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Zinc nutrition of three corn cultivars (Zea mays L.) as affected by environment and zinc rates

Michael Karl Wade

To the Graduate Council:

I am submitting herewith a thesis written by Michael Karl Wade entitled "Zinc nutrition of three corn cultivars (Zea mays L.) as affected by environment and zinc rates." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Plant, Soil and Environmental Sciences.

Gary Lessman, Major Professor

We have read this thesis and recommend its acceptance:

William Krueger, Russell Lewis

Accepted for the Council:
Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

June 1973

To the Graduate Council:

I am submitting herewith a thesis written by Michael Karl Wade entitled "Zinc Nutrition of Three Corn Cultivars (Zea mays L.) as Affected by Environment and Zinc Rates". I recommend that it be accepted for nine quarter hours of credit in partial fulfillment of the requirements for the degree of Master of Science, with a major in Plant and Soil Science.

Gary M. Lessman
Major Professor

We have read this thesis
and recommend its acceptance:

William A. Krueger

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ZINC NUTRITION OF THREE CORN CULTIVARS (*Zea mays* L.) AS AFFECTED BY ENVIRONMENT AND ZINC RATES

A Thesis

Presented to

The Graduate Council of

The University of Tennessee

In Partial Fulfillment

of the Requirements for the Degree

Master of Science

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by

Michael Karl Wade

June 1973

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ABSTRACT

Three varieties of corn (Zea mays L.) were grown under two different environmental conditions for 21 days in a growth chamber. The soil used was a Zn deficient Bradyville silt loam which was treated with five rates of Zn fertilizer. Available soil Zn was determined by four different extracting solutions.

The concentration of Zn in the plants, and the available soil Zn, were not changed between the cool and warm environment. However, the warmer environment decreased the number of Zn deficient plants. Phosphorus concentration in the tissue, as well as measured soil P, were lower in the warm condition. This decrease in P may partially alleviate the Zn-P imbalance and result in the reduced number of deficient plants. The Zn concentration and uptake and the P concentration and uptake were similar in all three varieties, yet they varied greatly in development of visual deficiency symptoms. The applied Zn rates increased Zn concentration in the plants, and available soil Zn. All four soil tests correlated well with plant Zn concentrations, but rather poorly with deficiency symptoms. Soil test correlations for both plant Zn and deficiency symptoms were very dependent on the variety of corn and the environmental condition.

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CHAPTER I

INTRODUCTION

Zinc deficiency symptoms of corn have been observed to be enhanced by cool, wet growing conditions. This may be due to reduced availability of Zn in the soil, retarded root growth or activity, or slowed metabolic processes of the plant. There is a shortage of published information concerning the effects that temperature has on Zn nutrition in the soil-plant system. The role of genetic make-up on Zn nutrition and the reliability of present-day soil test as affected by temperature is not known. A portion of this study was to examine how different cultivars of corn respond to varying Zn fertilization rates under two different temperature regimes. The other portion was to observe the effect these regimes had on the extractibility of Zn using different extracting solutions. These extractions are compared to Zn concentration and uptake, and the presence of Zn deficiency symptoms of the corn seedlings.

This study adds to present knowledge of the importance of genetic control and the reliability of commonly used soil tests. A better understanding of these relationships can be of real benefit to researchers and extension personnel in aiding farmers to prevent many of these problems.

CHAPTER II

LITERATURE REVIEW

Zinc compounds commonly found in soils include ZnS, ZnO, $ZnCO_3$, $Zn(PO_4)_2 \cdot 4H_2O$ (36), and $Zn(OH)_2$ and Ca zincates which are likely to form at pH values greater than 7.2 (15). Of these, ZnS, or sphalerite, is the most frequently occurring mineral (34). The solubility of all these forms decreases as pH levels increase.

Several workers have shown diffusion to be the main type of Zn movement through soils (2,28,43). However Clarke and Graham (15) report that diffusivity approaches zero at pH values greater than 7. Zinc diffuses through kaolinite more rapidly than through other clay minerals (21).

Recovery of Zn added to soils is generally low. Mordvedt and Giordano (41) reported that corn recovered less than 4% of the Zn mixed with the soil. The formation of insoluble Zn compounds and fixation of Zn into clay lattices is responsible for this poor recovery. The divalent Zn cation may substitute for Al in the octahedral layer, thereby resulting in a reduced CEC, or replace Mg which will not affect the CEC (15).

