ZINC AND COPPER NUTRITION OF CORN ON MANITOBA SOILS

By

ADOLF S. K. NYAKI

A Thesis submitted to the Faculty of Graduate Studies
in Partial Fulfillment of the Requirements
for the Degree of Master of Science

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ABSTRACT

Zinc and Cu nutrition of corn (Zea mays L) was studied both under controlled and field environments on soils low in DTPA extractable Zn and/or Cu. The influence of fertilizer P on the extent and severity of Zn and Cu deficiencies in corn was also investigated.

Application of as little as 2 ppm Zn as $ZnSO_4 . 7H_2O$ increased dry matter yield of eight-week old corn shoots when grown under controlled environment on an Almasippi loamy very fine sand containing 0.51 ppm DTPA extractable Zn. However, when corn was grown in the field on an Almasippi loamy fine sand containing 0.52 ppm DTPA extractable Zn, Zn fertilization had no influence upon grain or total dry matter yields despite additions of up to 32 kg Zn/ha. Similarly, application of Zn on a Reinland fine sandy loam and Neuenburg very fine sandy loam containing 1.25 and 0.76 ppm Zn, respectively, did not increase total dry matter yield of corn shoots. Zinc concentration and uptake into corn shoots were increased both in the field and in the greenhouse. Drought severely restricted growth in the field experiments and was likely at least partially responsible for the lack of response in yield to Zn fertilization.

Increasing the level of P from 50 to 200 ppm accentuated Zn deficiency in the greenhouse when Zn was not applied resulting in a drastic decrease in dry matter yield and severe Zn deficiency symptoms. This effect was not evident in the field, likely due to lack of response to applied P as a result of dry weather.

Corn did not respond to applied Cu either in the field on an

Almasippi loamy fine sand containing 1.1 ppm DTPA extractable Cu or under controlled environment on an Almasippi loamy very fine sand containing 0.23 ppm Cu although Cu concentrations and/or uptake into corn shoots were increased significantly by Cu fertilization both in the field and greenhouse.

Corn was found to be Zn deficient in the greenhouse regardless of P level when the Zn concentration in mature leaf blades just prior to silking was less than 7.0 ppm. The critical level in corn shoots depended upon the level of P decreasing from 12.5 ppm Zn when 50 ppm P were applied to 7.5 ppm when the P level was increased to 200 ppm.

Levels of Fe and Mn in plant tissue were adequate in all cases for optimum growth but N, K and S levels were often not quite adequate, particularly in the greenhouse. The Zn critical levels determined in the greenhouse could not be applied to field conditions and may have been influenced by deficiencies of N, K and S. Critical levels could not be determined in the field because of the lack of response in yield to Zn fertilization.

The influence of soil volume on Zn response under controlled environment was also studied. Zinc fertilization increased dry matter yield of corn shoots at silking. Dry matter yield was also increased with increasing soil volume. Zinc concentration or uptake was not influenced by soil volume when Zn was not applied suggesting that the often observed greater frequency of response to Zn fertilization under controlled conditions is caused by some factors other than the restricted soil volume under controlled conditions. When Zn was applied, Zn uptake decreased with increasing soil volume likely because of decreasing root-available Zn contact and/or depressive effect caused by increasing P uptake with increasing soil volume.

The uptake of all macronutrients into corn shoots increased with increasing soil volume because of increasing dry matter yield. However in the case of P and K plant concentrations also increased, suggesting that expanding soil volume increased plant uptake of P and K. The increase in yield with increasing soil volume may have resulted at least partially from correction of P and/or K deficiencies since plant concentrations of these nutrients were marginal.

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INTRODUCTION

Land area devoted to grain corn in Manitoba increased from 2,226 hectares in 1960 to 101,214 hectares in 1981. However, like many other crops, a limited amount of information is available concerning the micronutrient requirements of corn, particularly Zn and Cu. An extensive survey carried out in the mid-seventies indicated that on the basis of tissue analysis Zn was likely limiting corn yields in approximately 50% of Manitoba fields. The soils in the areas studied were perhaps not supplying enough Zn, but the plant critical levels of Zn in corn earleaves used to arrive at these conclusions were determined in the United States where growing conditions were quite different from those of Manitoba. Plant critical levels of Zn and Cu under Manitoba conditions need to be established. The increasing use of P fertilizers on the light textured corn soils and the known interaction between P and Zn necessitate studying the influence of applied P upon the extent and severity of Zn and Cu deficiencies.

