crop on an area basis using a pressurized hand sprayer beginning at the early pod set stage. Three applications totaling 60 Kg N/ha, 6Kg P/ha, 18 Kg K/ha, and 3 Kg S/ha were made.

Blackbeans were inoculated with Nitragin Culture D[(1)] in a slurry, and seeded at a rate of 45 kg/ha with a two row V-belt seed drill. The row spacing was 91 cm. Treflan pre-seeding incorporation and hand weeding were the methods of weed control.

At early pod stage, plant samples were cut from one meter of each treatment harvest row. Samples were washed, oven dried, weighed, and ground in a Wiley Mill. Selected treatments were analyzed for phosphorus and zinc content.

At maturity, a three meter harvest was taken from the center row of each treatment plot. The harvested samples were air dried, threshed, cleaned, and the seed sample was weighed. Subsamples of each bean seed sample were ground on a Wiley Mill. Selected treatments were analyzed for phosphorus and zinc content. Total nutrient uptake for phosphorus and zinc was calculated. The efficiency of utilization of applied fertilizer was estimated using the classical approximation:

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(1) Supplier: The Nitragin Company,
Milwaukee, Wis. 53219

$$\text{Efficiency or \% Recovery} = \frac{\text{Nutrient uptake by treatment} - \text{Nutrient uptake by control}}{\text{Applied Fertilizer}} \times 100\%$$

2. 1977 Blackbean Field Experiments.

a) Soils. Two soils were selected for field studies. One was an Orthic Black mapped as a Hochfeld fine sandy loam by Smith and Michalyna (1973). The second was a gleyed carbonated Rego Black mapped as a Neuenberg very fine sandy loam by Smith and Michalyna (1973).

b) Experimental Design and Procedure. A randomized block experiment containing four replicates and twenty treatments was designed with blackbeans (*Phaseolus vulgaris* (L) cv. 'Black Turtle') as the test crop. Treatment plots were 7.6 meters long and 2.7 meters wide. Replicates were separated by a 1.5 meter roadway. The four replicates were enclosed by four guard rows of blackbeans.

Treatments in the experiment are listed in Table 2. Nitrogen was added as ammonium nitrate (34-0-0). Phosphorus was added as ammonium phosphate (11-55-0) for the first fourteen treatments, and as monocalcium phosphate (0-46-0) for the remaining six treatments. Zinc was added as zinc sulfate, Zn-M-N-S(1) (9% N, 20% S, 15% Zn, 1.5%Mn as ammonium sulfate, manganese ammonium sulfite and zinc ammonium sulfite), "Zink Gro"(2) (a granular zinc sulfate; 36% Zn, 17.5% S), and disodium zinc

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(1) Supplier: Cominco
American Elephant brand

(2) Supplier: Eagle Picher Industries, Inc.,
Agricultural Chem. Division
Joplin, Mo.

TABLE 2

TREATMENTS USED IN 1977 BLACKBEAN FIELD EXPERIMENTS

Treat. No.	Amount ($Kg\ P_2O_5/ha$) and Method of Phosphate Application	Amount (Kg N/ha) and Method of Nitrogen Application	Kind, Amount (Kg Zn/ha) and Method of Zinc Application
	Treat. 1 to 14 (11-55-0) Treat. 15 to 20 (0-46-0)	(NH_4NO_3)	
1	30 sidebanded	30 sidebanded	0
2	30 sidebanded	30 sidebanded	10.0 Kg as ZnM-N-S granular broadcast
3	30 sidebanded	30 sidebanded	10.0 Kg as ZnM-N-S powder broadcast
4	30 sidebanded	30 sidebanded	5.0 Kg as ZnM-N-S granular sidebanded
5	30 sidebanded	30 sidebanded	5.0 Kg as ZnM-N-S powder sidebanded
6	30 sidebanded	30 sidebanded	2.5 Kg as $ZnSO_4.7H_2O$ solution broadcast
7	30 sidebanded	30 sidebanded	5.0 Kg as $ZnSO_4.7H_2O$ solution broadcast
8	30 sidebanded	30 sidebanded	10.0 Kg as $ZnSO_4.7H_2O$ solution broadcast
9	30 sidebanded	30 sidebanded	20.0 Kg as $ZnSO_4.7H_2O$ solution broadcast
10	30 sidebanded	30 sidebanded	2.5 Kg as "Zink Gro" sidebanded
11	30 sidebanded	30 sidebanded	5.0 Kg as "Zink Gro" sidebanded
12	30 sidebanded	30 sidebanded	10.0 Kg as "Zink Gro" sidebanded
13	30 sidebanded	30 sidebanded	2.0 Kg as Zn Na_2EDTA sidebanded
14	30 sidebanded	30 sidebanded	4.0 Kg as $ZnNa_2EDTA$ solution broadcast
15	30 sidebanded	0	10.0 Kg as $ZnSO_4.7H_2O$ solution broadcast
16	0	30 sidebanded	10.0 Kg as $ZnSO_4.7H_2O$ solution broadcast
17	30 sidebanded	100 sidebanded	10.0 Kg as $ZnSO_4.7H_2O$ solution broadcast
18	100 powder broadcast	30 sidebanded	10.0 Kg as $ZnSO_4.7H_2O$ solution broadcast
19	100 powder broadcast	30 sidebanded	10.0 Kg as ZnM-N-S powder broadcast
20	30 sidebanded	30 sidebanded	4.0 Kg as $ZnNa_2EDTA$ solution broadcast + 2.0 Kg Cu/ha as $CuNa_2EDTA$ solution broadcast

ethylenediaminetetra acetate (Na_2Zn EDTA). Copper was added as disodium copper ethylenediaminetetraacetate ($Na_2CuEDTA$).

There were five main types of fertilizer placement in this experiment. One method was banding fertilizer granules five cm. below and five cm. to each side of the blackbean seed row. A second method was banding powdered fertilizer five cm. below and five cm. to each side of the blackbean seed row. A third method was broadcasting and incorporating fertilizer granules. A fourth method was broadcasting and incorporating powdered fertilizer. The fifth method was spraying a fertilizer solution onto the soil and incorporating it.

Blackbeans were inoculated with Nitragin Culture D[1] in a slurry, and seeded at a rate of 45 kg/ha with a two row V-belt seed drill. The row spacing was 91 cm. Treflan pre-seeding incorporation and hand weeding were the methods of weed control.

At early pod stage, plant samples were cut from one meter of each treatment harvest row. Samples were washed in EDTA solution, dilute acid, and rinsed in deionized water to prevent possible surface contamination by soil or fertilizer dust. The samples were then oven dried at $85^{\circ}C$ for 24 hours, weighed, ground in a Wiley Mill, and analyzed for phosphorus, zinc, copper, and manganese. Selected treatments were analyzed for nitrogen.

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(1) Supplier: The Nitragin Company
Milwaukee, Wis. 5329

At maturity, plant samples were cut from three meters of each treatment harvest row. They were air dried, threshed, cleaned, and the seed sample was weighed. The seed and straw were ground in a Wiley mill and analyzed for phosphorus, zinc, copper, and manganese. Selected treatments were analyzed for nitrogen.

Total nutrient uptake for nitrogen, phosphorus, zinc, copper, and manganese was calculated. The efficiency of utilization of applied fertilizer was estimated using the classical approximation:

$$\text{Efficiency or \%Recovery} = \frac{\text{Nutrient uptake by treatment} - \text{Nutrient uptake by control}}{\text{Applied fertilizer}} \times 100\%$$

3. <u>1978 Blackbean Field Experiments</u>.

a) <u>Soils</u>. Two soils were selected for field studies. One was an Orthic Black mapped as a Hochfeld fine sandy loam by Smith and Michalyna (1973). The second was a gleyed carbonated Rego Black mapped as a Neuenberg very fine sandy loam by Smith and Michalyna (1973).

b) <u>Experimental Design and Procedure</u>. A randomized block experiment containing four replicates and ten treatments was designed with blackbeans (<u>Phaseolus vulgaris</u> (L) cv. 'Black Turtle') as the test crop. Treatment plots were 7.6 meters long and 2.7 meters wide. Replicates were separated by a 1.5 meter roadway. The four replicates were enclosed by four guard rows of blackbeans.

Treatments in the experiment are listed in Table 3. Nitrogen at a rate of 30 kg N/ha was sidebanded as urea (46-o-0). Phosphorus was broadcast and incorporated as monocalcium phosphate (0-46-0). Sulfur at a rate of 40 kg S/ha was banded into the soil prior to seeding as potassium sulfate (0-0-50). Zinc was broadcast in solution form and incorporated as zinc sulfate ($ZnSO_4.7H_2O$). Copper at a rate of 10kg Cu/ha was broadcast and incorporated as copper sulfate ($CuSO_4.5H_2O$).

Blackbeans were inoculated with Nitragin Culture D[(1)] in a slurry, and seeded at a rate of 45 kg/ha. with a two row V-belt seed drill. The row spacing was 91 cm. Treflan preseeding incorporation and hand weeding were the methods of weed control.

At early flowering stage, plant samples were cut from one meter of each treatment harvest row. Samples were washed in dilute acid and deionized water to prevent possible surface contamination by soil or fertilizer dust. The samples were then oven dried at 85°C for 24 hours, weighed, ground, and analyzed for phosphorus, zinc, copper, and manganese.

At maturity, plant samples were cut from three meters of each treatment harvest row. They were air dried, threshed, cleaned, and the seed was weighed. The seed and straw were ground and analyzed for phosphorus, zinc, copper, and manganese.

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(1) Supplier: The Nitragin Company
Milwaukee, Wis. 53209

TABLE 3

TREATMENTS USED IN 1978 BLACKBEAN FIELD EXPERIMENTS

Treatment Number	Zinc Added (kg Zn/ha)	Phosphorus Added (kg P_2O_5/ha)
	(1)	(1)
1	0	0
2	0	100
3	0	200
4	0	400
5	0	800
6	15	0
7	15	100
8	15	200
9	15	400
10	15	800

(1) Zinc was added as zinc sulfate. Phosphorus was added as monocalcium phosphate. Both nutrients were broadcast and incorporated.

Total nutrient uptake for phosphorus, zinc, copper, and manganese was calculated. The efficiency of utilization of applied fertilizer was estimated using the classical approximation:

$$\text{Efficiency or \% Recovery} = \frac{\text{Nutrient uptake by treatment} - \text{Nutrient uptake by control}}{\text{Applied Fertilizer}} \times 100\%$$

B. Growth Chamber Experiments.

1. The Effect of Zinc Placement on the Yield and Uptake of Zinc in Blackbeans.

a) Soils. A Neuenberg soil (Smith and Michalyna 1973) was selected for this growth chamber study. Soil was taken in the fall of 1977 from the 0 to 15 cm depth of cropped fields near Morden, Manitoba. The soil was air dried and passed through a two centimeter mesh plastic sieve. A representative sample of soil was taken for analyses.

b) Experimental Design and Procedure. A randomized block experiment containing three replicates and four treatments was designed using blackbeans (*Phaseolus vulgaris* (L) cv. 'Black Turtle') as the test crop.

Treatments in the experiment were as follows:

(1) Check treatment in which no zinc fertilizer was applied.

(2) "Zink Gro (1)" pellets (a granular zinc sulfate; 36% Zn, 17.5% S) sidebanded 2.5 cm. below and to each side of the seed at a rate of 24 mg Zn/pot.

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(1) Manufactured by Eagle Picher Industries, Inc.
Agricultural Chem. Division
Joplin, Mo.

(3) Fifteen "Zink Gro[1]" pellets systematically mixed throughout the soil at a rate of 24 mg Zn/pot.

(4) "Zink Gro [1]" pellets ground into a powder and thoroughly mixed throughout the soil at a rate of 24 mg Zn/pot.

All four treatments received 90 ppm nitrogen, 100 ppm phosphorus, 200 ppm potassium, 85 ppm sulfur, and five ppm copper on an air dry soil basis. Three thousand grams of air dry soil were weighed out and spread on a plastic sheet. Lumps of soil were crushed and straw was removed by hand. A diammonium phosphate plus potassium sulfate solution was applied to the soil in a fine spray with thorough mixing. Next, a copper sulfate pentahydrate solution was applied to the soil as a fine spray with thorough mixing. The soil was then placed into 17cm. diameter plastic pots. For treatment one, all of the soil was added to the pot. For treatment two, 2150 grams of soil was added to the pot and two bands (5 cm. apart) of equal sized "Zink Gro" pellets (24 mg. of Zn/pot or 8 ppm on an air dry basis) were placed on the soil. The locations of the two bands were marked on the outside of the pot and the remaining soil was carefully added. For treatment three, six--500 gram layers of soil were added to the pot. Five groups of three equally sized "Zink Gro" pellets were sandwiched inbetween the six layers

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(1) Manufactured by Eagle Picher Industries, Inc.
Agricultural Chem. Division
Joplin, Mo.

of soil. The three pellets were positioned in the middle of triangular portions of the soil surface. (4 cm. from the centre of the pot and 7 cm. from each other) A positioning guide was rotated sixty degrees after each layer to assure an even distribution of pellets throughout the soil. For treatment four, powdered "Zink Gro" pellets were systematically mixed into the soil, and then the soil was poured into the pot. Seeding was accomplished by pushing the seeds 1.5 cm. into the soil with a notched plastic rod. Banded zinc treatments (treatment two) were seeded inbetween the fertilizer bands and the other treatments were seeded in a circle located midway between the centre and side of each pot. Six seeds were planted and later thinned to two plants per pot.

The growth chamber incandescent and fluorescent lights were kept on 16 hours each day. Day air temperature was twenty degrees centigrade and humidity was fifty-five percent. During the eight hour night, air temperature was fifteen degrees centigrade and humidity was approximately eighty percent. Light intensity was 40 u E sec^{-1} m^{-2} (400-700 nm). The pots were rotated frequently in the growth chamber to minimize any shading differences. Only deionized or distilled water was used in watering and the soil was brought up to field capacity twice each day.

The legumes were uninoculated and it was assumed during the experiment, and after confirmed through a random screening of legume roots, that the legumes did not produce healthy nodules. Therefore, the legumes were dependent on soil nitrogen. Soil nitrogen was thought to be insufficient, since some plants were showing nitrogen deficiency symptoms. Therefore, 300 mg of NH_4NO_3 was added in solution form to each pot 33 days, 40 days, and 47 days after seeding. The above ground portions of the plants were harvested after 50 days in the early to mid-flowering stage. The plant material was rinsed in saturated EDTA solution, 0.025 N HNO_3, distilled water; dried at eighty-five degrees centigrade for 24 hours and weighed. It was then ground in a stainless steel Wiley Mill and analyzed for phosphorus, zinc, and copper.

2. Phosphorus-zinc Interactions in Blackbeans.

a) Soil. Previous work (McGregor 1972) in Manitoba indicated that plant zinc deficiencies tended to occur on calcareous soils. For this reason, an extremely calcareous Lakeland clay loam soil (Pratt *et al*. 1961) was selected for this growth chamber study.

b) Experimental Design and Procedure. A randomized block experiment containing three replicates and ten treatments was designed. Treatments in the experiment were as follows:

Treatment	Zn applied (ppm)	P applied (ppm)
(1)	0	0
(2)	0	20
(3)	0	40
(4)	0	80
(5)	0	160
(6)	8	0
(7)	8	20
(8)	8	40
(9)	8	80
(10)	8	160

Zinc, as $ZnSO_4.7H_2O$, phosphorus, as $Ca(H_2PO_4)_2.H_2O$, and 200 ppm potassium, as K_2SO_4 , were added to 3000 grams of Lakeland soil on an oven dry soil basis. The procedure was similar to growth chamber experiment one. Soil was weighed out and spread on a plastic sheet so that small lumps of soil could be crushed and straw could be removed. The phosphorus and potassium solutions were sprayed on and thoroughly mixed into the soil. The zinc solution was then sprayed on and mixed into the appropriate soils. The soil was placed into 17 cm. diameter plastic pots.

Blackbean seeds (<u>Phaseolus vulgaris</u> (L.) cv. 'Black Turtle') were inoculated with Nitragin Culture D[1] in a slurry. Seeding was accomplished by pushing the seeds 1.5 cm. into the soil with a notched plastic rod. Six seeds were placed in a

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1 Supplier: The Nitragin Company, Milwaukee, Wisconsin 53209

circle. The blackbeans were later thinned to two plants per pot.

The growth chamber incandescent and fluorescent lights were kept on 15 hours each day. Day air temperature was 28° C and humidity was set at forty percent. During the nine hour night, air temperature was 23° C and humidity was approximately eightly percent. The pots were rotated frequently in the growth chamber to minimize any differences in lighting. Only deionized water was used in this experiment.

The blackbeans were harvested 34 days after seeding and were in the early to mid-flowering stage. The plants were washed, dried, ground, and analyzed as described in growth chamber experiment one.

C. Analytical Methods and Materials

1. Soil Analyses

a) Soil pH. Soil pH was determined by measuring the pH of a water-saturated soil paste using a glass-calomel combination electrode.

b) Electrical Conductivity. Soil salinity was estimated by measuring the electrical conductivity of an extract from a water-saturated soil paste using a conductivity meter.

c) Organic Matter. Organic matter was determined using the method described by Walkley and Black (1934). Excess potassium dichromate was back titrated with 0.5 N $Fe\ SO_4$ using an automatic titrator with a 750 m V endpoint.

d) Inorganic Carbonate Content. 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. The CO_2 was adsorbed by ascarite in a Nesbitt tube and the weight of the adsorbed CO_2 was determined. Percent $CaCO_3$ equivalent was calculated.

e) Field Capacity. Air-dried soil was placed in 1000 ml. graduated cylinders. The cylinders were dropped four times from a 5 cm height to allow the soil to settle. Water was added to each sample until the wetting front had moved half way down the cylinder. The cylinders were covered with parafilm. After 48 hours, a sample was taken from the centre of the wetted portion of the soil. The soil was weighed, oven dried at 105° C, weighed again and the moisture content of the soil calculated on an oven-dry basis.

f) Soil Texture. The sand, silt, and clay content of the soils were determined by the hand, or "feel" method.

g) NO_3 - N. Soil nitrate-nitrogen was determined using a Phenoldisulfonic Acid method similar to the one described by Harper (1924). Fifty ml of nitrate extracting solution (0.2 liters of 1 N $CuSO_4 . 5H_2O$ + 1 liter of 0.6% Ag_2SO_4) was added to 10 grams of oven dried ground soil. NO_3-N was determined colorimetrically at 415 m u.

h) $NaHCO_3$ Extractable PO_4 - P (Olsen *et al.* 1954). One hundred ml of 0.5 N $NaHCO_3$ extracting solution plus one gram of pretreated activated charcoal were added to 5.00 gram soil samples in 500 ml shaker bottles. The samples were shaken for 30 minutes, filtered, and P level in the extract determined using the acid molybdate method of Murphy and Riley (1962).

i) NH$_4$OAc Extractable K. Five gram soil samples were shaken for one hour with 100 ml of 1.0 N NH$_4$OAc containing 250 ppm of lithium. This was filtered and the K level in the extract determined using a Perkin-Elmer model 303 atomic absorption spectrophotometer.

j) Water Extractable SO$_4$ - S. Fifty gram soil samples were shaken for 30 minutes with 100 ml of distilled water on a rotary shaker. Two grams of NaCl plus 2 grams of charcoal were added and shaken for 30 seconds. This was filtered and sulfur was determined using the barium chloride turbidimetric method.

k) DTPA Extractable Cu, Zn, Mn, Fe. Twenty-five gram soil samples were shaken for 2 hours with a DTPA (diethylenetriaminepentacetic acid) extracting solution (0.005 M DTPA, 0.01 M CaCl$_2$, and 0.1 M triethanolamine) (Lindsay and Norvell 1969). The suspensions were filtered and the Cu, Zn, Mn, and Fe concentrations were determined using a Perkin Elmer model 303 atomic absorption spectrophotometer.

2. Plant Analyses

a) Total Cu, Zn, Mn, Fe. One gram of oven-dried ground plant sample was placed into micro-Kjeldahl flasks with 5 ml of concentrated HNO$_3$. After one hour predigestion, 2.5 ml of 70 percent HClO$_4$ was added to each sample and the samples were digested by boiling. The digest was diluted to 25.0 ml with deionized water. Cu, Zn, Mn, and Fe concentrations were measured using a Perkin Elmer model 303 atomic absorption spectrophotometer.

b) Total P. An aliquot was taken from the micro-Kjeldahl digest, suitably diluted, and placed into 50 ml erlenmeyer flasks. Total phosphorus concentration was determined using the ammonium molybdate and ascorbic acid method described by Murphy and Riley (1962).

c) Total N. Total plant nitrogen was determined by the modified Kjeldahl-Gunning method described by Jackson(1958). The digestion accelerator used was a Kelpak [1] No. 2, which contained 0.3 g $CuSO_4$ and 10.0 g K_2SO_4.

3. Micro-nutrient Cleaning Procedure.

All experimental apparatus and equipment were cleaned by the following procedure to prevent micronutrient contamination.

(1) Rinse well with tap water to remove foreign particles.

(2) Rinse three times with distilled water.

(3) Rinse three times with deionized water.

(4) Immerse in 0.1 M Na_2EDTA(disodium ethylenediaminetetraacetate dihydrate) solution.

(5) Rinse with deionized water.

(6) Immerse for five minutes in ten percent nitric acid.

(7) Rinse well with deionized water.

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(1) Supplier: Canadian Lab Supplier, Ltd., 80 Jutland Road, Toronto, Ont.

D. Statistics.

Statistical calculations were performed using the "Manitoba Statistical Package" and "Statistics on Line" at the University of Manitoba. Abreviations used in the text and statistical formulas are listed below.

1) N = number of observations; x_i = sample value.
2) sample mean $(\bar{x}) = \Sigma\, xi/N$
3) variance $(s^2) = \Sigma\, (x_i - \bar{x})^2 / (N-1)$
4) standard deviation $(s) = \sqrt{\text{variance}}$
5) standard deviation of the mean $(s_{\bar{x}}) = s/\sqrt{N}$
6) standard error of the difference between two means $(sd) = (2s^2/N)^{\frac{1}{2}}$
7) Coefficient of Variation $(cv) = s/\bar{x}$ (expressed in percent)
8) For comparing two treatment means in an experiment, a two-tailed t-test value can be calculated as follows: $t = \dfrac{\bar{x}_2 - \bar{x}_1}{sd}$
9) Duncan's New Multiple Range test was calculated at the 5% level of significance. Any two values in vertical columns followed by the same letter are not significantly different.

E. Precision in the Analyses of Plant Material for Phosphorus, Zinc, and Copper Content.

Forty replicate samples of ground blackbean seed were chemically analyzed so that the precision of the analytical method could be calculated. The method to be tested consisted of four main stages: (1) plant samples were ground in a Wiley Mill, the ground material was mixed as uniformly as possible, and one gram samples were weighed out; (2) a nitric-perchloric acid digestion was performed on the one gram plant sample: (3) the digest was diluted to a level which was optimum for measurement on the atomic absorption spectrophotometer; and (4) phosphorus, zinc, and copper levels in the diluted digest were measured and levels in the plant were calculated.

Results of the blackbean seed analyses are listed in Table 4. Phosphorus concentration was found to be 3.8 ± 0.2 mg/gram dry matter; zinc concentration was 31 ± 2 ug/gram dry matter; and copper concentration was found to be 8.3 ± 0.4 ug/gram dry matter.