Elgawhary, Lindsay, and Kemper (19), showed that Zn cations moved through a column of soil saturated with 10^{-3}M ethylenediaminetetraacetic acid (EDTA) seventeen times faster than through a similar column saturated with water. They suggested that root exudates consisting of organic acids and complexing agents, will perform roles similar to that

performed by EDTA; and thus increase the diffusive movement of metallic micronutrients through the soil. On the other hand, Brown, Tiffin, and Holmes (11) said roots must compete with naturally occurring chelating agents such as microbial exudates and humus for such micronutrients. In an earlier report, Hodgson, Lindsay, and Trierweiler (29) stated that the increased mobility was a greater advantage than the increased competition was a disadvantage.

Zinc deficiencies have been shown to be induced or enhanced by high pH and high soil P levels (5,12,13,14,26,40,51). As stated above, the solubility of most Zn compounds is reduced and diffusion of the cation is decreased as pH levels increase. This provides a simple and straightforward explanation of why Zn deficiencies become more noticeable under high pH conditions.

The antagonism of P toward Zn is somewhat more complicated. A few researchers have demonstrated that additions of P, in fact, did not decrease Zn content in the plant (4,45). Several workers suggested that the P-Zn interaction does not occur in the soil, but in the root or at the root surface (6,12,55). Extractable soil Zn appears to undergo no significant changes when P additions are made (7,32). However, Zn metabolism is affected by P. Stukenholtz, et al. (55) said that translocation of Zn is inhibited in high P, low Zn conditions. Boawn and Brown (5) supported this with data showing that additions of P resulted in Zn deficient corn although Zn uptake was not reduced. Also Sharma, et al. (50) showed that Zn concentration decreased in the tops, but remained unchanged in the roots, when excess P was added.

It appears that the Zn concentration of a plant is not a very good indication of sufficient or insufficient supply, but must be considered along with the P concentration. Boawn and Legget (6) reported a P/Zn ratio above 400/1 resulted in Zn deficient corn, while Watanabe, Lindsay, and Olsen (60) suggested a P/Zn ratio greater than 300 gave deficiency symptoms. But Stukenholtz, et al. (55) reported that they could not correlate a P/Zn ratio with deficiency or yield.

Another factor that affects Zn nutrition of plants is temperature. This factor has received limited attention by researchers but is commonly noticed by farmers and extension agents. Cool wet seasons may cause Zn deficiency symptoms in corn grown on soils with low Zn levels, while these same areas will appear normal if the season is warmer and drier. Field grown corn tends to "grow out of" its deficiency symptoms later in the season. Ganiron, et al. (23) reported corn growing in low Zn nutrient solutions responded to a 10 C increase in temperature better than to Zn rate, carrier or source. In fact, the deficient corn did not respond to Zn fertilizer at the cooler temperature. Martin, McLean, and Quick (39) showed that at 0.9 ppm dithizone extractable Zn, P induced Zn deficiency at 10 and 15 C but not at 21 and 27 C. At 0.3 ppm, Zn deficiency was induced at all temperatures except 27 C, and at 0.1 ppm all temperatures gave Zn deficient plants. Also there was less response to applied Zn at higher temperatures indicating Zn is more available and/or mobile at the warmer temperatures. Bauer and Lindsay (3) found increasing temperatures increased uptake. Simply by increasing temperature from 31 C to 43 C, yield as well as Zn uptake increased, but neither the 0.1N HCl nor the dithizone extractants were able to detect

any differences in soil Zn. They hypothesized that the increased uptake may have been due to increased microbial activity, increased root activity, and/or increased growth rate of the plant.

Crops usually respond best to Zn fertilization if the Zn is applied alone as ZnO or $ZnSO_4$, and not incorporated into other fertilizer (24,43,56). Also, complexed Zn as Zn-EDTA will remain more soluble and therefore provide more available Zn than Zn salts (18,31,43), except on quite acid soils, in which case $ZnSO_4$ is more soluble whereas Zn-EDTA is unstable (33). Ellis, Davis, and Judy (20) reported that the water solubility of added $ZnSO_4$ decreased from 100% to less than 1% when incorporated into 10-20-10 fertilizer, while Zn-EDTA remained 10% soluble when similarly incorporated. Lessman and Ellis (35) stated that the water solubility of Zn in a fertilizer is the most important factor in determining its efficiency. Ammonium nitrate and ammonium pyrophosphate have been shown to be two of the better carriers if Zn is mixed with other fertilizers (24,42,56). However, these same workers disagree on the ranking of concentrated superphosphate, mono ammonium phosphate, and soil as a carrier for Zn. Thus there seems to be no generalization that can be made about types of fertilizers as carriers for Zn. Terman, Allen, and Bradford (56) gave an r^2 of 0.97 for correlation of yield with depression of pH caused by fertilizers. Giordano, Mortvedt, and Papendick (25) believed the reason they found ammonium sulfate to be the best carrier was because it reduced the pH more than other carriers. Several workers agree that mixing or broadcasting Zn fertilizer is superior to spot application or banding (25,41,52).