The greater frequency of response to micronutrients by crops grown under controlled environment as opposed to field conditions is difficult to explain despite the large amount of information reported regarding the influence of such factors as temperature, soil pH, soil texture, $CaCO_3$ content and organic matter content on micronutrient availability to crops. It has been suggested that the restricted soil volume involved in greenhouse experiments may be responsible for the larger and more frequent responses to micronutrient fertilization in the greenhouse. Studies were therefore initiated:

(1) to determine if corn would respond to Zn and Cu fertilization both under field and greenhouse conditions;

(2) to determine the plant critical levels of Zn and Cu under both conditions;

(3) to determine the influence of applied P on the critical levels determined, and

(4) to determine the influence of soil volume upon Zn response in corn.

LITERATURE REVIEW

Incidence of Zinc and Copper Deficiencies

Zinc and Cu deficiencies in field crops are scattered throughout the world and occasionally become major soil fertility problems. The severity and the pattern of deficiency symptoms varied from one crop to another (Burleson, et al., 1961; Bingham, et al., 1960; Boawn and Leggett, 1964; Sharma, et al., 1968; and Viets, et al., 1954). Corn was reported as one of the most sensitive to low levels of soil Zn. Viets, et al. (1954) compared the susceptibility of beans, potatoes, onions and mustard to Zn deficiency and found that of the four crops, beans were most susceptible. Extreme variation in susceptibility to Zn deficiency among corn varieties was also reported. Halim (1968) found that some corn inbreds exhibited early resistance to Zn deficiency but became susceptible at later stages of growth while others were susceptible in early stages but became resistant later.

In contrast to Zn, corn did not appear to be particularly susceptible to Cu deficiency although some cases were reported in which corn was found to be Cu deficient. Berger (1962) reported that Zn deficiency in corn was prevalent in twenty states in the United States but Cu deficiency in corn was reported in only three states. Various crops were also rated with respect to their degree of response to micronutrient fertilization under conditions which were favourable to deficiency. The response of corn to Zn addition was rated as high but response to Cu was rated as medium (Anon, 1970).

Work reported thus far on the nutritional status of Manitoba corn (Racz, 1967; Smid and Spratt, 1974; and Spratt and Andrews, 1978) revealed that corn in Manitoba might be deficient in Zn. Sadler and Fehr (1975) reported that nearly half of the corn grown in Manitoba was Zn deficient but that Cu levels were usually sufficient. However, these conclusions together with those of Smid and Spratt (1974) and Spratt and Andrews (1978) were based upon plant critical levels established in the United States where growing conditions were different from those of Manitoba. Zinc and Cu applications to Manitoba corn in the field resulted in slight yield increases but these were not statistically significant (Racz, 1967).

Elsewhere, however, a number of significant yield increases to Zn and/or Cu fertilization in corn were reported (Berger, 1962; Coffman and Miller, 1973; Navrot and Ravikovitch, 1969; Oplinger and Ohlrogge, 1974; and Terman and Allen, 1964).

In contrast to corn, Zn and/or Cu responses were reported in other crops in Manitoba, particularly in the growth chamber. There were no responses to either Zn or Cu in cereal crops on mineral soils in the field although Akinyede (1978) obtained total dry matter yield increases in the environmental chamber in barley which had been fertilized with Cu and Zn. Similarly there were no responses to Zn or Cu in flax in the field although Haluschak (1972) reported significant dry matter yield increases to added Zn and Cu in the growth chamber. Out of seven experiments with blackbeans in the field, responses in grain yield to added Zn occurred only in one experiment (Loewen-Rudgers, 1978). However, Hedayat (1978) obtained significant dry matter yield increases in blackbeans and fababeans to added Zn and Cu in the environmental chamber. McKenzie (1980) also reported increases in blackbean dry matter yield as a result of Zn fertilization in the environmental chamber.