The coefficient of variation was near six percent for all three nutrients. The results of this experiment were assumed to be representative of other plant analyses. Therefore, a coefficient of variations of six percent was used to estimate the standard deviation for those plant samples which had higher or lower nutrient concentrations than reported here.

TABLE 4

PHOSPHORUS, ZINC, AND COPPER CONTENT OF BLACKBEAN SEED USED IN GROWTH CHAMBER EXPERIMENT ONE.

Statistical Analysis	P	Zn	Cu
n	40	40	40
$\bar{x}$	3.76 mg/g DM	30.7 ug/g DM	8.34 ug/g DM
median	3.76 mg/g DM	30.1 ug/g DM	8.4 ug/g DM
s^2	0.06	4.39	0.18
s	0.24	2.10	0.43
$s_{\bar{x}}$	0.038	0.33	0.068
c.v. (%)	6.43	6.83	5.14

IV. RESULTS AND DISCUSSION

A. Field Experiments.

1. 1976 Blackbean Field Experiments.

In 1975, blackbeans were introduced as a commercial crop in Manitoba. Very little research had been done on the nutritional needs of field beans in Manitoba. Therefore, in 1976, the Department of Soil Science at the University of Manitoba commenced a three year investigation by examining the effect of nitrogen, phosphorus, potassium, zinc, and NPKS foliar applications on blackbean yield.

a) Soils. In 1976, field experiments were conducted at Jordan (Horndean CL), Winkler (Reinland FSL), and Portage (Gnadenthal FSL). Soil sampling at seeding showed that all soils were base saturated and had low soluble salt concentrations (Table 5). Soil NO_3-N (0-60 cm), according to Provincial Soil Testing Guidelines (Anon. 1977), was low in the Horndean CL and Reinland FSL and very low in the Gnadenthal FSL. Available phosphate ($NaHCO_3$ extractable) concentrations were low in the Reinland FSL and very low in the Horndean CL and the Gnadenthal FSL. Potassium (NH_4OAc exchangeable) concentrations were high to very high in all experimental sites. DTPA extractable zinc ranged from deficient to adequate in the Horndean CL and from marginal to adequate in the Reinland FSL and the Gnadenthal FSL (Viets and Lindsay 1973).

Table 5

Characteristics of Soils in the 1976 Field Experiments.

Site Characteristics		Jordan	Winkler	Portage
Legal Description		SE 26-3-5W	NE 29-3-4W	NE 4-13-7W
Soil Series		Horndean	Reinland	Gnadenthal
Subgroup		gleyed Orthic Black	gleyed carbonated Rego Black	gleyed carbonated Rego Black
Textural Class		clay loam	fine sandy loam	fine sandy loam
pH	(0-15 cm)	7.6	7.8	7.9
Conductivity	(0-15 cm)	0.6	0.6	0.8
% $CaCO_3$	(0-15 cm)	2.4	2.7	1.4
equivalent	(15-30 cm)	2.0	4.4	7.8
% organic matter	(0-15 cm)	5.2	3.6	4.3
NO_3 - N	(0-60)	36.9	35.2	14.3
(kg N/ha)	(0-120 cm)	55.7	79.2	20.4
$NaHCO_3$ extractable PO_4^{-3}P (kg P/ha)	(0-15 cm)	9.1	19.2	7.5
NH_4OAc exchangeable K (kg K/ha)	(0-15 cm)	630	320	320
DTPA extractable Zn (ppm)	(0-15 cm)	1.0 (0.44 to 1.50)	1.0 (0.86 to 1.22)	1.4 (0.92 to 2.20)

b) Effect of Nitrogen. Climatic conditions in 1976 were unfavorable for good blackbean growth. Dry weather after seeding resulted in uneven bean germination. At the Portage site, moisture continued to be a limiting factor for much of the growing season.

Yield of blackbeans harvested during the early pod stage was generally unaffected by the addition of nitrogen fertilizer at seeding (Table 6). Exceptions occured at Portage where 30, 60, and 120 kg N/ha significantly decreased the yield of bean forage. Inoculation of blackbeans increased the bean forage yield significantly only at the Portage site and only without added nitrogen at that site. This indicated that the soil was supplying adequate amounts of nitrogen to the bean plants except at the Portage site where inoculation was necessary.

Blackbean seed yields were low and variable especially at the Portage field site (Table 7). No rate of nitrogen fertilizer applied significantly increased blackbean seed yields at any of the field sites. Inoculating the blackbeans resulted in significantly increased yields only at the Jordan field site. However, average seed yield increases due to inoculation were fairly constant, ranging from 370 to 430 kg/ha for the three sites. Therefore, the low levels of nitrogen in the soil appeared to limit seed yield in the uninoculated treatment at all three sites. Once the plants were inoculated, nitrogen was no longer a limiting factor. This is in agreement with work done by Welch et al. (1973) with soybeans and Richards (1977) with fababeans.

Table 6

The Effect of Added Nitrogen on 1976 Midseason Blackbean Yields

Nitrogen Added (kg/ha)	Jordan Yield (kg/ha)	Winkler Yield (kg/ha)	Portage Yield (kg/ha)
	(2)	(1)	(1)
0 (no inoculum)	1220	2020 a	840 bc
0 (inoculated)	1680	2100 a-c	1860 ef
30 "	1380	2800 c	1110 b-d
60 "	1720	2730 bc	1000 b-d
90 "	1310	2380 a-c	1400 b-f
120 "	1180	1880 a	1110 b-d

(1) Duncan's test. P= .05.
(2) Not Significant at P = .05.

Table 7

The Effect of Added Nitrogen on 1976 Blackbean Seed Yields.

Nitrogen Added (kg/ha)	Jordan Yield (kg/ha)	Winkler Yield (kg/ha)	Portage Yield (kg/ha)
	(1)	(1)	(1)
0 (no inoculum)	1140 b	1170 bcd	380 abc
0 (inoculated)	1520 cde	1540 cd	810 cdef
30 "	1470 cde	1230 bcd	1090 ef
60 "	1620 cdef	1400 cd	660 bcde
90 "	1680 def	1670 d	890 def
120 "	1610 cdef	1390 cd	720 cdef

(1) Duncan's test. P =.05.

c) Effect of Phosphorus. Yield of blackbeans harvested during the early pod stage was not significantly increased when added phosphorus was placed with the seed, sidebanded, or broadcast and incorporated (Table 8). In fact, dry matter yields were significantly decreased at the Jordan and Portage sites when 80 kg P_2O_5 /ha was drilled with the seed. The yield decrease was largely due to germination damage caused by seed placed phosphate fertilizer and resulted in a decreased plant population.

Sidebanded or broadcast and incorporated phosphorus had no significant effect on seed yield at the three sites (Table 9). Forty kg P_2O_5 /ha at the Portage site and 80 kg P_2O_5 /ha placed with the seed at all three sites significantly reduced seed yields. A trend of yield reduction was evident at all levels of seed placed phosphorus.

Low rates of phosphorus placed with the seed have been found to improve early soybean growth (Ham et al. 1973), but it appeared that seed placed phosphorus at rates of 20 kg P_2O_5 /ha or higher were detrimental to blackbean yields. The soils at the 1976 Jordan, Winkler, and Portage field sites were low to very low in available phosphorus; however, under these low yielding conditions, the blackbeans were able to take up adequate phosphorus from the soil. Added fertilizer phosphorus did not increase yields and cannot be recommended under these conditions.

None of the phosphorus treatments significantly increased total phosphorus uptake (Table 10). Either the blackbeans were unable to take up the added phosphorus or they had a mechanism

Table 8

The Effect of Added Phosphorus on 1976 Midseason Blackbean Yields.

P_2O_5 Added (kg/ha)	Jordan Yield (kg/ha)	Winkler Yield (kg/ha)	Portage Yield (kg/ha)
(2)	(1)	(1a)	(1)
0	1660 bc	2800	1310 b-f
20 w.s.	1430 bc	2380	840 bc
40 w.s.	1650 bc	2410	820 b
80 w.s.	730 a	2390	90 a
20 s.b.	1500 bc	2780	1310 b-f
40 s.b.	1380 bc	2800	1110 b-d
80 s.b.	1900 c	2480	1360 b-f
80 B.	1580 bc	2100	1190 b-e

(1) Duncan's test. P = .05.
(1a) Not significant at P = .05.
(2) Placement; w.s. - "with seed" s.b. - "sidebanded"
B. - "broadcast"

Table 9

The Effect of Added Phosphorus on 1976 Blackbean Seed Yields.

P_2O_5 Added (kg/ha)	Jordan Yield (kg/ha)	Winkler Yield (kg/ha)	Portage Yield (kg/ha)
(2)	(1)	(1)	(1)
0	1480 cde	1360 bcd	940 def
20 w.s.	1360 bc	1110 bc	570 abcd
40 w.s.	1490 cde	850 ab	190 ab
80 w.s.	470 a	360 a	110 a
20 s.b.	1480 cde	1370 bcd	760 cdef
40 s.b.	1470 cde	1230 bcd	1090 ef
80 s.b.	1520 cde	1480 cd	800 cdef
80 B.	1440 bcde	1480 cd	800 cdef

(1) Duncan's test. P= .05.
(2) Placement; w.s. - " with seed"
s.b. - " side band"
B. - " broadcast"

Table 10

The Effect of Added P on Blackbean P Concentration and Uptake at the 1976 Field Sites.

Part of Plant Analyzed	P_2O_5 Added (kg/ha)	Jordan [P] (mg P/gDM)	Jordan Total P Uptake (kg P/ha)	Winkler [P] (mg P/gDM)	Winkler Total P Uptake (kg P/ha)	Portage [P] (mg P/gDM)	Portage Total P Uptake (kg P/ha)
	(2)	(1a)	(1a)	(1)	(1)	(1)	(1)
Midseason Total Plant	0	2.1	3.5	2.3 a	6.4 ab	2.2 a	2.9 b
	20 w.s.	3.0	4.3	2.2 a	5.2 a	2.4 ab	2.0 b
	40 w.s.	3.0	5.0	3.4 a	8.1 ab	2.8 b	2.3 b
	80 w.s.	3.0	2.2	4.9 b	11.7 b	2.6 ab	0.2 a
	20 s.b.	2.5	3.7	2.6 a	7.4 ab	2.2 a	2.9 b
	40 s.b.	3.4	4.7	3.2 a	8.9 ab	2.4 ab	2.6 b
	80 s.b.	2.5	4.8	3.0 a	7.5 ab	2.4 ab	3.3 b
	80 B.	2.4	3.8	2.5 a	5.3 a	2.2 a	2.6 b
		(1a)	(1a)	(1a)	(1a)	(1)	(1)
Seed	0	2.3	3.4	--	--	2.6 a	2.5 ab
	20 s.b.	2.6	3.9	--	--	2.7 ab	2.0 a
	40 s.b.	2.3	3.4	--	--	3.2 b	3.5 b
	80 s.b.	2.6	3.9	2.7	4.0	3.1 ab	2.5 ab
	80 B.	2.5	3.6	2.9	4.3	3.0 ab	2.4 ab

(1) Duncan's test. P = .05.
(1a) Not significant at P = .05.
(2) Placement;
w.s. - " with seed"
s.b. - " side band"
B. - " broadcast and incorporated"

for excluding phosphorus uptake. Midseason phosphorus concentrations at the early pod formation stage were as low as 2.1 mg P/g dry matter, but the lack of yield response to phosphorus fertilizer indicated that these plant phosphorus concentrations were adequate.

Generally, the sidebanded treatments appeared to be more efficient than the broadcast and incorporated treatments (Table 11), but it must be remembered that none of these differences were statistically significant. The negative values give an indication of the amount of variation occuring at each site.

Work by Papanicolaou et al. (1977) in Greece indicated that sidebanding was the most effective placement method. They added phosphorus to Phaseolus vulgaris and soybeans, and concluded that sidebanded phosphorus was far more efficient than broadcast and incorporated phosphorus.

d) Effect of Potassium. Yield of blackbeans harvested at the early pod stage was generally unaffected by three rates of potassium fertilizer applied at seeding (Table 12). However, there was a significant blackbean forage yield decrease with the addition of 30 kg K_2O /ha at the Winkler site. This forage yield decrease did not show up in the seed yield (Table 13). Seed yields of blackbeans were not significantly affected by any of the rates of applied potassium fertilizer at any of the field sites. This is to be expected since soil potassium levels were high to very high at the three sites. This agrees with Bailey's (Bailey 1976) findings that fababeans and soybeans needed potassium

Table 11

The Efficiency of Recovery of Phosphorus Fertilizer by Blackbeans in the 1976 Field Experiments.

Part of Plant Harvested	P_2O_5 Added (kg/ha) (1)	Apparent Recovery (2) (%)		
		Jordan	Winkler	Portage
Midseason Total Plant	20 w.s.	9.2	(-13.7)	(-10.3)
	40 w.s.	8.6	9.7	(- 3.2)
	80 w.s.	(-3.7)	15.2	(- 7.7)
	20 s.b.	2.3	11.5	0.0
	40 s.b.	6.9	14.3	(- 1.7)
	80 s.b.	3.7	3.2	1.1
	80 B.	0.9	(- 3.2)	(- 0.9)
Seed	20 s.b.	5.6	---	(- 5.6)
	40 s.b.	0.0	---	5.6
	80 s.b.	1.3	---	0.0
	80 B.	0.6	---	(- 0.2)

(1) Placement; w.s.-"with seed" s.b.- "side band" B. - "broadcast"

(2) Apparent Recovery =

$$\frac{\text{nutrient uptake in fertilizer treatment} - \text{nutrient uptake in control}}{\text{Amount of Fertilizer Applied}} \times 100\%$$

Table 12

The Effect of Added Potassium on 1976 Midseason Blackbean Yields.

K_2O Added (kg/ha)	Jordan Yield (kg/ha) (2)	Winkler Yield (kg/ha) (1)	Portage Yield (kg/ha) (2)
0	1380	2800 c	1110
30	1250	1960 a	1560
60	1460	2400 a-c	1500

(1) Duncan's test. P= .05.
(2) Not significant at P = .05.

Table 13

The Effect of Added Potassium on 1976 Blackbean Seed Yields.

K_2O Added (kg/ha)	Jordan Yield (kg/ha)	Winkler Yield (kg/ha)	Portage Yield (kg/ha)
	(1)	(1)	(1)
0	1470	1480	1090
30	1410	1300	840
60	1560	1680	770

(1) Not significant at P = .05 using Duncan's test.

Table 14

The Effect of NPKS Foliar Applications on 1976 Blackbean Seed Yields.

Foliar Applications	Jordan Yield (kg/ha)	Winkler Yield (kg/ha)	Portage Yield (kg/ha)
	(1)	(1)	(1)
0	1640	1530	860
NPKS	1450	1580	840

(1) Not significantly different at P = .05 using Duncan's test.

Table 15

The Effect of Added Zinc on 1976 Midseason Blackbean Yields.

Zn Added (kg/ha)	Jordan Yield (kg/ha)	Winkler Yield (kg/ha)	Portage Yield (kg/ha)
(2)	(1a)	(1)	(1)
0	1380	2800 c	1110 b-d
1 s.b. ($Na_2ZnEDTA$)	1740	2320 a-c	2000 f
5 s.b. ($ZnSO_4$)	1540	2050 ab	1420 b-f
5 B. ($ZnSO_4$)	1670	2440 a-c	1270 b-e

(1) Duncan's test. P =.05.
(1a) Not significant at P = .05.
(2) Placement; s.b. - "sideband" B. - "broadcast and incorporated"

fertilizer only on soils with less than 250 kg NH_4OAc-extractable K/ha (0-15 cm).

e) Effect of NPKS Foliar Applications. Seed yield of blackbeans was unaffected by NPKS foliar applications (Table 14). Foliar applications were initiated at early pod formation and were applied three times at weekly intervals. Soybean researchers have suggested that foliar fertilization minimizes nutrient depletion from the leaves which normally occurs during pod-filling (Garcia and Hanway 1976). Foliar fertilization would therefore increase yields by providing nitrogen, phosphorus, potassium, and sulfur to leaves, allowing the plant to maintain its photosynthetic and nitrogen capabilities for a greater length of time. The lack of response to the NPKS foliar applications in 1976 may indicate that the droughty conditions interfered with the plant's ability to respond. Therefore, moisture would be a more limiting growth factor than N,P, K, or S.

f) Effect of Zinc. Yields of blackbeans harvested during the early pod stage were generally unaffected by addition of zinc carriers applied at seeding (Table 15). Exceptions occured at Winkler where the sidebanded zinc sulfate treatment significantly decreased forage yield and at Portage where sidebanded Na_2Zn EDTA significantly increased blackbean forage yield by over eighty percent. At the Jordan site, $Na_2ZnEDTA$ increased yield by 26 percent but this was not statistically significant.

Blackbean seed yields were not significantly changed by zinc addition except at the Jordan site where Na_2Zn EDTA significantly increased seed yields by 390 kg/ha (Table 17). The Na_2Zn EDTA treatment also increased seed yield by 370 kg/ha at the Winkler site and 50 kg/ha at the Portage site, but these increases were not statistically significant. However, Na_2Zn EDTA was the best zinc treatment at every site.

In the midseason harvest, zinc concentrations were fairly low at the Portage and Winkler sites but appeared to be sufficient at the Jordan site (Table 16). To establish deficiency, marginal, and sufficiency zinc concentration zones for blackbeans, data from Hedayat (1977; pp 70) was run through a regression analysis and a curve was plotted (figure 1). Using a method developed by McAndrew (1979), the local maxima of the regression curve was determined to be the upper boundary of the marginally zinc deficient zone. Zinc concentration when yield was 85% of the maximum yield was taken as the lower boundary of the marginally deficient zone. Blackbean zinc concentrations less than 10.2 ug Zn/g dry matter were determined to be in the deficient zone. Zinc concentrations between 10.2 and 17.0 ug Zn/g dry matter were determined to be marginally deficient. Zinc concentrations greater than 17.0 ug Zn/g dry matter were determined to be sufficient. Using these values, the control treatments at the Winkler and Portage sites plus the broadcast zinc sulfate treatment at the Portage site were marginally deficient in zinc while all other treatments were sufficient. The only significant increase in zinc concentration was in the midseason harvest with broadcast and incorporated zinc sulfate at the Winkler site, but this was a concentration effect re-

Table 16

The Effect of Added Zinc on Blackbean Zinc Concentration and Uptake at the 1976 Field Sites.

Part of Plant Analyzed	Zn Added (kg/ha)	Jordan [Zn] (ug Zn/gDM)	Jordan Total Zn Uptake (g Zn/ha)	Winkler [Zn] (ug Zn/gDM)	Winkler Total Zn Uptake (g Zn/ha)	Portage [Zn] (ug Zn/gDM)	Portage Total Zn Uptake (g Zn/ha)
	(1)	(3)	(3)	(2)	(3)	(3)	(3)
Midseason Total Plant	0	31	43	16 a	46	14	16
	1 s.b. (Na_2 ZnEDTA)	34	59	18 ab	42	18	36
	5 s.b. ($ZnSO_4$)	31	48	17 a	34	17	24
	5 B. ($ZnSO_4$)	29	49	20 b	48	15	19
		(3)	(2)	(3)	(3)	(3)	(3)
Seed	0	29	43 a	24	30	24	26
	1 s.b. (Na_2 ZnEDTA)	29	53 c	23	34	27	31
	5 s.b. ($ZnSO_4$)	30	44 ab	24	29	25	25
	5 B. ($ZnSO_4$)	29	49 bc	24	33	24	21

(1) Placement; s.b.- "sidebanded" B.- "broadcast and incorporated"
(2) Duncan's test. P = .05.
(3) Not significant at P = .05.

Table 17

The Effect of Added Zinc on 1976 Blackbean Seed Yields.

Zn Added (kg/ha)	Jordan Yield (kg/ha)	Winkler Yield (kg/ha)	Portage Yield (kg/ha)
(2)	(1)	(1a)	(1a)
0	1470 cde	1230	1090
1 s.b.($Na_2ZnEDTA$)	1860 f	1500	1140
5 s.b.($ZnSO_4$)	1460 cde	1200	1010
5 B. ($ZnSO_4$)	1710 ef	1410	870

(1) Duncan's test. P = .05.
(1a) Not significant at P = .05.
(2) Placement; s.b.- "side band" B.- "broadcast and incorporated"

Table 18

The Efficiency of Recovery of Zinc Fertilizer by Blackbeans in the 1976 Field Experiments.

Part of Plant Harvested	Zn Added (kg/ha)	Apparent Recovery (2) (%)		
		Jordan	Winkler	Portage
	(1)			
Midseason Total Plant	1 s.b. ($Na_2ZnEDTA$)	1.60	(-0.40)	2.00
	5 s.b. ($ZnSO_4$)	0.10	(-0.24)	0.16
	5 B. ($ZnSO_4$)	0.12	0.04	0.06
Seed	1 s.b. ($Na_2ZnEDTA$)	1.00	0.40	0.50
	5 s.b. ($ZnSO_4$)	0.02	(-0.02)	(-0.02)
	5 B. ($ZnSO_4$)	0.12	0.06	(-0.10)

(1) Placement; s.b.- "sideband" B.- "Broadcast"

(2) $$\text{Apparent Recovery} = \frac{\text{nutrient uptake in fertilizer treatment} - \text{nutrient uptake in control}}{\text{Amount of Fertilizer Applied}} \times 100$$

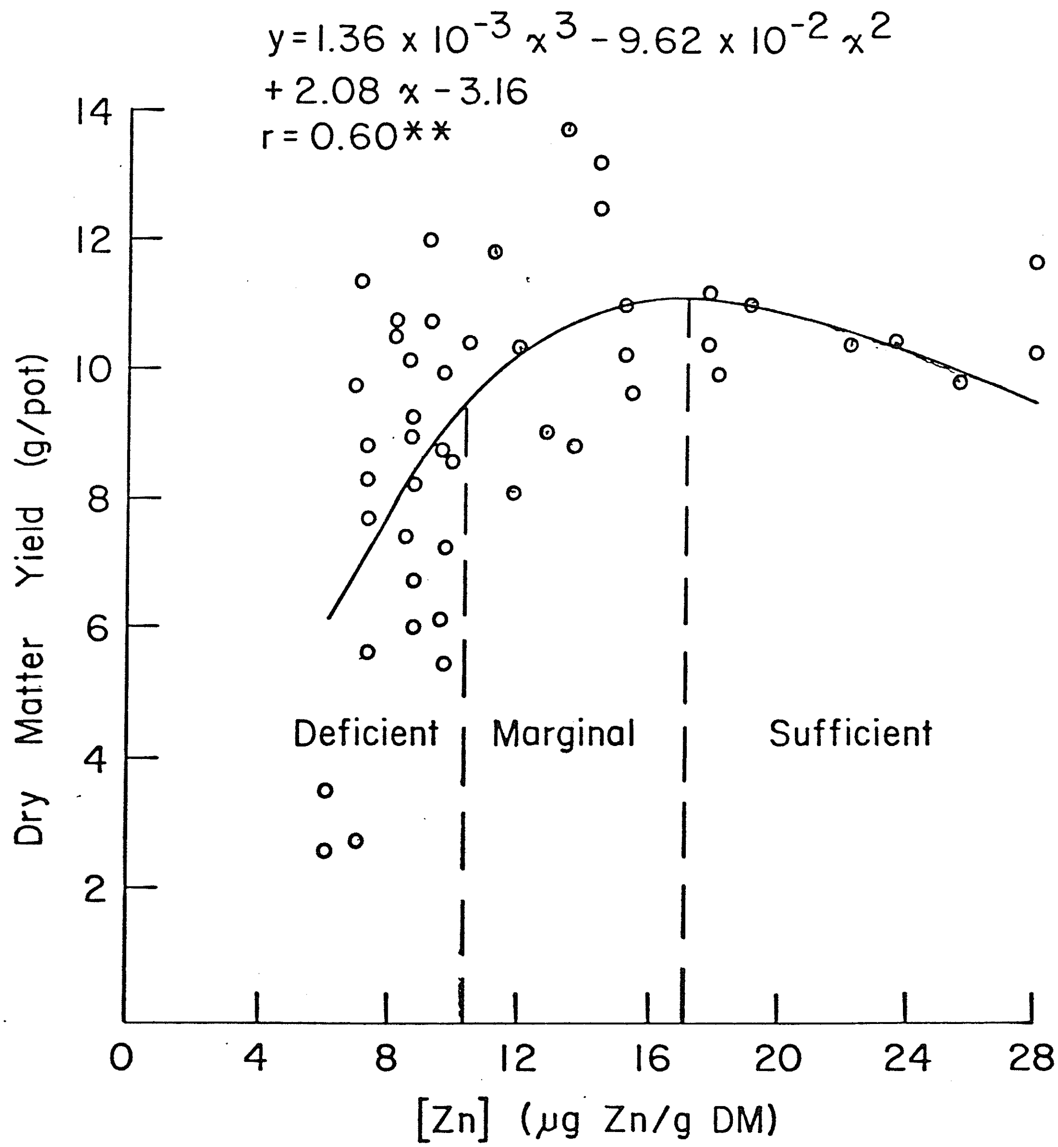

Figure 1. Deficient, marginal, and sufficient zinc concentration zones in blackbeans grown in a growth chamber. Data from Hedayat (1977); pp 70.

sulting from a yield increase.

Total zinc uptake in the midseason harvest increased in the Na_2Zn EDTA treatments at the Portage and Jordan sites. Other treatments did not appear to be particularly effective in increasing total zinc uptake.

In the seed harvest, zinc concentrations were generally higher at the Jordan site than at the Portage and Winkler sites. This correlated well with zinc concentrations in the midseason harvest but did not support the apparent seed yield response to Na_2Zn EDTA. There were no significant differences between zinc treatments at the three sites. Total zinc uptake appeared to increase in the Na_2Zn EDTA treatment at the three sites, but generally did not increase in the other zinc treatments. The zinc sulfate applications appeared to be ineffective. This can be readily seen by calculating the apparent recovery of zinc fertilizer (Table 18). Some fertilizer zinc was undoubtably being taken up by the plants, but the sidebanded Na_2Zn EDTA was the only treatment that appeared to be effective in increasing plant zinc uptake.

The seed yield increase due to added zinc fertilizer at the Jordan site was an important finding because it showed that some of Manitoba's most productive farmland could be deficient in some of the trace nutrients. The DTPA soil test ranged from 0.44 to 1.50 ppm extractable zinc, which showed that there were areas of zinc deficient as well as zinc sufficient soil at the site (Cox and Kamprath 1972). Although there were zinc deficient areas at the site, the average DTPA soil test (1.00 ppm extractable zinc) indicated that zinc fertilization was unnecessary. At the Winkler site, the average DTPA soil test was also 1.00 ppm extractable zinc, but the range (0.86 to 1.22 ppm extractable zinc) and the lack of yield response to zinc fertilizer showed that zinc fertilization was unnecessary. The discrepancy between average soil test results and the extent of actual zinc deficient areas has been a hinderance in predicting potential yield responses to zinc fertilizer. Unfortunately, soil tests usually must be done on composite samples because of the cost of analyses.

Midseason tissue analyses were not reliable in predicting seed yield response to added zinc at the Portage or Jordan sites. Plant tissue zinc concentration increased from 14 to 18 ug Zn/g dry matter with added zinc in the Portage midseason harvest, and this resulted in a significant yield increase; however, this yield response was not observed in the seed harvest. Conversely, at the Jordan site, tissue zinc concentrations were sufficient (29 to 34 ug Zn/g dry matter) in the midseason harvest and there was no resulting yield response to added zinc; but added zinc significantly increased the seed yield. These abnormalities cannot easily be explained.

The most efficient zinc carrier tested was Na_2Zn EDTA and a rate of 1 kg Zn/ha appeared to be effective in increasing total zinc uptake at one of three sites. Sidebanded or broadcast and incorporated zinc sulfate was not effective in increasing zinc uptake. Higher rates of both carriers were recommended for testing in subsequent field studies.

2. 1977 Blackbean Field Experiments.

Blackbeans grown in field trials in 1976 had shown significant yield responses to added zinc fertilizer. Sidebanded Zn EDTA was the most effective zinc carrier while broadcast and incorporated zinc sulfate appeared to be more effective than sidebanded zinc sulfate. Due to this significant yield response to zinc fertilizer, the emphasis of the blackbean investigation, in 1977, shifted to an examination of the effects of various zinc carriers, methods of carrier placement, and rates of application. In addition, the effects of various rates of nitrogen, phosphorus, and copper on blackbean yield and quality were studied.

a) Soils. In 1977, field experiments were conducted at Morden on a Hochfeld FSL and at Winkler on a Neuenberg VFSL. Soil sampling at seeding showed that all soils were base saturated and had low soluble salt concentrations (Table 19). Soil NO_3-N (0-60cm), according to Provincial Soil Testing guidelines (Anon. 1977), was very low in the Hochfeld FSL and low in the Reinland VFSL. Available phosphate ($NaHCO_3$ extractable) concentrations were low in both the Hochfeld and Reinland soils. DTPA extractable zinc ranged from deficient to marginal in the Hochfeld soil and ranged from deficient to adequate in the Reinland soil for susceptible crops such as beans (Viets and Lindsay 1973). DTPA extractable copper was marginally sufficient in both the Hochfeld and Reinland soils at seeding. DTPA extractable manganese was sufficient at both sites (Shuman 1979).

Table 19

Characteristics of Soils in the 1977 Field Experiments.

Site Characteristics		Morden	Winkler
Legal Description		NE 28-3-5W	SW 28-3-4W
Soil Series		Hochfeld	Neuenberg
Subgroup		Orthic Black	gleyed carbonated Rego Black
Textural Class		fine sandy loam	very fine sandy loam
pH (0-15 cm)		7.8	7.6
Conductivity(0-15 cm) (mmhos/cm)		0.8	0.9
% $CaCO_3$ equivalent	(0-15 cm)	0.4	2.6
	(15-30 cm)	0.5	4.4
% organic matter (0-15 cm)		3.9	3.3
NO_3-N (kg N/ha)	(0-60 cm)	16.4	29.4
	(0-120 cm)	17.7	52.3
$NaHCO_3$ extractable PO_4-P (kg P/ha)	(0-15 cm)	13.4	15.7
DTPA extractable Zn (ppm)	(0-15 cm)	0.58(0.16 to 0.84)	0.51(0.22 to 1.12)
DTPA extractable Cu (ppm)	(0-15 cm)	0.30(0.24 to 0.34)	0.33(0.24 to 0.50)
DTPA extractable Mn (ppm)	(0-15 cm)	3.0	2.1

b) Effect of Nitrogen. Climatic conditions in 1977 were favorable for good blackbean growth, except for an extended cloudy, cool wet period early in the growing season.

Blackbean seed yields were significantly increased with the addition of 100 kg N/ha at the Morden site (Table 20). Nitrogen also tended to increase seed yield at the Winkler site, and the midseason total plant yields at both sites. This indicated that nitrogen may have been a limiting nutrient.

The nitrogen content of the total plant at the early pod set stage was fairly uniform at both sites. The 100 kg N/ha treatment at the Winkler site did increase nitrogen content but this occurred with a decrease in forage yield and there was no resulting change in total nitrogen uptake. The seed nitrogen content was significantly increased in the 100 kg N/ha treatment at both sites, but there was no change resulting from the 30 kg N/ha treatment. Blackbean seed protein content was similar to protein levels reported for white beans (leveille et al. 1978).

Added nitrogen did not significantly change midseason total nitrogen uptake at either site, but the trends indicated that there was a slight increase. Seed nitrogen uptake was significantly increased by 38 percent at the Morden site and by 27 percent at the Winkler site with the addition of 100 kg N/ha. With 30 kg N/ha there was a marginal increase in total N uptake at the Winkler site and no increase at the Morden site. Apparent fertilizer uptake varied widely from one to thirty-one percent recovery. However, on average, both treatments had apparent nitrogen fertilizer recoveries of about 16 percent.

Table 20

The Effect of Added N on Blackbean Yield, Nitrogen and Protein Content, Total N Uptake, and Apparent Fertilizer Recovery at the 1977 Morden and Winkler Field Sites.

Part of Plant Analyzed	N Added (kg/ha)	Yield (kg/ha)	N (%)	Protein (%)(1)	Total N Uptake (kg N/ha)	Apparent Recovery (%)(2)
Morden Midseason Total Plant		(4)	(4)	(4)	(4)	
	0	1370	2.68	16.8	36.7	----
	30	1750	2.61	16.3	45.7	30.4
	100	1720	2.81	17.6	48.3	11.6
Morden Seed		(3)	(3)	(3)	(3)	
	0	2250 a	3.62 a	22.6 a	81.6 a	----
	30	2410 ab	3.39 a	21.2 a	81.8 a	1.2
	100	2770 bc	4.05 b	25.3 b	112.3 b	31.0
Winkler Midseason Total Plant		(4)	(3)	(3)	(4)	
	0	1450	2.73 a	17.1 a	39.6	----
	30	1690	2.73 a	17.1 a	46.1	21.6
	100	1320	3.17 b	19.8 b	41.7	2.1
Winkler Seed		(4)	(3)	(3)	(3)	
	o	1710	3.59 a	22.4 a	61.5 a	----
	30	1800	3.68 a	23.0 a	66.2 ab	15.8
	100	1900	4.12 b	25.8 b	78.3 b	16.7

(1) Protein conversion factor = 6.25.

(2)

(2) Apparent Recovery $= \dfrac{\text{nitrogen uptake by treatment} - \text{nitrogen uptake by control}}{\text{Amount of N applied}} \times 100\%$

(3) Duncan's test. P= .05.

(4) Not significant at P= .05.

It has long been observed that nitrate nitrogen depresses nodule formation in legumes (Vincent 1965). Possibly the 30 kg/ha nitrogen addition was decreasing symbiotic nitrogen fixation resulting in little or no net change in total nitrogen uptake. A 100 kg N/ha treatment has been reported to greatly inhibit nodule formation in soybeans (Regitnig, unpublished data 1979), but since total nitrogen uptake still increased, the amount of symbiotic nitrogen fixation taking place in the control treatment must have been very low. In 1976, symbiotic nitrogen fixation resulted in a total nitrogen uptake increase of about 15 kg/ha in the seed (assuming a 400 kg/ha seed yield increase with a 2.7 percent nitrogen content). Total nitrogen fixation by the plant may have been about 22 kg N/ha (assuming that about 2/3 of the plant's nitrogen was in the seed). This could easily have been replaced by fertilizer nitrogen addition. Recovery of fertilizer nitrogen has been reported to be 40 percent or higher (Regitnig 1979).

It is important to know whether nitrogen should be added to beans, and if so, when and how much should be added. If symbiotic nitrogen fixation is really as low as has been indicated, the plants are relying heavily on soil or fertilizer nitrogen. When soil nitrogen is in low supply, nitrogen uptake by the plant could be a limiting factor.

The nitrate nitrogen soil test has been one method which has been used to predict when nitrogen should be added to many of Manitoba's field crops. In 1977 at the Morden site, the soil nitrate nitrogen was 16 kg N/ha (0-60 cm) and a 100 kg N/ha addition resulted in a significant 520 kg/ha seed yield increase even though yields without added nitrogen had been good. At the 1976 Jorden site, the 1977 Winkler site, and the 1978 Winkler site (Regitnig 1979), seed yields were moderately but not statistically increased with nitrogen addition on soils with much higher levels of nitrate nitrogen. Certainly at the 1978 Morden site (Regitnig 1979), seed yields were excellent and blackbean seed yields did not respond to nitrogen addition, even though soil nitrate nitrogen was as low as 20 kg N/ha (0-60 cm). Although it is recognized that soil nitrogen mineralization was much greater in 1978 than 1977 due to warmer temperatures, it still appears that these two soil test results should be used for predicting yield responses to fertilizer nitrogen.

Therefore, 100 kg N/ha sidebanded at seeding is recommended for blackbean production in Manitoba when spring sampled soil nitrate nitrogen is less than 20 kg N/ha (0-60 cm). This recommendation would be especially valid for cool wet springs or for bean crops which are seeded in narrow rows.

c) Effect of Phosphorus. Blackbean yields were not significantly affected by phosphorus addition in 1977 (Table 21). However, at the Morden site, trends indicated that phosphorus was increasing midseason and seed yields.

Similar results were observed for plant phosphorus concentrations and total phosphorus uptake. The only statistically significant change in phosphorus concentration was a decrease in the 30 kg P_2O_5/ha treatment in the Winkler seed harvest, but this

Table 21

The Effect of Added P on Blackbean Yields, P Concentration, Total P Uptake, and Apparent Fertilizer Recovery at the 1977 Morden and Winkler Field Sites.

Part of Plant Analyzed	P_2O_5 Added (kg/ha)	Yield (kg/ha)	P concentration (mg P/g DM)	Total P Uptake (kg P/ha)	% Recovery (3)
		(2)	(2)	(2)	
Morden Midseason Total Plant	0	1640	2.2	3.7	----
	30	1750	2.4	4.2	3.7
	100	1780	2.3	4.1	0.9
		(2)	(2)	(2)	
Morden Seed	0	2220	5.0	11.0	----
	30	2410	4.8	11.5	3.7
	100	2560	4.7	12.1	2.4
		(2)	(2)	(2)	
Winkler Midseason Total Plant	0	1620	1.8	2.9	----
	30	1690	2.0	3.3	3.0
	100	1540	1.9	2.9	0.0
		(2)	(1)	(2)	
Winkler Seed	0	1810	4.0 b-e	7.3	----
	30	1800	3.6 a	6.5	(-5.9)
	100	1780	4.2 de	7.4	0.2

(1) Duncan's test. P= .05.
(2) Not significant at P= .05.

(3) $\% \text{ Recovery} = \dfrac{\text{P uptake by treatment} - \text{P uptake by control}}{\text{Amount of P Applied}} \times 100\%$

was not significant in the total seed phosphorus uptake. Apparently the plant midseason phosphorus concentrations were adequate. At the Morden site, they were above the 2.15 mg P/g dry matter sufficiency range established in growth chamber experiment two. At the Winkler site, midseason P concentrations were in the 1.4 to 2.15 mg P/g dry matter marginally deficient zone, which suggests that a slight yield increase may have occurred if P had been added.

Total phosphorus uptake was not significantly increased at either field site. At the Morden site, there was a trend towards an increase in total P uptake, but this was strongly related to the increases in yield. Apparent fertilizer phosphorus uptake was very low, but this does not mean that actual fertilizer P was unavailable to the plant. ^{32}P studies are needed to establish the fate of added phosphorus fertilizer.

Work by Kalra and Soper (1968) with soybeans has similarly shown that concentrated phosphorus fertilizer sources are not readily taken up by the plant's roots. In the United States, when soil phosphorus levels are low, phosphorus fertilization is commonly recommended for the alternate crops in a soybean rotation. Present evidence indicates that the same recommendation could very well apply to blackbeans, too.

d) Effect of Zinc. Due to the significant seed yield increase in 1976, further work with zinc fertilizer was planned for 1977. The effectiveness of three zinc carriers was compared under four methods of placement. Granular and powdered zinc treatments were sidebanded or broadcast and incorporated into the soil prior to seeding. Various rates of zinc were used in an attempt to find the optimum method of zinc addition. Where carriers were compared it was recognized that one unit of zinc applied as a chelate was equivalent to approximately 2 to 2.5 units applied in sulfate form (Boawn 1973). It was also thought that sidebanded zinc treatments would be twice as efficient as broadcast and incorporated treatments using the same carrier.

It should be noted that the soils at the two 1977 field sites, although potentially deficient in plant available zinc, ranged from severely deficient to nearly adequate (Viets and Lindsay 1973) at various spots throughout each plot. If a yield response to zinc could occur in some treatments, it is possible that soil variation could obscure the average yield result.

According to the 1977 yield data, there was no significant increase in yield at either site (Table 22). This can be readily explained in most instances by noting that there was rarely a significant increase in zinc uptake (Table 23). In the majority of treatments, added zinc fertilizer was not available to the plant for uptake. There were only three treatments which were exceptions. At the Morden site, total zinc uptake in the seed was significantly increased by sidebanding zinc sulfate pellets (Zink Gro fertilizer) or by sidebanding Na_2Zn EDTA. At the Winkler site, only broadcast and incorporated Na_2Zn EDTA significantly increased total seed zinc uptake. All the other treatments were ineffective.

Table 22

Effect of Zinc Addition on Blackbean Yield at the 1977 Field Sites.

Zinc Treatment	Morden Midseason (kg/ha)	Morden Seed (kg/ha)	Winkler Midseason (kg/ha)	Winkler Seed (kg/ha)
	(1)	(2)	(1)	(2)
Check	1980 b	2510	1560 abc	1920
10.0 kg Zn/ha as broadcast granular Zn MNS	1790 ab	2450	1530 abc	1820
10.0 kg Zn/ha as broadcast powder Zn MNS	1710 ab	2440	1650 abc	1730
5.0 kg Zn/ha as sidebanded granular ZnMNS	1960 ab	2520	1500 abc	1720
5.0 kg Zn/ha as sidebanded powder Zn MNS	1650 ab	2620	1780 c	1810
2.5 kg Zn/ha as broadcast solution Zn $SO_4.7H_2O$	1710 ab	2400	1530 abc	1680
5.0 kg Zn/ha as broadcast solution $ZnSO_4.7H_2O$	1850 ab	2370	1530 abc	1760
10.0 kg Zn/ha as broadcast solution Zn $SO_4.7H_2O$	1750 ab	2410	1690 abc	1800
20.0 kg Zn/ha as broadcast solution $ZnSO_4.7H_2O$	1780 ab	2680	1480 abc	1720
2.5 kg Zn/ha as sidebanded "Zink Gro" granules	1600 a	2460	1330 ab	1740
5.0 kg Zn/ha as sidebanded "Zink Gro" granules	1660 ab	2430	1410 abc	1570
10.0 kg Zn/ha as sidebanded "Zink Gro" granules	1660 ab	2410	1650 abc	1780
2.0 kg Zn/ha as sidebanded $Na_2ZnEDTA$	1920 ab	2600	1730 bc	1690
4.0 kg Zn/ha as broadcast solution $Na_2ZnEDTA$	1560 a	2370	1500 abc	1640

(1) Duncan's test. P= .05.
(2) No significant difference at P = .05.

Table 23

Effect of Zinc Addition on Blackbean Total Zinc Uptake at the 1977 Field Sites.

Zinc Treatment	Morden Midseason (g Zn/ha) (1)	Morden Seed (g Zn/ha) (1)	Winkler Midseason (g Zn/ha) (1)	Winkler Seed (g Zn/ha) (1)
Check	32 ab	53 ab	22 abcd	38 ab
10.0 kg Zn/ha as broadcast granular Zn MNS	34 ab	52 a	24 abcd	39 ab
10.0 kg Zn/ha as broadcast powder ZnMNS	32 ab	54 ab	25 abcd	40 ab
5.0 kg Zn/ha as sidebanded granular ZnMNS	35 ab	56 abd	21 abc	37 ab
5.0 kg Zn/ha as sidebanded powder Zn MNS	33 ab	58 abd	24 abcd	37 ab
2.5 kg Zn/ha as broadcast solution $ZnSO_4.7H_2O$	34 ab	60 abd	20 ab	39 ab
5.0 kg Zn/ha as broadcast solution $Zn SO_4.7H_2O$	34 ab	56 abd	26 abcd	43 abc
10.0 kg Zn/ha as broadcast solution $ZnSO_4.7H_2O$	40 ab	62 abd	34 d	45 bc
20.0 kg Zn/ha as broadcast solution $ZnSO_4.7H_2O$	42 b	67 bd	26 abcd	44 bc
2.5 kg Zn/ha as sidebanded "Zink Gro" granules	32 ab	61 abd	24 abcd	37 ab
5.0 kg Zn/ha as sidebanded "Zink Gro" granules	30 ab	68 d	17 a	33 a
10.0 kg Zn/ha as sidebanded "Zink Gro" granules	28 a	57 abd	21 abc	41 ab
2.0 kg Zn/ha as sidebanded powder $Na_2ZnEDTA$	40 ab	69 d	34 cd	46 bc
4.0 kg Zn/ha as broadcast solution $Na_2ZnEDTA$	34 ab	65 abd	31 bcd	52 c

(1) Duncan's test. P= .05.

It can be readily seen that the sidebanded zinc sulfate treatment was effective in only one or two treatments out of twelve separate harvests in 1977 (Table 24). It is especially disheartening to note that the highest $ZnSO_4$ sidebanded rate, the 10 kg Zn/ha treatment, was completely ineffective at both sites.

Therefore, it must be concluded that Na_2Zn EDTA was the only effective carrier for supplying zinc to the plant during the year of application. It should be noted that foliar zinc application is another viable alternative to soil applied Na_2Zn EDTA.

It is also disappointing that some field treatments which received zinc had plants which were actually below the critical level reported by Hedayat (1977) (Table 25). This was especially evident at the Winkler site. Plant zinc concentrations were significantly increased by several carriers but this was usually due to concentration effects resulting from yield decreases.

Table 24

Effect of Zinc Addition on Apparent Recovery[1] of Zinc Fertilizer by Blackbeans at the 1977 Field Sites.

Zinc Treatment	Morden		Winkler	
	Midseason (%)	Seed (%)	Midseason (%)	Seed (%)
Check	--	--	--	--
10.0 kg Zn/ha as broadcast granular ZnMNS	0.02	(-0.01)	0.02	0.01
10.0 kg Zn/ha as broadcast powder ZnMNS	0.00	0.01	0.03	0.02
5.0 kg Zn/ha as sidebanded granular ZnMNS	0.06	0.06	(-0.02)	(-0.02)
5.0 kg Zn/ha as sidebanded powder ZnMNS	0.02	0.10	0.04	(-0.02)
2.5 kg Zn/ha as broadcast solution $ZnSO_4 \cdot 7H_2O$	0.08	0.28	(-0.08)	0.04
5.0 kg Zn/ha as broadcast solution $ZnSO_4 \cdot 7H_2O$	0.04	0.06	0.08	0.10
10.0 kg Zn/ha as broadcast solution $ZnSO_4 \cdot 7H_2O$	0.08	0.09	0.12	0.07
20.0 kg Zn/ha as broadcast solution $ZnSO_4 \cdot 7H_2O$	0.05	0.07	0.02	0.03
2.5 kg Zn/ha as sidebanded "Zink Gro" granules	0.00	0.32	0.08	(-0.04)
5.0 kg Zn/ha as sidebanded "Zink Gro" granules	(-0.04)	0.30	(-0.10)	(-0.10)
10.0 kg Zn/ha as sidebanded "Zink Gro" granules	(-0.04)	0.04	(-0.01)	0.03
2.0 kg Zn/ha as sidebanded powder $Na_2ZnEDTA$	0.40	0.80	0.50	0.40
4.0 kg Zn/ha as broadcast solution $Na_2ZnEDTA$	0.05	0.30	0.22	0.35

(1) Apparent Recovery = $\frac{\text{Zn Uptake by treatment} - \text{Zn Uptake by control}}{\text{Amount of Zn added}} \times 100\%$

Table 25

Effect of Zinc Addition on Blackbean Zinc Content at the 1977 Field Sites.