These findings indicate that responses to micronutrient fertilization on mineral soils were more prevalent in the growth chamber or greenhouse than in the field where significant yield increases occurred very infrequently. However, on organic soils, responses to Cu occurred both in the field and in the growth chamber although responses in the growth chamber were larger. McAndrew (1979) obtained significant increases in wheat grain yields on organic soils in the field after fertilizing with Cu. Copper additions to barley and oats in the field resulted in small increases in grain yields but these were not significant. However, in the growth chamber there were responses to Cu in wheat, barley, oats, flax and rapeseed although wheat and flax were considerably more responsive to Cu than the other three crops. Tokarchuk, et al. (1979) and Reid and Racz (1980) reported similar grain yield increases in wheat receiving Cu on organic soils. On one site, Reid and Racz (1980) also reported responses to Cu fertilization of barley. Rapeseed grain yields were not significantly increased by Cu fertilization. It is possible that if corn were grown on organic soils it would be deficient in Cu. But, the cool microclimate on organic soils in Manitoba precludes their use for corn production.

Soils likely to be Zinc and Copper Deficient

Reports in the literature from other areas Peech (1941); Berger (1962); Bingham, et al. (1964); Thorne (1957); and Vintosh, et al. (1973) suggested that Zn deficiency should be most likely in Manitoba on high-lime soils particularly when coarse-textured and when the weather is cool and wet during the early growing season. Work done by

McGregor (1972) and Akinyede (1978) on such soils resulted in responses to Zn application in the growth chamber in wheat and barley, but as mentioned earlier there were no responses to Zn on such soils in the field. Reports from other areas suggested that Cu deficiency should be most likely in Manitoba on organic (peat) soils but sandy soils may also be Cu deficient because of absolutely low levels of Cu. The lower pH of many sandy soils should make the Cu that is there quite available. Sandy soils containing lime may be higher in total Cu but their higher pH decreases plant availability of Cu. As mentioned earlier, Cu deficiencies were observed in Manitoba crops on organic soils by Tokarchuk, et al. (1979) and Reid and Racz (1980), and Cu fertilization resulted in increased yields. Copper fertilization did not increase wheat, oat, barley or flax yields on sandy mineral soils containing low available Cu. But crop yields in those experiments were often limited by other factors such as hail, frost, drought and armyworm damage.

The severity and extent of deficiency depended on the type of crop as well as weather conditions that prevailed during the growing season. Tokarchuk, et al. (1979) for example, reported significant yield increases to Cu fertilization in wheat on organic soils but no response in barley while Reid and Racz (1980) working on similar soils reported increases in barley yields on one site as a result of Cu fertilization. Despite lack of responses to Cu in wheat in 1980, wheat grain yields at all locations were greater than those obtained in previous years. Those increases were attributed to warmer temperatures in 1980. It should be apparent from the information presented thus far concerning the incidence of Zn and Cu deficiencies in Manitoba that more work is needed in order to determine the true extent and severity of both Zn and Cu deficiencies in Manitoba corn.

Zinc and Copper Deficiency Symptoms in Corn and Other Crops

Tisdale and Nelson (1975) indicated that Zn deficiency symptoms began in most crops on the younger leaves as interveinal chlorosis. In many crops Zn deficiency resulted in shortened internodes which led to rosetted appearance in crops such as flax. Zinc deficiency in corn and sorghum was often called "white bud" because the newly emerging leaves appeared pale green or white. Viets, et al. (1954) reported that in corn interveinal chlorosis was accompanied by severely shortened internodes and severe stunting of the entire plants. Similar symptoms were observed earlier in corn by Barnette (1935). More recently, Bates and Johnstone (1975) reported that Zn deficiency in corn in Ontario was very common but was rarely severe. It occurred in patches in the field at the 4th to 6th leaf stage. They described the less severe Zn deficiency symptoms as broad whitish stripes on one or both sides of the midrib in the second and third leaf from the top.

As mentioned earlier, Halim, et al. (1968) found that not only the degree but also the pattern of Zn deficiency symptoms varied with strains of corn. He observed that susceptible varieties had poor root development and that they either exhibited white chlorosis or purple coloration at the base of the shoot. Others exhibited "white bud" symptoms. He added that under severe conditions one cross developed necrosis of leaves followed by death of the plants.

Severity of Zn deficiency also varied among crops as mentioned before. Viets, et al. (1954) found that field beans were very sensitive to Zn deficiency compared to crops such as potatoes, wheat, barley, oats and alfalfa which did not exhibit Zn deficiency symptoms when grown on the same soil as the beans. They added that in some cases application of Zn did not result in significant yield increases although Zn deficiency symptoms were very apparent, while in other cases yield increases were obtained on applying Zn fertilizer without any visible Zn deficiency symptoms. Berger (1962) reported increases of up to 30% in corn yields on applying Zn without apparent Zn deficiency symptoms. Similar findings were reported by Shukla and Morris (1967).