Zinc Treatment	Morden Midseason (ugZn/gDM) (1)	Morden Seed (ugZn/gDM) (1)	Winkler Midseason (ugZn/gDM) (1)	Winkler Seed (ugZn/gDM) (1)
Check	16.1 a	21.5 a	14.2 abc	19.9 a
10.0 kg Zn/ha as broadcast granular ZnMNS	19.0 abc	21.6 a	16.0 abce	21.4 abc
10.0 kg Zn/ha as broadcast powder ZnMNS	18.9 abc	22.1 ab	15.1 abc	23.0 abcd
5.0 kg Zn/ha as sidebanded granular ZnMNS	17.8 abc	22.3 ab	13.6 ab	21.1 abc
5.0 kg Zn/ha as sidebanded powder ZnMNS	19.9 abcd	22.3 ab	13.6 ab	20.8 ab
2.5 kg Zn/ha as broadcast solution $ZnSO_4.7H_2O$	19.8 abcd	25.0 abdef	12.9 a	23.4 bcd
5.0 kg Zn/ha as broadcast solution $ZnSO_4.7H_2O$	18.4 abc	23.6 abd	17.0 abce	24.2 cdg
10.0 kg Zn/ha as broadcast solution $ZnSO_4.7H_2O$	22.4 cd	25.4 bdef	19.9 ce	25.2 dg
20.0 kg Zn/ha as broadcast solution $ZnSO_4.7H_2O$	24.0 d	24.9 abdef	17.0 abce	25.8 dg
2.5 kg Zn/ha as sidebanded "Zink Gro" granules	20.0 abcd	24.9 abdef	17.8 abce	21.5 abc
5.0 kg Zn/ha as sidebanded "Zink Gro" granules	18.1 abc	28.0 f	12.4 a	20.8 ab
10.0 kg Zn/ha as sidebanded "Zink Gro" granules	17.2 ab	24.0 abde	13.0 a	22.8 abcd
2.0 kg Zn/ha as sidebanded powder $Na_2ZnEDTA$	21.0 bcd	26.5 def	19.0 bce	27.1 g
4.0 kg Zn/ha as broadcast solution $Na_2ZnEDTA$	22.2 cd	27.4 ef	21.1 e	31.6 l

(1) Duncan's test. P= .05.

e) Effect of Copper. Two kg Cu/ha, applied as Na_2Cu EDTA solution sprayed on the soil and incorporated, significantly increased blackbean seed yield by 570 kg/ha at the Morden field site (Table 26). There was a 120 kg/ha seed yield increase at the Winkler site but this was not significant. Midseason yield increased by about 10 percent at the Morden site and did not increase at the Winkler site.

Copper concentration of the seed at the Morden site was significantly increased with addition of copper. A plot of midseason yield vs copper concentration according to the method developed by McAndrew (1979) showed that the plant was sufficient at early pod stage when copper was greater than 5.9 ug Cu/g DM; it was marginal when the concentration was 3.8 to 5.9 ug Cu/g DM; and the concentration was deficient when it was below 3.8 ug Cu/g DM (figure 2). Since the regression analysis was not statistically significant, these values should be considered as tentative.

Total copper uptake was significantly increased in the seed at the Morden site and in the midseason harvest, but at the Winkler site there was no increase in copper uptake. The lack of yield increase was unexpected since some reps were marginally deficient in copper. A lack of copper uptake would explain this discrepancy. Work by McAndrew (1979) and McGregor (1972) has shown that Na_2Cu EDTA banded with the seed was ineffective or detrimental for flax, wheat, oats, and barley growth. Broadcast and incorporated copper was shown to be a more effective treatment. Sidebanding copper fertilizer still needs to be tested.

DTPA extractable copper ranged from 0.24 to 0.34 ppm

Table 26

The Effect of Added Copper on Blackbean Yield, Copper Concentration and Uptake, and Apparent Recovery at the 1977 Field Sites.

Part of Plant Analyzed	Cu Added (kg/ha)	Yield (kg/ha)	[Cu] (ug Cu/ha)	Total Cu Uptake (g Cu/ha)	Apparent Recovery (%)
		(3)	(3)	(3)	
Morden	0	1560	4.0	6.4	--
Midseason	2	1720	5.4	9.4	0.15
		(2)	(2)	(2)	
Morden	0	2370 a	5.8 a	13.6 a	--
Seed	2	2940 b	7.6 b	22.4 b	0.44
		(3)	(3)	(3)	
Winkler	0	1500	5.7	8.4	--
Midseason	2	1510	5.3	8.0	(-0.02)
		(3)	(3)	(3)	
Winkler	0	1640	9.7	16.0	--
Seed	2	1760	9.2	16.1	0.005

(1) $$\text{Apparent Recovery} = \frac{\text{Cu Uptake by treatment} - \text{Cu Uptake by control}}{\text{Amount of Cu Added}} \times 100\ \%$$

(2) Duncan's test. P = .05.

(3) Not significantly different at P = .05.

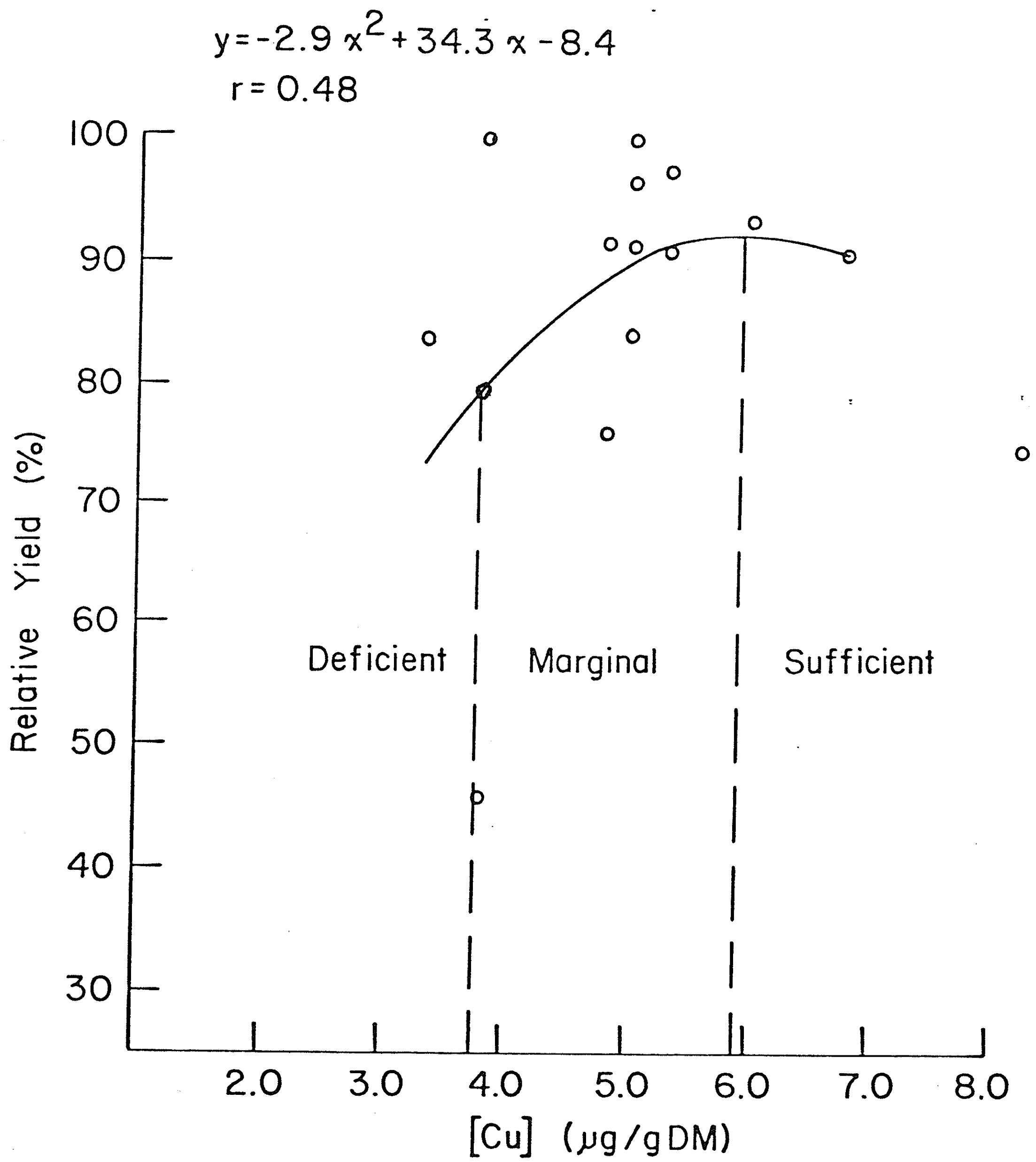

Figure 2. Deficient, marginal, and sufficient zones of copper concentration in blackbeans harvested in the early pod stage at the 1977 field sites.

at the Morden site where the yield response occured. At the Winkler site, DTPA extractable copper ranged from 0.24 to 0.50 ppm and it was noted that some replicate samples may have been copper deficient at the early pod formation stage. Overall, it can be concluded that the copper critical level for DTPA extractable copper may be approximately 0.3 ppm for blackbeans.

f) Effect of Iron on Blackbeans. A visual response to iron addition was noted early in the growing season at the Winkler site. Most of the blackbeans began showing symptoms of chlorosis within the first few weeks of growth due to an extended cloudy, cool, wet period. Guard rows were sprayed with a one percent solution of iron sulfate and the blackbean plants turned dark green within a few days. The rest of the Winkler field plot gradually recovered from the chlorosis and turned dark green over the next week to ten days without foliar application of iron sulfate. It is possible that yields were decreased due to this period of iron deficiency.

Subsequent to this, soil samples were analyzed for DTPA-extractable iron content. These soil samples had been ground in a Wiley mill and may have been contaminated with iron. However, the soil samples ranged from 2.0 to 3.0 ppm DTPA-extractable iron. Lindsay and Norvell (1978) have established a critical level of 4.5 ppm DTPA-extractable iron for sorghum in small pot growth chamber experiments. Soils with less than 2.5 ppm DTPA-extractable iron were describes as being deficient while soils between 2.5 ppm and 4.5 ppm were described as being borderline. Beans, like sorghum, are highly responsive to iron fertilization on iron deficient soils (Lucas and Knezek 1972). Therefore, it is possible that the 1977 Winkler blackbean crop would have responded to foliar iron applications. Morden may also have responded but this was not tested. It is also interesting that the DTPA soil iron test was able to predict a visual response to foliar iron application.

3. <u>1978 Blackbean Field Experiments</u>.

Hedayat (1977) investigated the influence of phosphorus on zinc utilization by blackbeans on a zinc deficient Lakeland silty clay loam in a growth chamber study. He found that blackbean yield did not increase with phosphorus addition unless zinc was also added. When 8 ppm of zinc was added, shoot dry matter yield increased linearly with increasing rates of added phosphorus up to 80 ppm. It was also noted that 160 ppm phosphorus interfered in zinc uptake or zinc translocation to the shoots even when 8 ppm zinc was added.

Blackbeans were grown in field studies in 1978 to find out: 1) if high rates of added phosphorus would reduce zinc uptake and/or induce zinc deficiencies in field grown blackbeans. 2) if zinc sulfate addition could prevent a phosphorus induced reduction in plant zinc uptake. 3) if phosphorus and/or zinc addition would increase midseason or seed yields. Rates of zinc sulfate and monocalcium phosphate were broadcast and incorporated to give comparable furrow slice fertilizer concentrations as those used in Hedayat's growth chamber study.

a) <u>Soils</u>. In 1978, field experiments were conducted at Morden on a Hochfeld FSL and at Winkler on a Neuenberg VFSL. Soil sampling at seeding showed that all soils were base saturated and had low soluble salt concentrations (Table 27). Soil NO_3-N (0-60 cm), according to Provincial Soil Testing guidelines (Anon. 1977), was low at both sites. Available phosphorus ($NaHCO_3$ extractable) levels ranged from very low to medium in the Hochfeld

Table 27

Characteristics of Soils in the 1978 Field Experiments.

Site Characteristics		Morden	Winkler
Legal Description		NE 28-3-5W	SW 28-3-4W
Soil Series		Hochfeld	Neuenberg
Subgroup		Orthic Black	gleyed carbonated Rego Black
Textural Class		fine sandy loam	very fine sandy loam
pH	(0-15 cm)	7.1	7.8
Conductivity (mmhos/cm)	(0-15 cm)	0.3	0.4
% $CaCO_3$ equivalent	(0-15 cm)	0.3	0.2
	(15-30 cm)	0.5	2.2
% organic matter		2.9	4.1
NO_3-N (Kg N/ha)	(0-60 cm)	24.7	33.0
	(0-120 cm)	49.6	72.3
$NaHCO_3$ extractable PO_4-P (Kg P/ha)	(0-15 cm)	14.3 (9.5 to 22.4)	13.4 (1.1 to 29.1)
DTPA extractable Zn (ppm)	(0-15 cm)	1.38 (0.86 to 2.08)	0.48 (0.12 to 1.16)
DTPA extractable Cu (ppm)	(0-15 cm)	0.44 (0.34 to 0.60)	0.83 (0.66 to 0.92)
DTPA extractable Mn (ppm)	(0-15 cm)	22.6	18.8
DTPA extractable Fe (ppm)	(0-15 cm)	22.0	12.0

FSL and from near zero to high in the Neuenberg VFSL. DTPA-extractable zinc ranged from marginal to adequate in the Hochfeld FSL and from very deficient to adequate in the Neuenberg VFSL for susceptible crops such as beans (Viets and Lindsay 1973). DTPA-extractable copper, manganese, and iron were adequate at both sites.

b) Effect of Phosphorus and Zinc on Blackbean Yield and Quality. Climatic conditions in 1978 were very favorable for blackbean growth. Above normal temperatures, adequate rainfall, and a warm late fall contributed to good blackbean yields.

Yields of blackbeans harvested in the early flowering stage were increased by added phosphorus and zinc at the Morden site, but not at the Winkler site (Table 28). At the Morden site, dry matter yield increased linearly with increasing rates of added phosphorus (Figure 3). Added zinc increased dry matter yield at every level of added phosphorus; however, this effect appeared to be more pronounced in the 200, 400, and 800 kg P_2O_5/ha treatments than at lower rates of added phosphorus even though the F-test for the interaction was not significant. At the Winkler site, neither phosphorus nor zinc addition had an effect on mid-season dry matter yeild. This was unexpected since $NaHCO_3$ extractable soil phosphorus was low, similar to the Morden site, and DTPA extractable soil zinc indicated that the soil was deficient in plant available zinc.

Blackbean seed yields were increased by phosphorus addition at the Morden site but not at the Winkler site. Seed yield was increased from 2690 to 3070 kg/ha at the Morden site with the

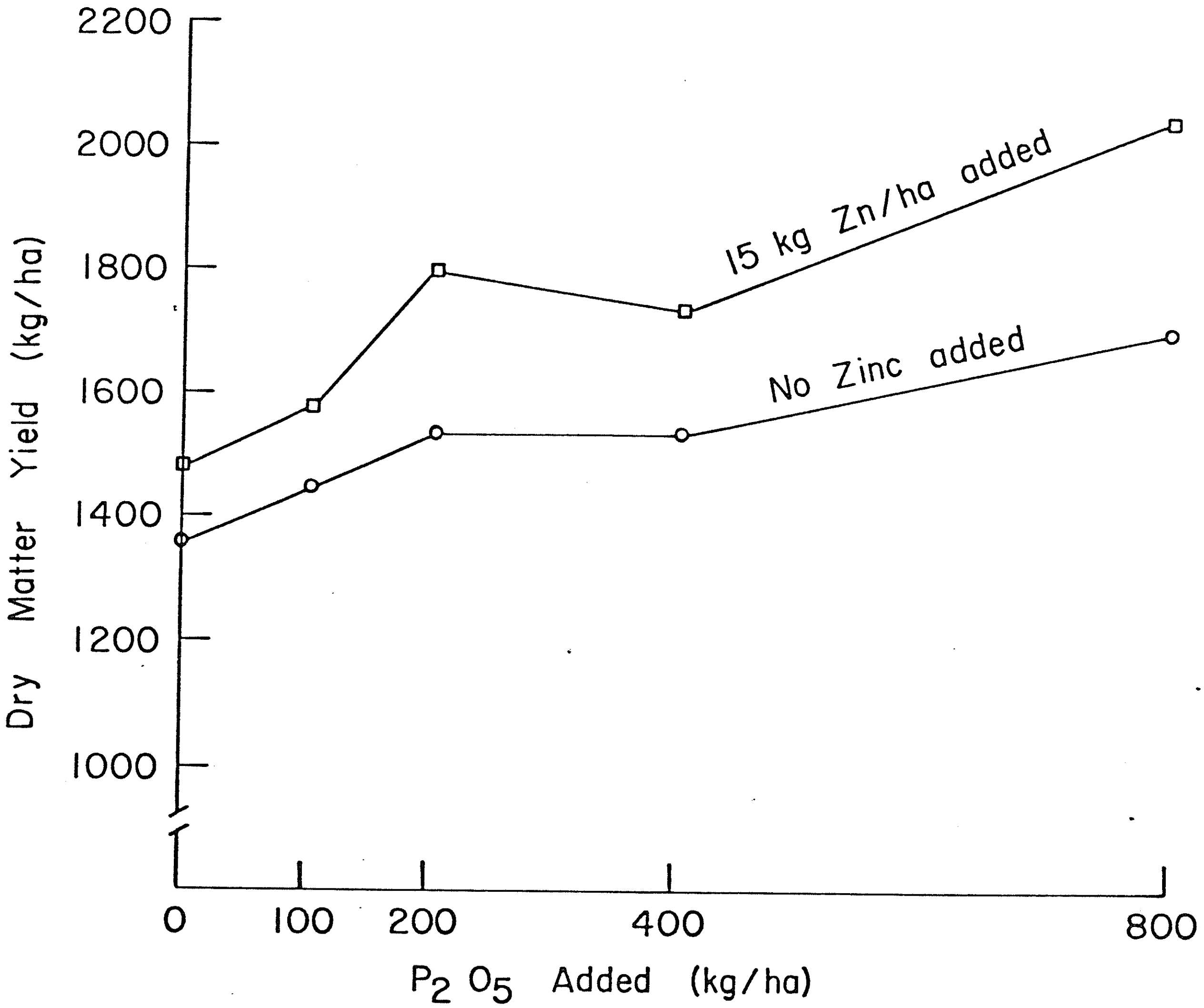

Figure 3. The effect of added phosphorus and zinc on midseason blackbean yield at the 1978 Morden field site.

Table 28

The Effect of Phosphorus and Zinc on Blackbean Yield at the 1978 Field Sites.

P_2O_5 Added (kg/ha)	Morden Midseason Yield (kg/ha)		Morden Seed Yield (kg/ha)		Winkler Midseason Yield (kg/ha)		Winkler Seed Yield (kg/ha)	
	No Zn	15 kgZn/ha	No Zn	15 kgZn/ha	No Zn	15 kgZn/ha	No Zn	15 kgZn/ha
	(2)		(2)		(2)		(2)	
0	1360	1480	2710	2670	1760	1730	2710	2410
100	1450	1580	3140	3000	1730	1800	2310	2520
200	1540	1800	2930	3020	1680	1760	2700	2400
400	1540	1740	2930	3130	1650	1830	2900	2520
800	1710	2050	2910	3170	1680	1840	2560	2740

	Morden Midseason	Morden Seed	Winkler Midseason	Winkler Seed
F-test P	2.62 (4)	3.47 (5)	0.02 (3)	1.73 (3)
F-test Zn	4.82 (5)	0.94 (3)	0.82 (3)	1.30 (3)
F-test Px Zn	0.17 (3)	1.00 (3)	0.15 (3)	2.04 (3)
error df= 27				
s	305	236	320	281
cv	18.7	8.0	18.3	10.9

P Main Effect

P_2O_5 Added (kg/ha)	Morden Midseason (1)	Morden Seed (1)	Winkler Midseason	Winkler Seed
0	1420 a	2690 a	N.S.	N.S.
100	1520 a	3070 b		
200	1670 ab	2970 b		
400	1640 ab	3030 b		
800	1880 b	3040 b		

(1) Duncan's test. P=.05.
(2) Px Zn interaction is not significant.
(3) Not significant at P=.10.
(4) Significant at P=.10.
(5) Significant at P=.05.

addition of 100 kg P_2O_5 /ha, but higher rates of added phosphorus had no further effect on seed yield. Added zinc had no significant effect on seed yield at either site, but at the Morden site zinc addition appeared to increase seed yield at high rates of added phosphorus (Figure 4).

Midseason zinc uptake was increased by zinc addition at both sites, but zinc uptake was not affected by added phosphorus (Table 29). Seed zinc uptake at the Morden site appeared to be increased by the addition of 100 kg P_2O_5 /ha, and then decreased with higher rates of added phosphorus. At the Winkler site, seed zinc uptake was markedly decreased by all rates of added phosphorus, but zinc fertilizer addition prevented the phosphorus induced reduction in zinc uptake. This phosphorus-zinc interaction also appeared to be present in the Winkler midseason yields, but it was not statistically significant (Figure 5).

At the Winkler site, a phosphorus induced reduction in zinc uptake and/or translocation to plant tops probably resulted from low availability of soil zinc (DTPA extractable soil zinc was 0.48 ppm). When plant available soil zinc was higher, as at the Morden site (1.4 ppm DTPA extractable soil zinc), the phosphorus induced reduction in zinc uptake was much less severe. Hedayat (1977) reported an extreme case of phosphorus-induced reduction in zinc uptake which was due to very low plant available soil zinc in a growth chamber pot experiment. It was very encouraging to note that zinc sulfate addition could prevent phosphorus-induced reduction in blackbean zinc uptake in the growth chamber and field experiments.

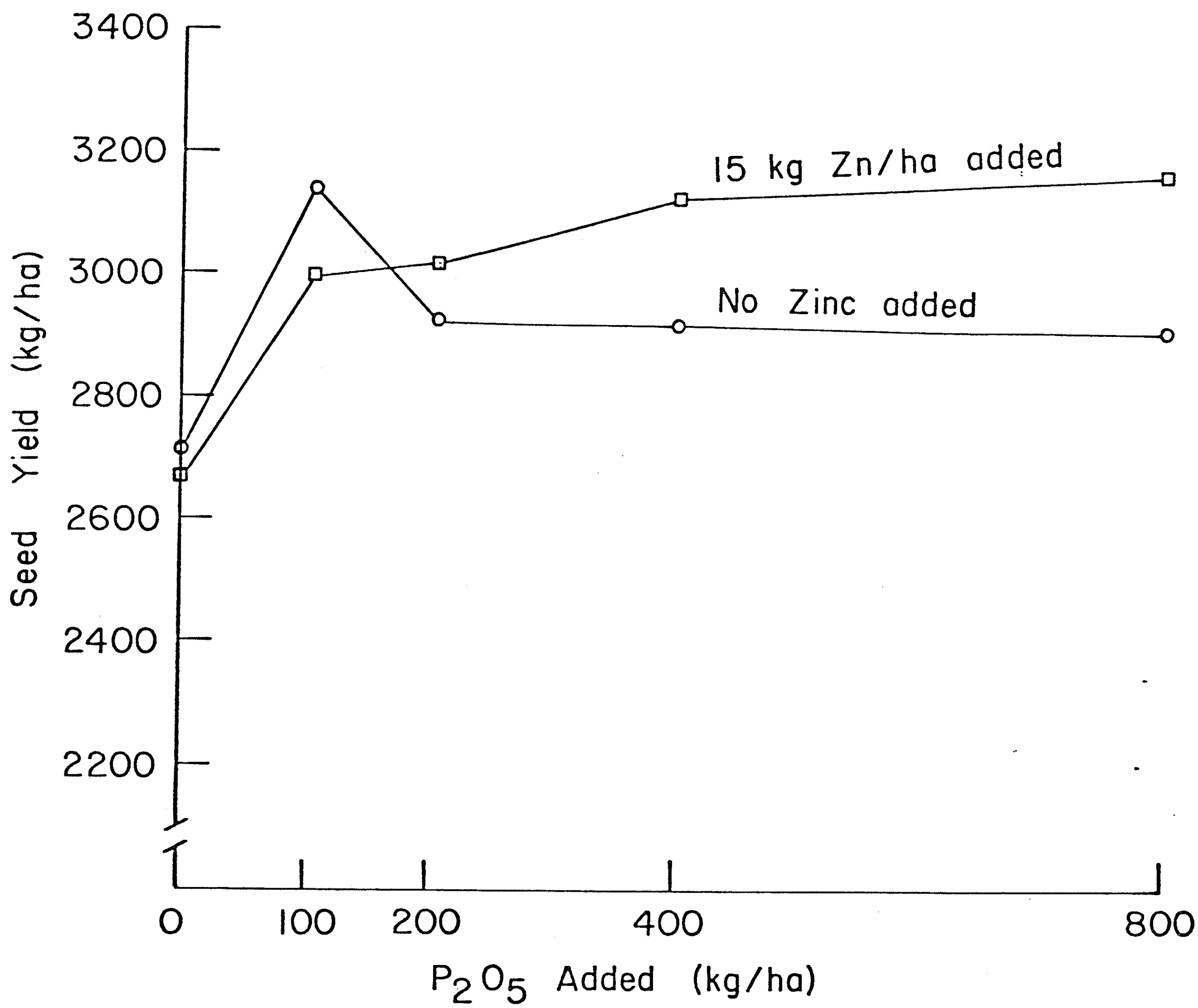

Figure 4. The effect of added phosphorus and zinc on blackbean seed yield at the 1978 Morden field site.

Table 29

The Effect of Phosphorus and Zinc on Blackbean Total Zinc Uptake at the 1978 Field Sites.

P_2O_5 Added (kg/ha)	Morden Midseason (g Zn/ha) No Zn	Morden Midseason (g Zn/ha) 15 kgZn/ha	Morden Seed (g Zn/ha) No Zn	Morden Seed (g Zn/ha) 15kg Zn/ha	Winkler Midseason (g Zn/ha) No Zn	Winkler Midseason (g Zn/ha) 15kg Zn/ha	Winkler Seed (g Zn/ha) No Zn	Winkler Seed (g Zn/ha) 15kg Zn/ha
	(2)		(2)		(2)		(1)	
0	35	43	76	83	43	45	77 c	71 bc
100	37	44	85	88	31	43	49 a	70 bc
200	32	47	77	89	28	42	48 a	68 bc
400	26	43	69	91	27	44	55 ab	70 bc
800	28	50	66	78	25	41	43 a	75 c
F-test P	1.12 (3)		3.06 (4)		2.07 (3)		3.30 (4)	
F-test Zn	46.1 (5)		16.4 (5)		25.6 (5)		27.0 (5)	
F-test PxZn	1.78 (3)		1.40 (3)		1.12 (3)		3.67 (4)	
error df= 27								
s	6.45		8.56		8.12		10.2	
cv	16.8		10.7		22.0		16.3	
P Main Effect								
P_2O_5 Added (kg/ha)			(1)				(1)	
0			79 ab				74 a	
100			87 b				59 b	
200	N.S.		83 b		N.S.		58 b	
400			80 ab				63 b	
800			72 a				59 b	

(1) Duncan's test. P= .05. (2) PxZn interaction is not significant.
(3) Not significant at P= .10. (4) Significant at P= .05.
(5) Significant at P= .005.

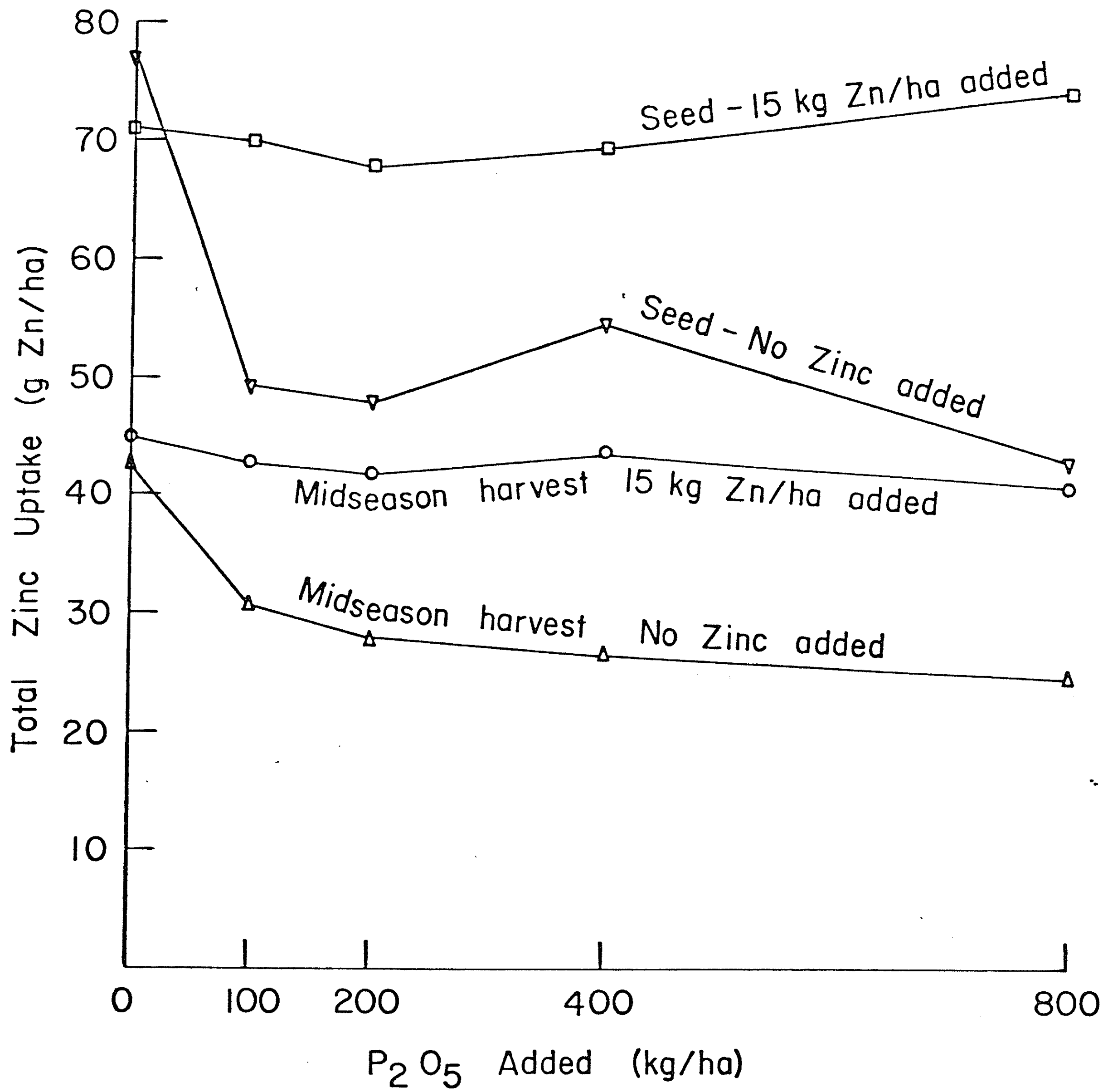

Figure 5. The effect of added phosphorus and zinc on blackbean total zinc uptake at the 1978 Winkler field site.

Blackbean zinc concentrations decreased with increasing rates of added phosphorus due to dilution and/or a phosphorus induced reduction in total zinc uptake (Table 30). High rates of added phosphorus reduced blackbean forage zinc concentration to marginally deficient levels (less than 17 ug Zn/g dry matter) at both sites, but zinc fertilizer addition successfully increased zinc concentrations to sufficiency levels (greater than 17 ug Zn/g dry matter).

Apparent recoveries of zinc fertilizer in 1978 were similar to recoveries observed in previous field studies. Recoveries were consistently much lower in the field than has been observed in the growth chamber (Table 31). In growth chamber experiment two, apparent zinc fertilizer recovery ranged from 0.44 to 0.52 percent and generally appeared to increase with increasing rates of added phosphorus. Apparent zinc recoveries also appeared to increase in the field with increasing rates of added phosphorus but recoveries were much lower. Hedayat (1977) reported data showing apparent zinc fertilizer recoveries of 0.22 percent when zinc sulfate was thoroughly mixed with the soil and 0.10 percent when zinc sulfate was sidebanded in growth chamber pot experiments. Hedayat's added zinc and phosphorus fertilizer concentrations would correspond to a 15 kg Zn/ha and 500 kg P_2O_5 /ha fertilizer application in the field. An interpolation of the 1978 midseason field data at 500 kg P_2O_5 /ha would give a 0.12 percent zinc recovery at the Morden site and a 0.11 percent zinc recovery at the Winkler site. Compared to Hedayat's data, the field results indicate that zinc was being taken up similarly to a band application

Table 30

The Effect of Phosphorus and Zinc on Blackbean Zinc Concentration at the 1978 Field Sites.

P_2O_5 Added (kg/ha)	Morden Midseason (ug Zn/gDM) No Zn	Morden Midseason (ug Zn/gDM) 15 kgZn/ha	Morden Seed (ug Zn/g DM) No Zn	Morden Seed (ug Zn/g DM) 15 kg Zn/ha	Winkler Midseason (ug Zn/g DM) No Zn	Winkler Midseason (ug Zn/g DM) 15 kgZn/ha	Winkler Seed (ug Zn/g DM) No Zn	Winkler Seed (ug Zn/g DM) 15 kgZn/ha
	(2)		(2)		(1)		(1)	
0	25	30	28	31	24 b	26 b	28 c	30 c
100	26	28	27	29	18 a	24 b	21 b	28 c
200	20	27	26	30	16 a	24 b	18 ab	28 c
400	17	24	24	29	16 a	24 b	19 ab	28 c
800	16	24	23	25	15 a	23 b	16 a	27 c
F-test P	9.55 (6)		13.5 (6)		9.03 (6)		8.76 (6)	
F-test Zn	35.5 (6)		34.0 (6)		77.8 (6)		86.0 (6)	
F-test P xZn	1.27 (3)		1.41 (3)		2.57 (4)		4.42 (5)	
error df=27								
s	3.03		1.70		2.30		2.60	
cv	12.6		6.3		10.9		10.7	

P Main Effect

P_2O_5 Added (kg/ha)	Morden Midseason	Morden Seed	Winkler Midseason	Winkler Seed
	(1)	(1)	(1)	(1)
0	27 a	29 a	25 a	29 a
100	27 a	28 ab	21 b	25 b
200	24 b	28 ab	20 b	23 b
400	21 b	26 b	20 b	23 b
800	21 b	24 c	19 b	22 b

(1) Duncan's test. P= .05.
(2) PxZn interaction is not significant.
(3) Not significant at P= .10.
(4) Significant at P= .10.
(5) Significant at P= .01.
(6) Significant at P= .005.

Table 31

The Effect of Phosphorus on the Efficiency of Zinc Fertilizer Recovery at the 1978 Field Sites.

Part of Plant Analyzed	P_2O_5 Added (kg/ha)	Site: Morden Apparent Recovery(1) (%)	Site: Winkler Apparent Recovery(1) (%)
Midseason Total Plant	0	0.05	0.01
	100	0.05	0.08
	200	0.10	0.09
	400	0.11	0.11
	800	0.15	0.11
Seed	0	0.05	(-0.04)
	100	0.02	0.14
	200	0.08	0.13
	400	0.15	0.10
	800	0.08	0.21

(1) Apparent Recovery; $= \dfrac{\text{zinc uptake by treatment} - \text{zinc uptake by control}}{\text{amount of zinc added}} \times 100\%$

even though it was sprayed on the soil and incorporated with a disc.

Total phosphorus uptake was increased by added phosphorus at the Morden site but not the Winkler site; while added zinc had no effect on phosphorus uptake at either site (Table 32). At the Morden site, total phosphorus uptake in the midseason harvest increased curvilinearly with increasing rates of added phosphorus, but in the seed harvest there was an increase in phosphorus uptake with 100 kg P_2O_5/ha and no further increase at higher rates of added phosphorus.

Phosphorus concentration was increased by added phosphorus in the midseason harvest at both sites and in the Morden seed harvest but not in the Winkler seed harvest; while added zinc increased seed phosphorus concentration at the Winkler site and decreased phosphorus concentration in the other three harvests (Table 33). It was expected that phosphorus fertilizer addition would increase phosphorus concentration in every harvest, but in the Winkler seed harvest this did not happen. Since seed phosphorus concentration was very high in the control treatment (5.5 mg P/g dry matter), it is possible that the plant had a mechanism for preventing higher seed phosphorus concentrations. Zinc fertilizer addition was highly significant in increasing seed phosphorus concentration; as opposed to decreasing total plant phosphorus uptake in growth chamber experiment two; so possibly zinc was involved in a mechanism controlling translocation of phosphorus to the seed. Reductions in phosphorus concentration, when zinc was added in the Morden seed harvest and the two midseason harvests were dilution

Table 32

The Effect of Phosphorus and Zinc on Blackbean Total Phosphorus Uptake at the 1978 Field Sites.

P_2O_5 Added (kg/ha)	Morden Midseason (kg P/ha)		Morden Seed (kg P/ha)		Winkler Midseason (kg P/ha)		Winkler Seed (kg P/ha)	
	No Zn	15 kgZn/ha	No Zn	15kgZn/ha	No Zn	15kgZn/ha	No Zn	15kgZn/ha
	(2)		(2)		(2)		(2)	
0	4.2	4.4	12.1	11.8	6.0	5.6	14.8	13.6
100	4.8	5.2	16.2	14.8	6.0	5.9	11.4	12.9
200	5.7	6.1	16.0	15.3	6.3	6.4	12.7	13.7
400	6.2	6.3	15.7	16.2	6.3	6.5	14.5	14.4
800	7.6	7.9	16.0	16.9	7.7	7.0	13.2	15.5
F-test P	11.6 (4)		14.0 (4)		2.07 (3)		1.41 (3)	
F-test Zn	0.58 (3)		0.25 (3)		0.34 (3)		0.91 (3)	
F-test PxZn	0.03 (3)		0.96 (3)		0.17 (3)		0.66 (3)	

P Main Effect

P_2O_5 Added (kg/ha)	Morden Midseason	Morden Seed	Winkler Midseason	Winkler Seed
	(1)	(1)		
0	4.3 a	11.9 a		
100	5.0 ab	15.5 b		
200	5.9 bc	15.6 b	N.S.	N.S.
400	6.2 c	16.0 b		
800	7.8 d	16.4 b		

(1) Duncan's test P= .05. (2) PxZn interaction is not significant.
(3) Not significant at P= .10. (4) Significant at P= .005.

Table 33

The Effect of Phosphorus and Zinc on Blackbean Phosphorus Concentration at the 1978 Field Sites.

P_2O_5 Added (kg/ha)	Morden Midseason (mg P/g DM)		Morden Seed (mg P/g DM)		Winkler Midseason (mg P/g DM)		Winkler Seed (mg P/gDM)	
	No Zn	15 kgZn/ha	No Zn	15kg Zn/ha	No Zn	15kg Zn/ha	No Zn	15kg Zn/ha
	(2)		(2)		(2)		(2)	
0	3.1	3.0	4.5	4.4	3.4	3.2	5.5	5.6
100	3.3	3.3	5.2	4.9	3.5	3.3	5.0	5.2
200	3.7	3.4	5.5	5.1	3.8	3.6	4.7	5.6
400	4.0	3.6	5.4	5.2	3.9	3.6	5.0	5.7
800	4.5	3.9	5.5	5.3	4.6	3.8	5.1	5.7
F-test P	17.9 (6)		20.0 (6)		13.5 (6)		0.53 (3)	
F-test Zn	9.30 (5)		7.26 (4)		13.9 (6)		5.11 (4)	
F-test PxZn	1.05 (3)		0.60 (3)		1.81 (3)		0.43 (3)	
error df= 27								
s	0.30		0.25		0.27		0.73	
cv	8.5		4.9		7.3		13.8	

P Main Effect

P_2O_5 Added (kg/ha)	Morden Midseason (1)	Morden Seed (1)	Winkler Midseason (1)	Winkler Seed
0	3.0 a	4.4 a	3.3 a	
100	3.3 ab	5.1 b	3.4 a	
200	3.5 bc	5.3 bc	3.7 b	N.S.
400	3.8 c	5.3 bc	3.7 b	
800	4.2 d	5.4 c	4.2 c	

(1) Duncan's test. P= .05. (2) PxZn interaction is not significant.
(3) Not significant at P= .10. (4) Significant at P= .05.
(5) Significant at P= .01. (6) Significant at P= .005.

effects.

Apparent phosphorus fertilizer recovery was very low in the midseason harvests at both sites and in the seed harvest at the Winkler site (Table 34). In the Morden seed harvest, 100 kg P_2O_5 /ha significantly increased P uptake and resulted in a 9.2 percent apparent phosphorus fertilizer recovery. Further increases in rates of added phosphorus did not affect total P uptake, so, apparent phosphorus recovery decreased proportionately. Generally, phosphorus concentrations in most treatments were high and it appeared that the plant had a mechanism for restricting further phosphorus uptake and/or translocation to the shoots.

Even though extractable phosphorus levels were low at both sites, excellent seed yields of 2700 kg/ha were obtained without the addition of zinc or phosphorus fertilizer. Yield responses to added phosphorus were significant at the Morden site and would have been profitable to a farmer growing beans in Southern Manitoba. However, the amount of yield response was not as great as has been reported for other crops. Blackbeans may be quite similar to soybeans in that it would be more profitable to apply phosphorus to the alternate crops in a rotation and let blackbeans feed off the residual phosphorus.

It had been determined in growth chamber studies that the best method of placement for inorganic zinc carriers was to mix the carrier as thoroughly as possible with the soil. In the 1978 field experiments, this was accomplished by spraying zinc sulfate solution on the soil and incorporating with a disc. This proved to be an effective method of zinc addition when high rates of

Table 34

The Effect of Phosphorus and Zinc on Apparent Phosphorus Fertilizer Recovery at the 1978 Field Sites.

Zn Added (kg/ha)	P_2O_5 Added (kg/ha)	Morden		Winkler	
		Midseason %Recovery(1)	Seed %Recovery(1)	Midseason %Recovery(1)	Seed %Recovery(1)
0	0	---	---	---	===
0	100	1.37	9.40	0.00	(-7.80)
0	200	1.72	4.47	0.34	(-2.41)
0	400	1.15	2.06	0.17	(-0.17)
0	800	0.97	1.18	0.49	(-0.46)
15	0	---	---	---	---
15	100	1.83	6.87	0.69	(-1.60)
15	200	1.95	4.01	0.92	0.11
15	400	1.09	2.52	0.52	0.46
15	800	1.00	1.46	0.40	0.54

(1) Apparent Recovery = $\dfrac{\text{P uptake by treatment} - \text{P uptake by control}}{\text{Amount of P added}} \times 100\%$

phosphorus were applied, since zinc sulfate increased midseason and seed yields, and increased plant zinc concentrations to levels which were considered sufficient. However, at low levels of added phosphorus, zinc sulfate was not effective in increasing zinc uptake by the above ground portion of the plant. Since zinc sulfate addition increased the amount of chemically available and plant available zinc, as shown by the increase in zinc uptake at high rates of added phosphorus; the lack of response to added zinc at low rates of added phosphorus was unexpected and cannot readily be explained.

The lack of a yield response to added zinc was unexpected at the Winkler site, since DTPA extractable soil zinc (0.48 ppm) was thought to indicate a deficiency in plant available zinc. Furthermore, a yield increase with added zinc at the Morden site was unexpected because DTPA extractable soil zinc (1.4 ppm) indicated that the soil was sufficient in plant available zinc. Along with a yield response in 1976 when soil DTPA extractable zinc was 1.0 ppm and no yield response in 1977 at soil DTPA levels of 0.58 and 0.51 ppm Zn; the 1978 results cast severe doubt on the reliability of the DTPA soil zinc test when it is used to predict blackbean yield response to zinc fertilizer in the field.

Zinc fertilizer recommendations may be made on the basis of plant tissue analyses. Where plant tissue analyses have shown zinc to be low (less than 10 ug Zn/g dry matter), a 1 to 2 kg Zn/ha addition applied as zinc chelate would be a good corrective measure. A 10 to 20 kg Zn/ha addition of zinc sulfate solution, sprayed on the soil and incorporated, would be the second best method of zinc addition.

B. Growth Chamber Experiments

1. The Effect of Zinc Placement on the Yield and Uptake of Zinc in Blackbeans.

Hedayat (1977) was able to show that placement of zinc was critically important in the efficiency of recovery of zinc fertilizer by blackbeans. Application of reagent grade zinc sulfate in a point below the seed did not increase growth or zinc concentration in blackbeans grown on a highly calcareous Lakeland silty clay loam containing 0.35 ppm DTPA extractable zinc. Banding zinc sulfate below the seed and mixing zinc sulfate throughout the soil at a rate of 2 ppm zinc were equally effective in increasing dry matter yield of blackbeans. However, zinc uptake into blackbean shoots was greater when zinc sulfate was mixed throughout the soil than when banded below the seed. Therefore, the efficiency of recovery of this zinc fertilizer increased with increased mixing with the soil.