Giordano (1966) reported that Zn deficiency symptoms appeared in corn in the field three to four weeks after seeding. The time of appearance of Zn deficiency symptoms may vary particularly in the greenhouse depending on the factors which affect Zn availability such as soil and air temperature, light conditions, soil pH and available soil P.

Tisdale and Nelson (1975) and Berger (1962) also described symptoms of Cu deficiency in crops as yellowing and stunting of the younger leaves which later became pale as severity increased, followed by dieback of the older leaves. Teakle, et al. (1941) reported that leaves of Cu deficient corn became chlorotic, followed by withering and graying of the tips. They added that the tips later bent and lost turgor and those of newly emerging leaves died. This description indicates that Cu deficiency symptoms in corn is mainly confined to the leaves while in the case of Zn the internodes are also affected as described before. Experience with vegetable crops showed that when adequate Cu was lacking, flowering failed to take place (Tisdale and Nelson, 1975). Like Zn, tolerance to low Cu varied among crops. McAndrew (1979) proposed the order of tolerance to low Cu as rapeseed> barley> oats> wheat>

flax.

Plant Critical Levels

The definition of plant "critical level" varied greatly among researchers. Ulrich, et al. (1967) defined plant critical level as the nutrient concentration in the plant which produced 90% of the maximum yield. Jones (1967) and Farhoomand, et al. (1968) defined it as the nutrient concentration in the plant below which growth or crop yield was restricted. Oplinger and Ohlrogge (1974) defined critical levels from the economic point of view as the nutrient concentration beyond which further application of nutrient did not return a profit. Occasionally, responses to micronutrient fertilization were reported in which nutrient concentration in the tissue were above critical levels. Oplinger and Ohlrogge (1974) reported such findings in corn.

Many workers demonstrated that critical levels varied among crops and depended upon the plant part sampled, as well as the stage of growth. Taking this into consideration, Jones (1967) emphasized that careful sampling was important for meaningful interpretation of plant critical levels. The earleaves nutrient concentration at silking was normally used as a standard for comparison in corn. Using the earleaves Jones (1967) reported that Zn deficiency occurred when the Zn concentration at silking was less than 10 ppm while Cu deficiency occurred when the earleaves Cu concentration was less than 2 ppm. However, Stukenholtz, et al. (1966) reported that the earleaf critical level of Zn varied from 12 ppm in some hybrids of corn to 20 ppm in others. Melsted, et al. (1969) felt that the critical level of Zn in the earleaves was 15 ppm while that of Cu was 5 ppm. They added that these levels were also valid for wheat sampled as a whole plant at the boot stage and for soybeans when the youngest mature leaves and petioles at early podding were sampled. Some workers also used whole corn plants to establish critical concentrations of Zn and/or Cu in the plants. Coffman and Miller (1973) found that the critical level of Zn in thirty-day old corn plants was 12 ppm. Lockman (1969) used whole plants 30-45 days after emergence and reported that corn at this stage was sufficient in Zn when the concentration in the plants was 20-50 ppm and sufficient in Cu when the levels were 7-20 ppm. Critical levels of Zn and/or Cu in other crops in Manitoba were reported. Akinyede (1978) found that the critical Zn and Cu concentrations in six-week old barley grown in the environmental chamber were 12.5 ppm and 5.2 ppm, respectively. McGregor (1972) reported critical levels of Zn and Cu in eight-week old flax as 13 ppm and 3 ppm, respectively. McKenzie (1980) determined plant critical level of Zn in blackbeans in the growth chamber. He found that at the early flowering stage blackbeans were Zn deficient when tissue concentration was less than 10 ppm, the lower limit of the marginal range.

Jones (1973) criticized the use of critical levels on the grounds that they designated only the lower end of the sufficiency range. Instead, he suggested the use of concentration ranges termed deficiency, marginal and sufficiency as used earlier by Jones (1967) when he reported that ranges of 20-70 ppm Zn in the earleaves at silking were sufficient. Neubert, et al. (1969) reported a Zn sufficiency range in corn earleaves of 50-150 ppm. McAndrew (1979) reported the marginal range of Cu as 2.3-3.7 ppm for barley, 1.7-2.5 ppm for oats, 3.0-4.9 ppm for wheat, 2.4-3.5 ppm for flax and 1.7-2.7 ppm for rapeseed at 45, 49,