Hedayat (1977) also tested the effect of method of application of the commercial product Zn M-N-S [(1)] upon zinc utilization by blackbeans. Dry matter yield and zinc uptake were not significantly affected by banding or mixing Zn M-N-S pellets throughout the soil. However, both yield and zinc up-

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(1) Manufactured by Cominco. (9% N, 20% S, 15% Zn, 1.5% Mn as ammonium sulfate, manganese ammonium sulfite and zinc ammonium sulfite).

take were significantly increased when the Zn M-N-S was finely ground and mixed throughout the soil. This indicated that the commercial carrier, Zn MNS, was ineffective in the short term due to the large pellet size and the insoluble nature of zinc sulfite. However, decreasing the particle size by powdering, and mixing the powder evenly throughout the soil did make Zn MNS an effective carrier.

A similar growth chamber experiment was designed to test the effect of method of placement of the commercial zinc carrier Zink Gro[(1)] on the yield and uptake of zinc in black-beans. Zink Gro pellets at a rate of 8 ppm Zn were sidebanded, mixed evenly throughout the soil, or powdered and mixed evenly throughout the soil in this experiment.

a) Soil. The Neuenberg soil used was an alkaline non-calcareous coarse-textured soil which was suspected of being marginally deficient in zinc and copper (Table35). Copper, as copper sulfate, was mixed into the soil to guard against copper deficiency in the plants. Nitrogen, phosphorus, potassium, and sulfur were added at rates designed to optimize growth in the uninoculated blackbeans.

b) Blackbean Yield and Zinc Recovery. Zinc addition

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(1) Manufactured by Eagle Picher Industries, Inc. Agricultural Chem Div. (A granular zinc sulfate; 36% Zn, 17.5% S).

Table 35

Soil Chemical and Physical Characteristics for Growth Chamber Experiment One.

Soil Series	Neuenberg
Subgroup	gleyed carbonated Rego Black
Textural Class	V.F.S.L.
DTPA Extractable Zn (ppm)	0.68
DTPA Extractable Cu (ppm)	0.35
$NaHCO_3$ Extractable P (ppm)	13.3
NO_3 - N (ppm)	10.4
Organic Matter Content (%)	4.1
pH	7.5
Electrical Conductivity (mmhos/cm)	0.44
% $CaCO_3$ Equivalent	1.2
Moisture Content at Field Capacity	28.6 (24 hr.)

increased dry matter yields and total zinc uptake in all three treatments, but only the Zink Gro powder mixed throughout the soil was significant (Table 36). It should be noted that all four treatments had zinc concentrations which were at or below the critical level reported by Hedayat (1977). The control plants had severe zinc deficiency symptoms while the banded and mixed pellet treatments ranged from severely zinc deficient to moderately zinc deficient. The plants in the mixed powder treatment appeared to be healthy and were much larger than zinc deficient plants. Zinc deficient plants characteristically had interveinal yellow chlorotic splotches on older leaves. The leaves were pale green and were both shorter and narrower than leaves of healthy plants. New leaves on zinc deficient plants were a healthy green color but were much smaller than new leaves on zinc sufficient plants.

The efficiency of recovery of zinc fertilizer was similar for the banded and mixed pellet treatments. The recovery of zinc in the mixed powder treatment was about three times larger than the two pellet treatments. This result agrees with Hedayat's (1977) data for Zn MNS and indicates that zinc sulfate carriers should be finely divided and mixed throughout the plow layer to maximize recovery in blackbeans.

Table 36

Effect of Zinc Sulfate[1] Placement on Yield, Zinc Concentration, Zinc Uptake, and the Efficiency of Recovery of Zinc Fertilizer in Blackbeans Grown in the Growth Chamber.

Zinc Treatment	Dry Matter Yield (g/pot)	[Zn] (ug/g DM)	Total Zinc Uptake (ug/pot)	% Recovery (2)
	(3)	(3)	(3)	
No Zinc Added	8.2 a	7.9 a	64 a	--
24 mg Zn (banded pellets)	13.0 a	9.2 ab	121 a	0.24
24 mg Zn (mixed pellets)	13.6 a	9.9 b	134 a	0.29
24 mg Zn (mixed powder)	18.7 b	13.5 c	252 b	0.78
error df = 6				
F	7.04 (4)	24.4 (5)	11.6 (5)	
Sd	2.3	0.69	33	
cv	21.0	8.3	28.2	

(1) A granular zinc sulfate (36% Zn, 17.5% S). Manufactured by Eagle Picher Industries, Inc. Agricultural Chem. Div. Joplin, Mo.

(2) $\% \text{ Recovery} = \dfrac{\text{Zn uptake in treatment} - \text{Zn uptake in control}}{\text{24 mg added Zn}} \times 100\ \%$

(3) Any two values in vertical columns not followed by the same letter are significantly different at P = .05 by Duncan's New Multiple Range test.

(4) F-test shows a significant difference between treatment means at P = .05

(5) F-test shows a significant difference between treatment means at P = .01.

2. <u>The Effect of Temperature on Phosphorus-Zinc Interactions in Blackbeans</u>.

Hedayat (1977) reported that high rates of added phosphorus aggravated a severe zinc deficiency when blackbeans were grown at a $20^{o}c/15^{o}c$ (day/night) temperature. It was thought that the phosphorus-induced reduction in plant zinc uptake may have been related to temperature; therefore, blackbeans were grown at a temperature of $28^{o}c/23^{o}c$ (day/night) to find out: 1) if blackbeans would be zinc deficient at the higher temperature; 2) if high rates of added phosphorus would reduce zinc uptake and/ or translocation to the above ground portion of the plant at the higher temperature.

a) <u>Soil</u>. The same calcareous Lakeland silty clay loam soil was used in this experiment as was used by Hedayat (1977; pp. 45-59) in his phosphorus-zinc interaction growth chamber study (Table 37). Monocalcium phosphate and zinc sulfate were mixed into the soil at the same concentrations (0, 20, 40, 80, 160 ppm P; and 0 and 8 ppm Zn at each level of P) which Hedayat used; however, due to a limited supply of Hedayat's soil, 3000 g of soil was used in this experiment while Hedayat used 5000 g of soil. This meant that soil volume was a complicating factor when comparing the two studies: although, it may be assumed that Hedayat's blackbeans would have taken up less phosphorus and zinc, and been more deficient in these two nutrients, if they had been grown in 3000 g of soil.

Table 37

Soil Chemical and Physical Characteristics for Growth Chamber Experiment Two.

Soil Series	Lakeland
Subgroup	gleyed carbonated Rego Black
Textural Class	Si.C.L.
DTPA Extractable Zn (ppm)	0.42
DTPA Extractable Cu (ppm)	1.20
$NaHCO_3$ Extractable P (ppm)	7.1
NO_3^- - N (ppm)	18.4
Organic Matter Content (%)	3.8
pH	7.8
Electrical Conductivity (mmhos/cm)	0.65
% $CaCO_3$ Equivalent	42.3
Moisture Content at Field Capacity	24.5 (48 hr.)

b) Blackbean Yield and Nutrient Uptake. Blackbean dry matter yield was increased at every level of added zinc and phosphorus by a temperature increase of 8°c (Figure 6). Without added zinc, the magnitude of the yield increase due to increased temperature remained relatively constant with increasing rates of added phosphorus. When zinc was added, the magnitude of the yield increase due to a 8°c higher temperature appeared to increase up to 120 mg P/pot and then decreased at higher rates of added phosphorus. At both temperatures, adding phosphorus to the soil without added zinc appeared to increase dry matter yield at lower rates of added phosphorus followed by a leveling off or a decline at higher rates (Tables 38 and 40). When zinc was added to the soil a yield response to added phosphorus occured at both temperatures. At a 20°c/15°c day/night temperature there was a linear yield response up to 400 mg P/pot and no further increase at 800 mg P/pot. At a 28°c/23°c day/night temperature there was a curvilinear yield response with increasing rates of added phosphorus. Dry matter yield was significantly increased by added zinc in every treatment which received fertilizer phosphorus at the 28°c/23°c day/night temperature, but only in the 200, 400, and 800 mg P/pot treatments at the 20°c/15°c day/night temperature.

Total phosphorus uptake was reduced by zinc addition at high rates of added phosphorus at a 28°c/23°c day/night temperature (Table 38). The observation of a zinc induced reduction in total plant phosphorus uptake has not commonly been reported in the literature. Safaya (1976) observed that zinc had the ability to control the rate of P absorption in corn roots, and he speculated that

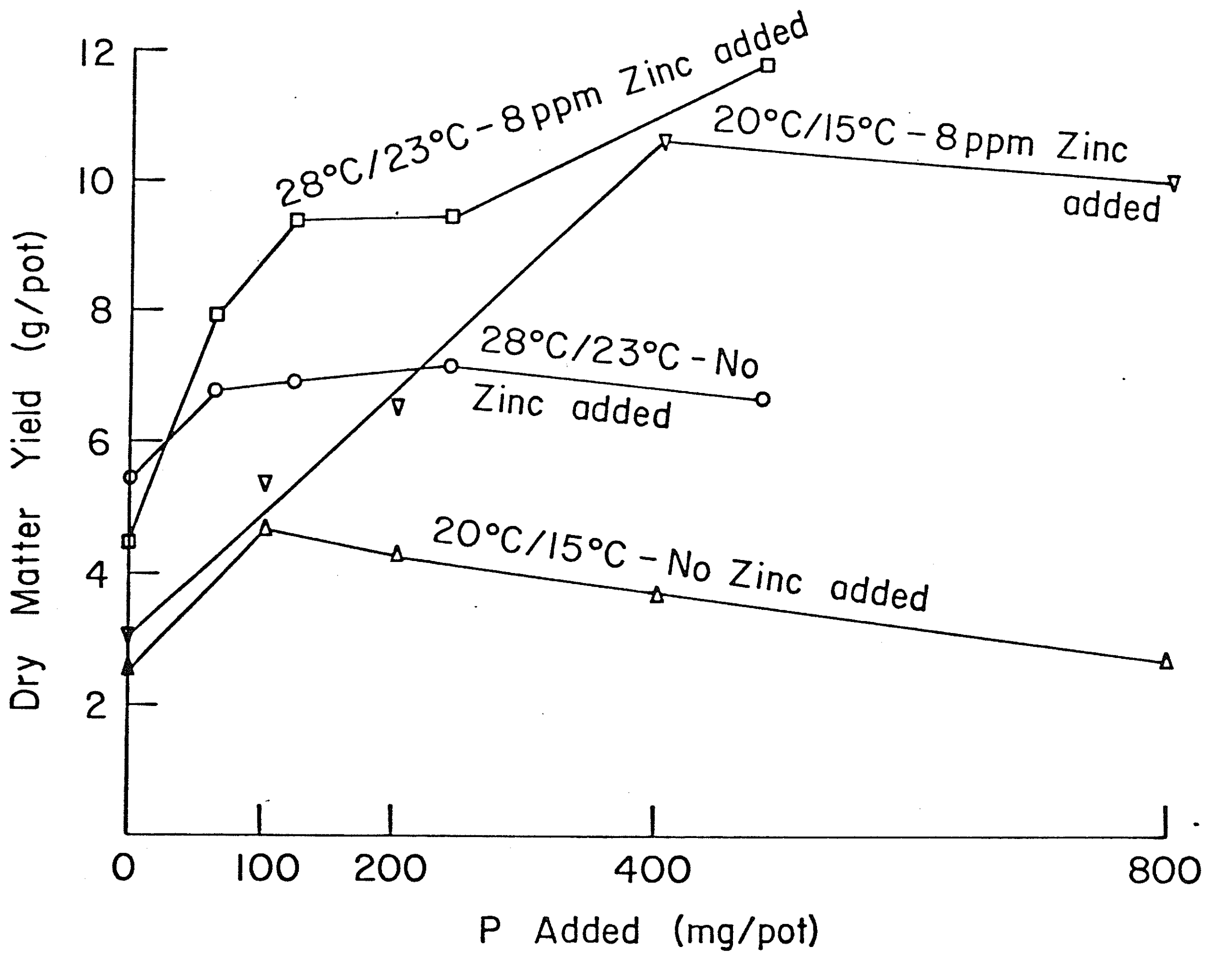

Figure 6. The effect of added zinc and phosphorus on dry matter yield of blackbeans grown at 20^{o} c/15^{o} c (data from Hedayat 1977) and 28^{o}c/ 23^{o} c in growth chamber studies.

Table 38

The Effect of Phosphorus and Zinc on Yield, P Concentration, and P Uptake by Blackbeans Grown at a 28° c / 23° c Day/Night Temperature in Growth Chamber Experiment Two.

P Added (ppm)	DM Yield (g/pot) No Zn	DM Yield (g/pot) 8 ppm Zn	[P] (mgP/g DM) No Zn	[P] (mgP/g DM) 8 ppm Zn	Total P Uptake (mg/pot) No Zn	Total P Uptake (mg/pot) 8 ppm Zn	Apparent P Fertilizer Recovery (2) (%) No Zn	Apparent P Fertilizer Recovery (2) (%) 8 ppm Zn
	(1)		(1)		(1)			
0	5.48 a	4.58 a	1.09 ab	1.18 abc	6.0 a	5.4 a	----	----
20	6.82 b	7.95 c	1.27 bc	1.06 a	8.7 b	8.4 b	4.5	5.0
40	6.97 bc	9.40 d	1.87 e	1.20 abc	13.0 c	11.3 c	5.8	4.9
80	7.21 bc	9.50 d	2.50 f	1.36 c	18.2 d	12.9 c	5.1	3.1
160	6.69 b	11.88 e	4.20 g	1.56 d	28.3 e	18.5 d	4.6	2.7
F-test P	44.3 (3)		289 (3)		281 (3)			
F-test Zn	87.6 (3)		587 (3)		91.8 (3)			
F-test PxZn	20.8 (3)		160 (3)		23.8 (3)			
error df= 18								
s	0.59		0.11		1.0			
cv	7.8		6.0		7.7			
P Main Effect								
P Added (ppm)	(1)		(1)		(1)			
0	5.03 a		1.13 a		5.7 a			
20	7.39 b		1.16 a		8.5 b			
40	8.19 c		1.54 b		12.2 c			
80	8.36 c		1.95 c		15.5 d			
160	9.28 d		2.90 d		23.4 e			

(1) Duncan's test. P=.05.

(2) $$\text{Apparent Recovery} = \frac{\text{P Uptake by treatment} - \text{P Uptake by control}}{\text{Amount of P Added}} \times 100\%$$

(3) Significant at P=.005.

Table 39

The Effect of Phosphorus and Zinc on Zinc Concentration and Uptake by Blackbeans Grown at a 28^{o} c/ 23^{o} c Day/Night Temperature in Growth Chamber Experiment Two.

P Added (ppm)		[Zn] (ug Zn/g DM)		Total Zn Uptake (ug Zn/pot)		Apparent Zn Fertilizer Recovery (3) (%)	
		No Zn	8 ppm Zn	No Zn	8 ppm Zn	No Zn	8 ppm Zn
		(1)		(2)			
0		7.6 b	32.4 f	42	148	----	0.44
20		4.9 a	19.0 e	33	151	----	0.49
40		5.1 a	15.4 cd	36	145	----	0.45
80		4.5 a	16.5 d	32	157	----	0.52
160		5.6 ab	13.4 c	37	160	----	0.51
F-test	P	65.7 (5)		0.3 (4)			
	Zn	842 (5)		624 (5)			
	PxZn	37.9 (5)		0.6 (4)			
error df= 18							
	s	1.3		13			
	cv	10.5		13.6			
P Main Effect							
P Added (ppm)		(1)					
0		20.0 c					
20		12.0 b					
40		10.3 a		N.S.			
80		10.5 ab					
160		9.5 a					

(1) Duncan's test. P=.05. (2) PxZn interaction is not significant.

(3) Apparent Recovery = $\dfrac{\text{nutrient uptake by treatment} - \text{nutrient uptake by control}}{\text{Amount of Nutrient added}} \times 100\ \%$

(4) Not significant at P=.10. (5) Significant at P=.005.

Table 40

The Effect of Phosphorus and Zinc on Yield, P Concentration, and P Uptake by Blackbeans Grown at a 20° c/15° c Day/Night Temperature (data from Hedayat 1977; pp. 45-59) in a Growth Chamber Experiment.

P Added (ppm)		DM Yield (g/pot)		[P] (mg P/g DM)		Total P Uptake (mg/pot)		Apparent P Fertilizer Recovery (2) (%)	
		No Zn	8 ppm Zn	No Zn	8 ppm Zn	No Zn	8 ppm Zn	No Zn	8 ppm Zn
		(1)		(1)		(1)			
0		2.60 a	3.05 a	1.5 a	2.0 ab	3.6 a	6.4 a	----	----
20		4.75 b	5.38 bc	3.5 c	2.5 b	16.8 bc	13.4 b	13.2	7.0
40		4.31 b	6.63 c	4.0 cd	2.4 b	17.5 bc	16.1 bc	7.0	4.8
80		3.96 ab	10.7 d	4.6 d	2.3 b	18.4 c	25.5 d	3.7	4.8
160		2.73 a	10.1 d	6.6 e	2.5 b	18.0 c	25.6 d	1.8	2.4
F-test	P	25.2 (4)		40.9 (4)		49.1 (4)			
	Zn	133 (4)		147 (4)		5.97 (3)			
	PxZn	23.9 (4)		30.4 (4)		5.52 (4)			
error df= 18									
	s	0.83		0.39		2.4			
	cv	15.4		12.1		15.2			
<u>P Main Effect</u>									
P Added (ppm)		(1)		(1)		(1)			
0		2.80 a		1.8 a		4.8 a			
20		5.05 b		3.0 b		14.8 b			
40		5.47 bc		3.2 bc		16.5 b			
80		7.32 d		3.5 c		21.6 c			
160		6.42 cd		4.6 d		21.7 c			

(1) Duncan's test. P= .05.

(2) Apparent Recovery = $\frac{\text{nutrient uptake by treatment} - \text{nutrient uptake by control}}{\text{Amount of nutrient added}} \times 100\ \%$

(3) Significant at P= .05.
(4) Significant at P= .005.

Table 41

The Effect of Phosphorus and Zinc on Zinc Concentration and Uptake by Blackbeans Grown at a 20° c/15° c Day/Night Temperature (data from Hedayat 1977; pp. 45-59) in a Growth Chamber Experiment.

P Added (ppm)	[Zn] (ug Zn/g DM) No Zn	[Zn] (ug Zn/g DM) 8 ppmZn	Total Zn Uptake (ug Zn/pot) No Zn	Total Zn Uptake (ug Zn/pot) 8 ppm Zn	Apparent Zn Fertilizer Recovery (2) (%) No Zn	Apparent Zn Fertilizer Recovery (2) (%) 8 ppm Zn
	(1)		(1)			
0	6.8 b	26.7 g	17.5 a	82.4 b	----	0.16
20	4.5 a	22.6 f	21.3 a	120 c	----	0.25
40	4.4 a	19.1 e	19.0 a	125 c	----	0.26
80	4.2 a	16.0 d	16.7 a	170 d	----	0.39
160	3.9 a	12.4 c	10.6 a	125 c	----	0.29
F-test P	55.8 (3)		14.3 (3)			
F-test Zn	1351 (3)		845 (3)			
F-test PxZn	27.0 (3)		15.0 (3)			
error df= 18						
s	1.1		10.2			
cv	9.0		14.3			

<u>P Main Effect</u>

P Added (ppm)	[Zn] (1)	Total Zn Uptake (1)
0	16.8 a	50 a
20	13.6 b	71 b
40	11.8 c	72 b
80	10.1 d	94 c
160	8.1 e	68 b

(1) Duncan's test. P=.05.

(2) Apparent Zn Recovery= $\frac{\text{Zn uptake by treatment} - \text{Zn uptake by control}}{\text{Amount of Zn added}} \times 100\%$

(3) Significant at P=.005.

this was through some functional association in the cell membrane. Lorincz et al. (1978) concluded that zinc chelate should not be added at rates greater than 3 kg Zn/ha because higher rates of zinc would decrease P uptake and transport. In the 1978 field experiments it was concluded that zinc had a regulating effect on phosphorus translocation into the above ground portion of the plant and into the seed.

Blackbean phosphorus uptake was greater at the $20^{o}c/15^{o}c$ than the $28^{o}c/23^{o}c$ temperature when zinc was added; however, without added zinc, phosphorus uptake was greater at the lower temperature only in the 100 and 200 mg P/pot treatments (Figure 7). Without added zinc, blackbean phosphorus uptake at $20^{o}c/15^{o}c$ was greatly increased by 100 mg P/pot and then leveled off at higher rates of added phosphorus; while at $28^{o}c/23^{o}c$, phosphorus uptake increased linearly with increasing rates of added phosphorus. When zinc was added to the soil, phosphorus uptake increased curvilinearly with increasing rates of added phosphorus at both temperatures.

Hedayat (1977) reported data showing that blackbean phosphorus concentration increased curvilinearly with increasing rates of added phosphorus, both with and without added zinc, when blackbeans were grown at a $20^{o}c/15^{o}c$ day/night temperature (Table 40). Blackbeans, grown at a $28^{o}c/23^{o}c$ day/night temperature, had phosphorus concentrations which increased linearly with increasing rates of added phosphorus. (Figure 8).

Plant phosphorus concentrations were higher in every treatment in blackbeans grown at a $20^{o}c/15^{o}c$ day/night temperature (Tables 38 and 40). A plot of plant phosphorus concentrations vs

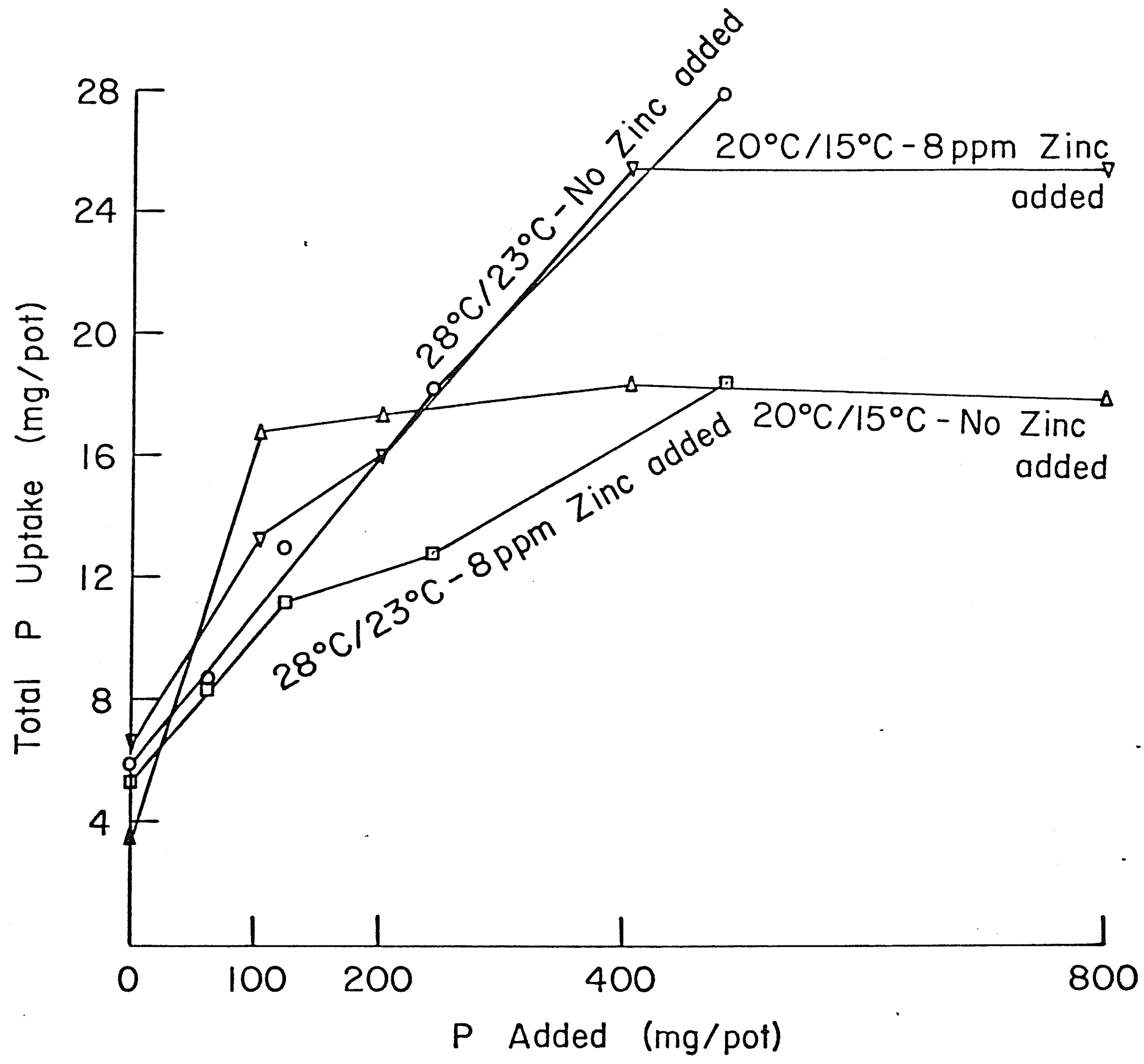

Figure 7. The effect of added zinc and phosphorus on total P uptake by blackbeans grown at 20° c/15° c (data from Hedayat 1977) and 28° c/ 23° c in growth chamber studies.

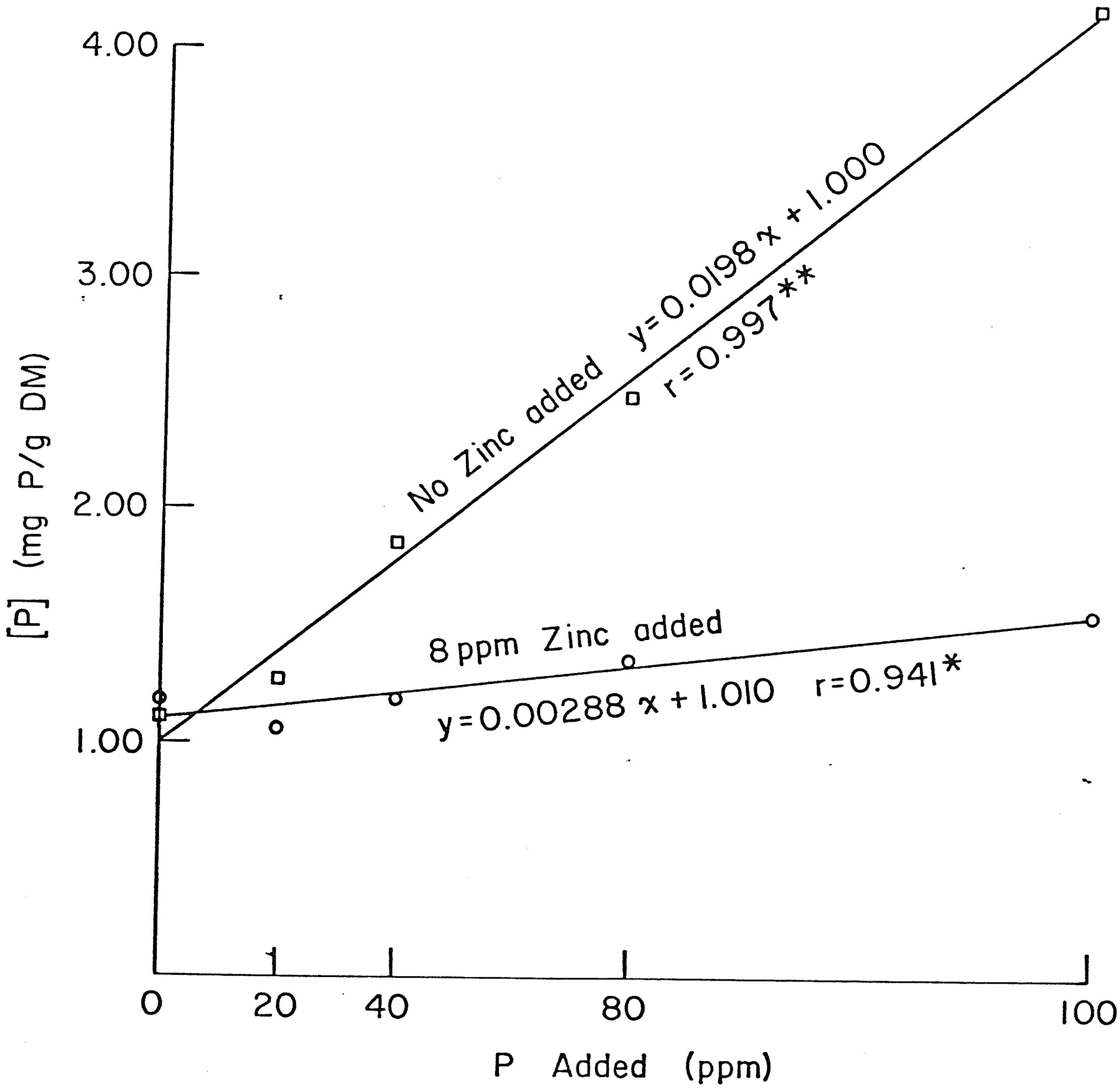

Figure 8. The effect of added zinc and phosphorus on P concentration of blackbeans grown at 28° c/23° c in growth chamber experiment two.

relative yield shows that higher phosphorus concentrations were required for growth at $20^{o}c/15^{o}c$ than at $28^{o}c/23^{o}c$ (Figures 9 and 10). At each temperature, the data was divided into two groups; one for each rate of zinc. In each group the highest yield was given a value of 100 and the other yields were calculated on a percentage of this value. The two groups were plotted together against their respective phosphorus concentrations and a regression line was calculated. According to a method used by McAndrew (1979), the local maxima of the regression curve was designated as the upper boundary of the marginally deficient zone and a 15 percent yield reduction on the curve designated the lower boundary. Using this method, at $20^{o}c/15^{o}c$ blackbeans in the early flowering stage were deficient when phosphorus concentration was less than 2.6 mg P/g dry matter; marginally deficient from 2.6 to 4.0 mg P/g dry matter, and sufficient when greater than 4.0 mg P/g dry matter. At $28^{o}c/23^{o}c$ the plants were larger and lower phosphorus concentrations were present. The deficiency level was less than 1.4 mg P/g dry matter; marginal deficiency was 1.4 to 2.15 mg P/g dry matter; and sufficiency was greater than 2.15 mg P/g dry matter. It should be noted that a majority of the plants used were deficient or marginally deficient in zinc, and this may have had an effect on the P deficiency levels which were calculated.

Apparent phosphorus fertilizer recovery at $28^{o}c/23^{o}c$ was less affected by phosphorus and zinc addition than at $20^{o}c/15^{o}c$ (Tables 38 and 40). At $28^{o}c/23^{o}c$ without added zinc, apparent P recovery was fairly constant, ranging from 4.5 to 5.8 percent at the four rates of added phosphorus. When zinc was added, P re-

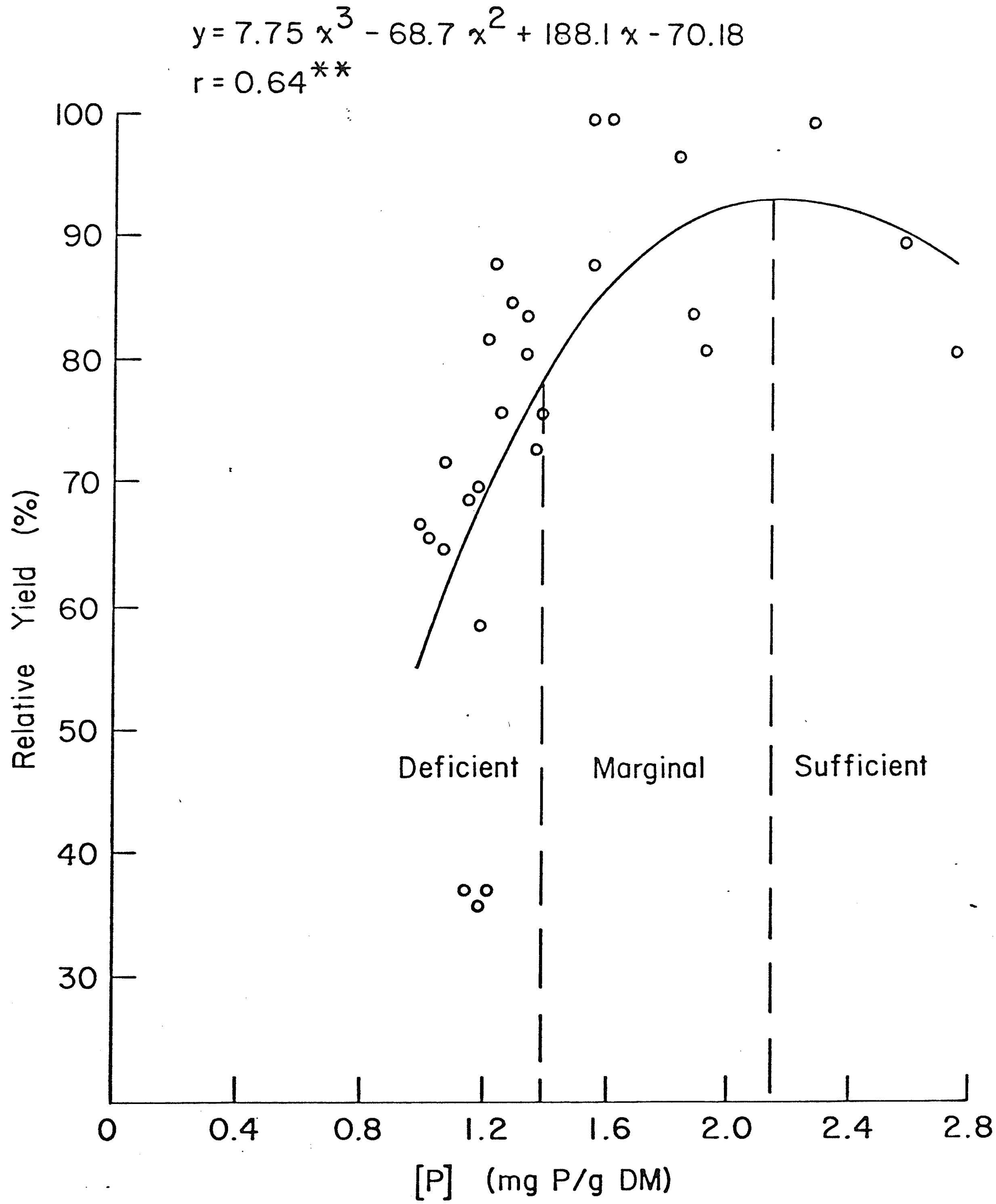

Figure 9. The deficient, marginal, and sufficient levels of phosphorus in blackbeans grown at a 28° c/23° c day/night temperature in growth chamber experiment two.

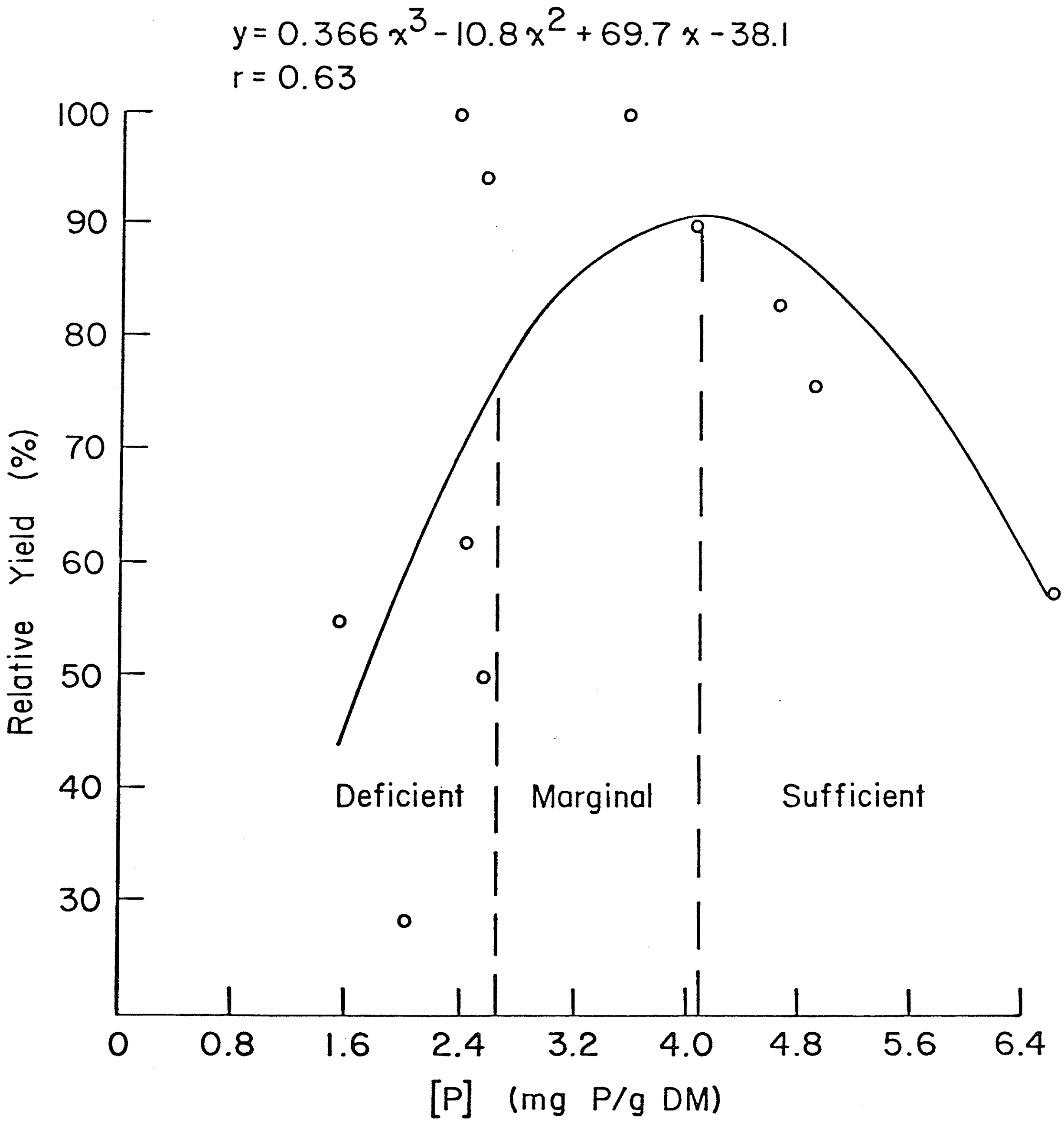

Figure 10. The deficient, marginal, and sufficient levels of phosphorus in blackbeans grown at a 20° c/15° c day/night temperature by Hedayat (1977; pp 45-59) in a growth chamber experiment.

covery was near five percent in the 20 and 40 ppm P treatments, but declined to near three percent in the 80 and 160 ppm P treatments. At $20^{o}c/15^{o}c$, P recovery was much higher at low rates of added phosphorus than had been observed at the higher temperature, but P recovery decreased rapidly with increasing rates of added phosphorus. At $20^{o}c/15^{o}c$, P recovery was much higher at low rates of added phosphorus when zinc was not added, but at high rates of added phosphorus P recovery was greater in the treatments which received zinc. At both temperatures, zinc addition had a controlling effect on blackbean phosphorus uptake.

Blackbean zinc uptake was increased by zinc addition but was not affected by added phosphorus at $28^{o}c/23^{o}c$ (Table 39). Although blackbeans in the $28^{o}c/23^{o}c$ experiment were growing in a smaller soil volume which would decrease the amount of plant available zinc; total zinc uptake was greater in nine of ten treatments at the higher temperature (Tables 39 and 41). Without added zinc, added phosphorus had no effect on total zinc uptake at either temperature; although Hedayat (1977) did note that total zinc uptake appeared to be reduced at the higher levels of added phosphorus. When zinc was added, phosphorus increased total zinc uptake at the $20^{o}c/15^{o}c$ temperature but had no effect at $28^{o}c/23^{o}c$. Possibly, increasing rates of added phosphorus increased root growth at the $20^{o}c/15^{o}c$ temperature and this enabled the plants to increase uptake of zinc. At the $28^{o}c/23^{o}c$ temperature, a small soil volume and favorable growing conditions for the roots would probably ensure adequate root exploration at all levels of added phosphorus. Hedayat (1977) did report that phosphorus reduced zinc uptake in the 800 mg P/pot treatment at a 20°c/15°c temperature, but this was not observed at 28°c/23°c since 480 mg P/pot was the highest rate of applied phosphorus. An examination of blackbean P/Zn ratios indicates that the plants grown at the lower temperature were subject to a much greater zinc stress and would be more likely to suffer from phosphorus induced zinc deficiency (Table 42).

Blackbean zinc concentrations were remarkably similar at the two temperatures when each P-Zn treatment was compared; although the higher temperature resulted in slightly higher plant zinc concentrations when no phosphorus was added (Tables 39 and 41). Increased plant zinc uptake at the higher temperature appeared to result in increased dry matter yield. Plant zinc concentrations were deficient (below 10 ug Zn/g dry matter) without added phosphorus, but were reduced with phosphorus addition. Zinc addition increased plant zinc concentration to sufficiency levels, but high rates of added phosphorus lowered zinc concentrations to marginally deficient levels (10 to 17 ug Zn/g dry matter).

Apparent zinc fertilizer recovery was higher in every level of added phosphorus at the higher temperature (Tables 39 and 41). This would indicate that increased temperature was making the fertilizer more available to the plants. At 28°c/23°c, zinc recovery ranged from 0.44 to 0.52 percent and appeared to be increasing slightly with each increase in the rate of added phosphorus. At 20°c/15°c, zinc recovery was low (0.16 percent) without added phosphorus but increased with increasing rates of added phosphorus to 0.39 percent in the 400 mg P/pot treatment. In the 800 mg P/pot

Table 42

The Effect of Phosphorus and Zinc on P/Zn Ratios in Blackbeans Grown at a 20° c/15° c Day/Night Temperature (data from Hedayat 1977; pp 45-59) and a 28° c/23° c Day/Night Temperature in Growth Chamber Studies.

P Added (ppm)	20°c/15°c		28°c/23°c	
	No Zn	8 ppm Zn	No Zn	8 ppm Zn
0	206	78	143	36
20	789	112	264	56
40	921	129	361	78
80	1100	150	569	82
160	1700	205	765	116

P treatment, phosphorus reduced zinc uptake and/or translocation and reduced apparent zinc recovery to 0.29 percent.

In summary, it was shown that blackbeans were zinc deficient when grown at a higher temperature. Although total plant uptake of zinc was greatly increased by the temperature increase; much of the zinc went to increased dry matter yields so plant zinc concentrations remained relatively the same for each phosphorus-zinc treatment. High rates of added phosphorus were shown to aggravate zinc deficiency at $20^{o}c/15^{o}c$ but this was not observed at $28^{o}c/23^{o}c$.

At $28^{o}c/23^{o}c$ added zinc was observed to reduce plant phosphorus uptake at high rates of added phosphorus. It was concluded that zinc had some part in regulating phosphorus uptake and/or translocation to the above ground portion of the plant.

Blackbean phosphorus concentrations required for growth were shown to decrease with an increase in temperature. At $20^{o}c/15^{o}c$, blackbeans in the early flowering stage were deficient when plant phosphorus concentration was less than 2.6 mg P/g dry matter; marginally deficient between 2.6 and 4.0 mg P/g dry matter; and sufficient when greater than 4.0 mg P/g dry matter. At $28^{o}c/23^{o}c$, deficiency levels were less than 1.4 mg P/g dry matter: marginal deficiency was between 1.4 and 2.15 mg P/g dry matter, and sufficiency was greater than 2.15 mg P/g dry matter.

V. SUMMARY AND CONCLUSIONS

In 1975, blackbeans were introduced as a commercial crop in Manitoba. Since there had been very little previous work done on the nutritional needs of field beans, a three year investigation was initiated in 1976 by the Department of Soil Science at the University of Manitoba with the purpose of establishing fertilizer recommendations for field grown beans. This thesis respresents a portion of the investigation in which the effect of adding N, P, K, Zn, Cu, and Fe on blackbean yield and quality was examined at seven field sites and in two growth chamber studies.

The effect of nitrogen addition on the yield of inoculated blackbeans was tested as part of five field trials run near Morden, Winkler, and Portage La Prairie, Manitoba, in 1976 and 1977. An uninoculated blackbean treatment showed that nitrogen fixation was increasing seed yield by approximately 400 kg/ha at each of the three 1976 field sites. Total nitrogen fixation in the blackbean plant was estimated to be about 22 kg N/ha. Nitrogen fixation plus soil nitrogen were adequate for the plant's needs in four of the five field trials, since sidebanded nitrogen treatments, at rates up to 120 kg N/ha, failed to increase forage or seed yields. At the fifth site, soil nitrogen was very low (extractable NO_3-N was 16 kg/ha (0-60 cm)) and nitrogen fixation was not high enough to prevent nitrogen from being a limiting nutrient; consequently, a nitrogen addition of 100 kg/ha increased seed yield by 520 kg/ha.

It is possible that a blackbean seed yield increase due to added nitrogen can be predicted when: 1) soil nitrogen is low in the spring (less than 20 kg NO_3-N/ha (0-60 cm)); 2) spring soil temperatures are below average (this would decrease soil nitrogen mineralization); and 3) blackbean seed yield expectations are high (over 2000 kg/ha). Since there were no yield responses to low rates of added nitrogen; a large application of nitrogen, such as 100 kg N/ha sidebanded at seeding, is recommended to increase blackbean yields when the three conditions of low soil nitrogen, cool spring weather, and high yield expectations are met.

A 100 kg N/ha addition increased seed protein content and total N uptake at both 1977 field sites. Thirty kg N/ha had no effect on seed yield, protein content, or total N uptake; possibly because nitrogen fixation was being decreased in direct proportion to the increase in fertilizer nitrogen uptake. Regitnig (unpublished data 1979) found that 30 kg N/ha reduced nodule formation while 100 kg N/ha greatly inhibited nodule formation. A 100 kg N/ha rate was sufficient to increase blackbean N uptake at both 1978 sites tested, since fertilizer nitrogen recovery was 40 percent or higher (Regitnig 1979).

Various rates of seed placed, sidebanded, as well as broadcast and incorporated phosphorus were tested as part of seven field trials in 1976, 1977 and 1978. Seed placed phosphorus decreased germination and seed yield, and cannot be recommended. There was no yield response to sidebanded phosphorus using rates up to 120 kg P_2O_5/ha at five field sites. There was only one yield response to broadcast and incorporated phosphorus out of seven field trials. This one yield response to 100 kg P_2O_5/ha was not expected since midseason phosphorus concentrations were considered to be sufficient (4.3 mg P/g dry matter) without added phosphorus fertilizer. Phosphorus addition did increase blackbean P concentration and uptake and this caused the yield increase. At the six sites which did not have yield increases when phosphorus was added, total phosphorus uptake in the above ground portion of the plant was not increased. The plant was either unable to take up fertilizer phosphorus; or, if phosphorus fertilizer was taken up, it was substituting for soil phosphorus uptake in the blackbeans. It should be noted that blackbeans yielded extremely well (up to 2700 kg seed/ha) without added phosphorus fertilizer on soils low in available phosphorus. Due to these high yield results, and the general lack of yield response to added phosphorus fertilizer; phosphorus fertilizer addition is not recommended for field grown blackbeans.

Blackbean yields were not increased by potassium fertilizer addition at three field sites which had high to very high soil potassium levels. Further work would be needed to establish a recommendation for soils with lower levels of soil potassium.

Foliar applications of NPKS during pod formation did not affect seed yield at three field sites in 1976; however, moisture appeared to be limiting yields. Further work would be needed to establish a recommendation, since NPKS foliar applications would be expected to be most beneficial when potential yields were high and being limited by plant stores of N, P, K, or S.

Various zinc carriers, methods of application, and rates of application were tested in fifty treatments spread over the seven field sites in 1976, 1977, and 1978. Zinc addition increased midseason forage yield at two field sites and seed yield at one field site. Zinc chelates were more effective than inorganic carriers in increasing blackbean zinc concentration and uptake. Zinc chelate addition, at a rate of 1 to 2 kg Zn/ha, is the recommended corrective measure to take when blackbeans are to be grown on zinc deficient soil.

Zinc sulfate was more effective than the other inorganic zinc carriers, but only when zinc sulfate solution was sprayed on the soil and incorporated. Zn M-N-S, manufactured by Cominco, was added as banded pellets, incorporated pellets, banded Zn M-N-S powder, and incorporated Zn M-N-S powder. In all field treatments, Zn M-N-S was ineffective in increasing blackbean yield, zinc content, or zinc uptake in the year of application. Banded Zink Gro pellets, manufactured by Eagle Picher, and banded reagent grade zinc sulfate septahydrate were also ineffective in the year of application. Zinc sulfate solution, sprayed on the soil and incorporated, effectively increased midseason yield at one site, increased midseason and seed zinc concentration at two sites, increased midseason zinc uptake at two sites, and increased seed zinc uptake at three sites. A 10 to 20 kg Zn/ha addition of zinc sulfate solution, sprayed on the soil and incorporated, would be the second best zinc recommendation for blackbeans being grown on a soil low in available zinc.

Zinc carriers tested in growth chamber studies have been found to be more effective in increasing blackbean yield, zinc concentration, and zinc uptake than in field studies. Zink Gro was found to be an effective zinc fertilizer when the pellets were finely ground and thoroughly mixed with the soil. Banded or mixed Zink Gro pellets did not increase blackbean dry matter yield or zinc uptake, although the mixed pellets did increase plant zinc concentration. Zink Gro powder mixed throughout the soil increased dry matter yield, blackbean zinc concentration, and zinc uptake over the control and the two Zink Gro pellet treatments. Hedayat (1977) has reported similar results for Zn M-N-S and for zinc sulfate septahydrate. Treatments where Zn M-N-S or zinc sulfate septahydrate were powdered and mixed throughout the soil increased blackbean dry matter yield, zinc uptake, and zinc concentration; while treatments containing banded Zn M-N-S pellets, mixed Zn M-N-S pellets, or spot placed zinc sulfate septahydrate were no different from the control treatments. Possibly powdered zinc treatments mixed throughout the soil were more effective in small pot experiments because the zinc could be more thoroughly mixed into the soil than can be accomplished in the field.

Blackbean zinc deficiency levels were calculated with a regression analysis technique used by McAndrew (1979). Blackbeans were grown in a growth chamber study by Hedayat (1977) with various rates of zinc addition. At the early flowering stage, blackbeans were determined to be zinc deficient when tissue concentrations were less than 10 ug Zn/g dry matter; marginally deficient between 10 and 17 ug Zn/g dry matter; and sufficient when greater than 17 ug Zn/g dry matter.

There were indications that some Manitoba soils may be low or deficient in plant available copper and/or iron. Addition of 2 kg Cu/ha, as Na_2Cu EDTA solution sprayed on the soil and incorporated, increased seed yields by 570 kg/ha at one of two sites in 1977. A soil critical level of 0.30 ug/g soil DTPA extractable copper was estimated from the two field experiments. It was tentatively concluded that blackbean tissue in the early pod formation stage was deficient when the copper content was less than 3.8 ug Cu/g dry matter; marginally deficient between 3.8 and 5.9 ug Cu/g dry matter; and sufficient when greater than 5.9 ug Cu/g dry matter.

A visual response to a foliar application of iron was noted early in the growing season at the 1977 Winkler site. Most of the blackbeans began showing symptoms of chlorosis within the first few weeks of growth due to an extended cloudy, cool, wet period. Guard rows were sprayed with a one percent solution of iron sulfate and the blackbean plants turned dark green within a few days. Subsequent to this, DTPA extractable iron was found to be less than 3.0 ug Fe/g soil, which was in the deficient to marginally deficient zone described by Lindsay and Norvell (1978) in sorghum small pot experiments. Although the iron deficiency symptoms disappeared with warm, dry weather, it was interesting to observe a possible iron deficiency problem which may be affecting yields of crops grown on some Southern Manitoba soils.

The influence of temperature on phosphorus-zinc interaction in blackbeans was investigated in a small pot growth chamber study. Hedayat (1977) reported that high rates of added phosphorus aggravated a severe zinc deficiency when blackbeans were grown at a 20^{o} c/15^{o} c day/night temperature. It was thought that the phosphorus-induced reduction in plant zinc uptake may have been related to temperature; therefore, blackbeans were grown at a temperature of 28^{o} c/23^{o} c (day/night) to find out: 1) if blackbeans would be zinc deficient at the higher temperature; and 2) if high rates of added phosphorus would reduce zinc uptake and/or translocation to the above ground portion of the plant at the higher temperature. The increase in temperature was shown to markedly increase soil and fertilizer zinc availability to blackbeans. Much of the zinc went to increased dry matter yields, so plant zinc concentrations remained relatively the same for each P-Zn treatment. Without added zinc, increasing rates of added phosphorus aggravated plant zinc deficiency and decreased yield at 20^{o} c/15^{o} c but not at 28^{o} c/23^{o} c. The increase in temperature did not appear to affect soil or fertilizer phosphorus availability to blackbeans; however, phosphorus concentrations required for growth were markedly decreased by the temperature increase. Deficiency levels for blackbeans harvested at the early flowering stage were calculated to be 2.6 mg P/g dry matter at 20^{o} c/15^{o} c and 1.4 mg P/g dry matter at 28^{o} c/23^{o} c. At 28^{o} c/23^{o} c, zinc addition reduced P uptake by the above ground portion of the plant at high rates of added phosphorus, and was thought to be controlling phosphorus uptake by the roots and/or translocation into the above ground portion of the plant. At 20^{o} c/15^{o} c, zinc addition increased P uptake because high rates of added phosphorus aggravated a severe zinc deficiency and reduced dry matter yield when zinc was not added.

In the 1978 field experiments, phosphorus and zinc fertilizer were added at levels designed to give similar phosphorus and zinc fertilizer concentrations in the acre-furrow slice as were used in the growth chamber studies so that yield, phosphorus uptake, and zinc uptake trends could be compared. Addition of 15 kg Zn/ha increased midseason yield, but zinc addition had no effect on seed yield at the Morden site. Added phosphorus increased both midseason and seed yields at the Morden site. Winkler yields were not affected by added zinc or added phosphorus. Zinc addition increased blackbean concentration and uptake at the Morden site; however, at the Winkler site zinc addition did not increase blackbean zinc concentration or zinc uptake without phosphorus addition. Without added zinc, added phosphorus appeared to be impeding zinc uptake in the roots and/or translocation to the plant tops. Zinc addition prevented the phosphorus induced reduction in zinc uptake. Tissue zinc concentrations were reduced to marginally deficient levels (less than 17 ug Zn/g dry matter) at both sites when high rates of phosphorus were added without added zinc. Zinc addition raised plant zinc concentrations to sufficiency levels at both sites. Added phosphorus increased blackbean P uptake and concentration in both harvests at the Morden site, but only midseason P concentration was increased at the Winkler site. Zinc addition did not affect blackbean P uptake at either site; but added zinc increased P concentration in the Winkler seed harvest and decreased P concentration in the other three harvests. This may indicate that zinc has a regulating effect on the amount of phosphorus being translocated within the plant.

Although soil phosphorus and zinc levels at the Winkler site (6.4 ug/g soil $NaHCO_3$ extractable PO_4-P; 0.48 ug/g soil DTPA extractable Zn (0-15 cm)) were similar to phosphorus and zinc levels in the growth chamber soil (7.1 ug/g soil $NaHCO_3$ extractable PO_4-P; 0.42 ug/g soil DTPA extractable Zn); blackbeans grown at the field site without added phosphorus or zinc yielded extremely well (2700 kg seed/ha) and showed no symptoms of either zinc or phosphorus deficiency. This indicates that the restricted soil volume was the major factor causing phosphorus and zinc deficiencies in the growth chamber small pot experiments. Low spring soil temperatures may enhance zinc or phosphorus deficiencies in crops grown on some Manitoba soils, but these deficiencies should lessen as the soil increases in temperature.

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APPENDIX

Table 1A

P and Zn Concentrations in the Midseason Total Plant Harvest at the 1976 Field Sites.

Treatment Number (1)	Winkler		Portage		Jordan	
	[Zn] (ug Zn/g DM)	[P] (mg P/g DM)	[Zn] (ug Zn/g DM)	[P] (mg P/g DM)	[Zn] (ug Zn/g DM)	[P] (mg P/g DM)
1	18.4	2.3	15.8	2.2	38.7	2.1
2	18.8	2.2	14.5	2.4	30.3	3.0
3	17.5	3.4	16.8	2.8	30.6	3.0
4	20.7	4.9	15.3	2.6	26.3	3.0
5	15.9	2.6	16.1	2.2	33.6	2.5
6	16.4	3.2	14.3	2.4	31.0	3.4
7	17.3	3.0	14.6	2.4	33.3	2.5
8	16.6	2.5	13.4	2.2	37.2	2.4
9	17.8	3.9	15.0	2.1	34.4	2.4
10	22.2	4.3	14.5	2.2	31.8	2.6
11	17.1	3.6	17.4	2.3	30.3	2.6
12	18.2	3.8	17.6	2.2	31.2	2.4
17	18.3	3.8	17.9	2.4	34.1	3.0
18	16.6	2.5	17.0	2.1	31.3	2.7
19	19,8	2.4	15.1	2.4	29.3	2.5

(1) See Table 1 for treatment descriptions.

Table 2A

P and Zn Concentrations in the Seed Harvest at the 1976 Field Sites.

Treatment Number (1)	Winkler		Portage		Jordan	
	[Zn] (ug Zn/g DM)	[P] (mg P/g DM)	[Zn] (ug Zn/g DM)	[P] (mg P/g DM)	[Zn] (ug Zn/g DM)	[P] (mg P/g DM)
1	25.7	--	25.5	2.6	29.3	2.3
5	25.5	--	21.6	2.7	31.4	2.6
6	24.1	--	23.9	3.2	29.0	2.3
7	20.9	3.0	22.5	3.1	28.0	2.6
8	22.5	2.9	24.0	3.0	34.5	2.5
11	21.8	2.9	28.9	2.4	27.3	2.5
12	23.4	2.9	28.9	2.8	27.5	2.2
17	22.8	3.0	27.4	2.6	28.6	2.2
18	24.5	3.1	25.0	3.0	30.1	2.2
19	23.5	2.9	23.9	3.0	28.6	2.1

(1) See Table 1 for treatment descriptions.

Table 3A

P, Zn, Cu, and Mn Concentrations in the Midseason Total Plant Harvest at the 1977 Morden Field Site.

Treatment Number (1)	[P] (mg P/g DM) (2)	[Zn] (ug Zn/g DM) (2)	[Cu] (ug Cu/g DM) (2a)	[Mn] (ug Mn/g DM) (2)
1	2.3 ab	16.1 a	4.3	44 a
2	2.4 ab	19.0 a-e	4.1	48 a
3	2.3 ab	18.9 a-e	3.8	44 a
4	2.1 a	17.8 a-c	4.6	41 a
5	2.3 ab	19.9 a-f	5.4	46 a
6	2.5 ab	19.8 a-f	6.4	50 a
7	2.3 ab	18.4 a-d	3.8	48 a
8	2.4 ab	22.4 c-g	4.4	46 a
9	2.4 ab	24.0 fg	4.8	50 a
10	2.4 ab	20.0 a-f	5.3	47 a
11	2.1 a	18.1 a-c	4.4	47 a
12	2.2 ab	17.2 ab	4.4	38 a
13	2.2 ab	21.0 b-g	4.5	42 a
14	2.3 ab	22.2 c-g	4.0	49 a
15	2.4 ab	22.9 d-g	4.2	49 a
16	2.2 ab	21.5 b-g	4.5	43 a
17	2.3 ab	23.1 efg	4.1	63 b
18	2.3 ab	21.1 b-g	4.7	45 a
19	2.3 ab	19.2 a-e	4.4	45 a
20	2.6 b	25.0 g	5.4	48 a
error df = 57				
F test	1.00(3)	2.93(5)	1.60(4)	1.62(4)
Sd	0.18	2.0	0.7	5.5
cv	10.8	13.7	22.1	16.7

(1) See Table 2 for treatment descriptions.
(2) Duncan's test. P=.05 (2a) Not significant at P=.05
(3) Not significant at P=.10
(4) Significant at P= .10
(5) Significant at P= .005.

Table 4A

P, Zn, Cu, and Mn Concentrations in the Seed Harvest at the 1977 Morden Field Site.

Treatment Number(1)	[P] (mg P/g DM)	(2)	[Zn] (ug Zn/g DM)	(2)	[Cu] (ug Cu/g DM)	(2)	[Mn] (ug Mn/g DM)	(2)
1	4.6	abc	21.5	a	6.8	b-e	9.7	a
2	4.6	abc	21.6	a	6.0	a-d	10.3	a-c
3	4.8	abc	22.1	ab	6.4	a-e	9.8	ab
4	4.9	abc	22.3	a-c	7.4	de	9.6	a
5	4.7	abc	22.3	a-c	6.2	a-e	9.6	a
6	5.0	cd	25.0	a-f	6.2	a-e	10.4	a-d
7	4.8	abc	23.6	a-d	5.5	a-c	10.8	bcd
8	4.8	abc	25.4	b-f	6.5	a-e	11.1	cdef
9	4.4	ab	24.9	a-f	5.9	a-c	11.0	cdef
10	5.1	cde	24.9	a-f	5.8	a-c	11.0	dcef
11	6.6	g	28.0	fgh	6.0	a-d	11.5	defg
12	5.5	ef	24.0	a-e	5.7	a-c	11.7	efgh
13	5.4	def	26.5	d-g	6.0	a-d	11.6	efg
14	5.5	ef	27.4	efgh	5.8	a-c	12.0	fghj
15	5.8	f	27.4	efgh	5.4	ab	12.6	hj
16	5.0	bcd	29.2	gh	6.1	a-e	12.9	j
17	4.3	a	26.0	cdef	5.1	a	12.5	ghj
18	4.7	abc	27.1	defgh	6.2	a-e	12.8	j
19	5.0	bcd	30.3	h	7.1	cde	14.1	k
20	4.7	abc	27.0	defgh	7.6	e	12.8	j
error df= 57								
F test	11.4 (4)		5.16 (4)		1.92(3)		14.3(4)	
Sd	0.22		1.6		0.65		0.48	
cv	6.3		8.9		14.9		6.0	

(1) See Table 2 for treatment descriptions.
(2) Duncan's test. P= .05.
(3) Significant at P = .025.
(4) Significant at P = .005.

Table 5A

P, Zn, Cu, and Mn Concentrations in the Midseason Total Plant Harvest at the 1977 Winkler Field Site.

Treatment Number (1)	[P] (mg P/g DM)	[Zn] (ug Zn/g DM)	[Cu] (ug Cu/g DM)	[Mn] (ug Mn/g DM)
	(2a)	(2)	(2)	(2)
1	2.0	14.2 a-c	5.1 ab	39 ab
2	1.9	16.0 a-e	5.2 ab	44 ab
3	1.9	15.1 a-d	5.2 ab	45 b
4	1.9	13.6 ab	4.0 a	44 ab
5	2.0	13.6 ab	5.1 ab	42 ab
6	1.9	12.9 a	4.6 ab	39 ab
7	1.9	17.0 a-f	4.9 ab	46 b
8	2.0	19.9 cdef	5.4 ab	39 ab
9	1.9	17.0 a-f	4.9 ab	41 ab
10	1.8	17.8 a-f	5.5 ab	46 b
11	2.1	12.4 a	5.0 ab	43 ab
12	2.1	13.0 a	5.2 ab	43 ab
13	1.8	19.0 b-f	4.7 ab	42 ab
14	2.1	21.1 ef	5.7 b	43 ab
15	2.0	16.4 a-f	4.7 ab	40 ab
16	1.8	20.8 def	5.7 b	41 ab
17	1.8	22.1 f	4.8 ab	46 b
18	1.9	14.2 a-c	4.4 ab	39 ab
19	2.1	18.1 a-f	5.5 ab	43 ab
20	2.1	20.4 c-f	5.3 ab	36 a
error df- 55				
F test	1.11(3)	3.12(4)	0.84(3)	1.24(3)
Sd	0.13	2.4	0.65	3.5
cv	9.7	20.3	18.4	11.7

(1) See Table 2 for treatment descriptions.
(2) Duncan's test. P=.05. (2a) Not significant at P= .05.
(3) Not significant at P= .10.
(4) Significant at P= .005.

Table 6A

P, Zn, Cu, and Mn Concentrations in the Seed Harvest at the 1977 Winkler Field Site.

Treatment Number (1)	[P] (mg P/g DM) (2)	[Zn] (ug Zn/g DM) (2)	[Cu] (ug Cu/g DM) (2)	[Mn] (ug Mn/g DM) (2)
1	4.1 de	19.9 a	7.6 a-d	10.8 a
2	4.0 a-e	21.4 a-c	7.2 ab	11.2 ab
3	4.0 a-e	23.0 a-e	6.6 a	11.1 a
4	4.1 de	21.1 a-c	7.3 abc	11.0 a
5	4.0 a-e	20.8 ab	8.0 cde	11.5 abc
6	4.0 a-e	23.4 b-f	7.7 a-d	11.4 ab
7	4.0 a-e	24.2 c-g	8.2 cde	12.0 abc
8	3.6 a	25.2 d-g	7.8 a-d	11.4 ab
9	3.8 a-d	25.8 defg	7.7 a-d	11.0 a
10	3.7 a-c	21.5 a-c	8.2 cde	11.8 abc
11	4.1 de	20.8 ab	7.9 cde	12.8 cd
12	4.1 de	22.8 a-d	8.8 def	12.8 cd
13	4.2 e	27.1 ghjk	8.0 cde	12.5 bcd
14	4.2 e	31.6 l	9.7 f	12.5 bcd
15	4.2 e	26.4 fghj	7.9 cde	13.6 de
16	4.0 a-e	29.2 hjkl	9.1 ef	13.6 de
17	3.8 a-d	30.0 kl	8,6 def	14.3 e
18	4.2 e	26.1 efgh	8.0 cde	14.3 e
19	4.3 e	27.0 ghjk	8.3 cde	14.7 e
20	3.7 abc	29.5 kl	9.2 ef	13.6 de
error df= 57				
F test	2.83 (3)	12.2 (3)	3.83(3)	10.3 (3)
Sd	0.17	1.4	0.51	0.56
cv	6.1	8.1	9.0	6.3

(1) See Table 2 for treatment descriptions.
(2) Duncan's test. P= .05.
(3) Significant at P= .005.

Table 7A

Cu and Mn Concentrations in the Midseason and Seed Harvests at the 1978 Field Sites.

Treatment Number (1)	Part of Plant Analyzed	Morden [Cu] (ug Cu/g DM)	Morden [Mn] (ug Mn/g DM)	Winkler [Cu] (ug Cu/g DM)	Winkler [Mn] (ug Mn/g DM)
		(2)	(3)	(2)	(2)
1	Midseason Total Plant	7.4 b	53	9.3 d	64 b
2		6.9 b	59	7.8 c	59 ab
3		6.2 ab	60	7.6 bc	53 a
4		5.9 ab	61	7.4 a-c	55 ab
5		6.5 ab	54	6.9 ab	52 a
6		6.8 b	56	7.8 c	50 a
7		6.2 ab	62	7.8 c	52 a
8		7.1 b	58	7.3 a-c	56 ab
9		6.1 ab	56	6.8 a	59 ab
10		5.0 a	65	6.6 a	54 ab
		(2)	(2)	(2)	(2)
1	Seed	8.3 b	12.3 a	9.5 d	11.6 bcd
2		8.5 b	13.0 a-c	7.6 a-c	11.2 a-d
3		7.2 ab	13.8 c	7.1 ab	9.4 a
4		6.8 ab	12.8 a-c	7.4 a-c	9.7 ab
5		7.3 ab	12.0 a	7.0 a	10.6 a-c
6		8.4 b	12.2 a	9.0 cd	11.7 bcd
7		9.0 b	12.4 a	8.7 bcd	11.2 a-d
8		9.2 b	12.6 ab	8.8 cd	12.2 cd
9		8.6 b	12.3 a	8.5 a-d	12.2 cd
10		5.2 a	13.6 bc	8.2 a-d	12.7 d

(1) See Table 3 for treatment descriptions.
(2) Duncan's test. P= .05.
(3) Not significant at P= .05.

Table 8A

P and Cu Concentrations in Growth Chamber One Blackbeans.

Treatment Number (1)	[P] (mg P/g DM) (2)	[Cu] (ug Cu/g DM) (2)
1	8.2 c	5.7 c
2	4.9 b	4.6 b
3	5.2 b	4.5 b
4	3.1 a	3.4 a
F test	43 (3)	133 (3)

(1) See section III B 1 for treatment descriptions.
(2) Duncan's test. P= .01.
(3) Significant at P= .005.

Table 9A

Cu Concentrations and Uptake in Growth Chamber Two Blackbeans.

Treatment Number (1)		[Cu] (ug Cu/g DM) (2)	Total Cu Uptake (ug/pot) (2)
1		4.7 bc	26 ab
2		4.9 bc	34 cd
3		5.3 c	37 cde
4		5.4 c	39 cde
5		6.6 d	44 e
6		4.9 bc	22 a
7		4.1 ab	32 bc
8		3.7 a	35 cd
9		3.6 a	34 cd
10		3.4 a	41 de
error df = 18			
P	F test	0.14 (3)	16.2 (5)
Zn		6.84 (4)	4.01(4)
P x Zn		9.44 (5)	0.17(3)
S		0.50	4.0
cv		10.7	11.7

(1) See section III B 2 for treatment descriptions.
(2) Duncan's test. P = .05.
(3) Not significant at P = .10.
(4) Significant at P= .10.
(5) Significant at P= .005.