Several soil tests have been developed by researchers attempting to measure the available Zn in the soil. Extraction solutions such as dithizone (51), 0.1N HCl (62), EDTA-$(NH_4)_2CO_3$ (57), diethylenetriamine-pentaacetic acid (DTPA) (37), double acid (0.5N HCl + 0.25N H_2SO_4) (46), 2N $MgCl_2$ (53), and 0.2M $MgSO_4$ (38) are commonly used. Certain problems have been reported when using these various tests. Brown, Krantz, and Martin (8) reported 0.55 ppm dithizone extractable Zn was a good indication of a critical level for soil Zn. However, the Zn concentration of the extractions did not change as pH increased. Even though some of the Zn was made insoluble by higher pH, it was still extractable by the dithizone method. Similarly, Bauer and Lindsay (3) found that neither 0.1N HCl nor dithizone extractions would distinguish differences in available soil Zn when increased temperature increased Zn uptake by corn.

Comparisons of soil tests have been made in order to evaluate their relative effectiveness in predicting Zn deficient soils. Correlation of Zn uptake by corn with soil test values on California soils ranked correlation coefficients of DTPA > dithizone > 0.1N HCl > EDTA (9). Wisconsin soil tests correlated with Zn uptake by millet gave the following ranking of correlation coefficients: 2N $MgCl_2$ > 0.1N HCl > dithizone (53). Other work in Wisconsin suggested that 0.2M $MgSO_4$ gave a better measure of solution and readily available Zn than 0.1N HCl, dithizone, or a bioassay with Asperigillas niger (38). Alabama soils correlated with Zn uptake by corn in the order of double acid > 0.1N HCl > EDTA (61). EDTA gave better predictions of Zn deficiency on Virginia soils than 0.1N HCl, double acid, or DTPA. Kanehiro, Yoshinori, and Sherman (31) stated that 0.1N HCl was better correlated

with Zn deficiency than was total Zn on soils of Hawaii. One outstanding problem with Zn soil tests is that with all the comparisons and studies, none of the tests have consistently, if ever, correlated well with yield.

One very interesting paper has been published concerning the response of different lines of corn to different levels of Zn and P (27). In this study, 34 lines (10 inbreds and 24 single crosses) were grown on the same soil type for 4 weeks. Some cultivars showed no deficiency symptoms, some showed symptoms early in growth and then disappeared, some showed symptoms later in the growing period, and the remaining lines were deficient throughout the duration of the experiment. Similar erratic results occurred when large amounts of P were added. The P was antagonistic to Zn uptake on some varieties, did not affect others, and caused an increase in Zn uptake in the remainder. This indicates that perhaps the factor of genetic control has been overlooked in the study of Zn nutrition, and definitely deserves further investigation.

The role of Zn in the metabolism of plants has been investigated to a limited extent. Currently, it is known to be an essential cofactor in carbonic anhydrase, a variety of dehydrogenases, proteinases and peptidases (59). Zinc deficiency results in a decrease in the levels of RNA and ribosomal content (10), as well as causing cytoplasmic ribosomes of Euglena gracilis to become quite unstable (47). Also tryptophan has been shown to correct Zn deficiency symptoms, and therefore Zn must be required for synthesis of this amino acid (49). Further study in this area of metabolism is essential for understanding nutritional needs for crop production.

CHAPTER III

MATERIALS AND METHODS

Soil Selection and Preparation

The soil selected for this experiment was a Bradyville silt loam from Bedford County, Tennessee. It is a member of the fine, mixed, thermic family of Typic Hapludalfs. The parent material of the dark reddish brown A horizon and upper portion of the red silty clay loam B horizon is loess or old alluvium. The lower portion of the B horizon has a higher clay content and developed from limestone. Limestone bedrock is found at an average depth of 1.2 meters.

The soil was collected from a field where corn had been observed to exhibit severe Zn deficiency symptoms. It was found to be high in available P and K, and had a pH value of 7.1.

The soil was obtained from the site, placed in plastic bags, and brought to the Agricultural campus. The soil was sieved through a six mm stainless steel screen. The moisture content was determined, and the equivalent of three kg air dry soil was weighed into each of 90, number 10 cans, that had been lined with a plastic bag. A moisture retention curve was made from the soil using the pressure membrance method (48).

Growth Chamber Experiment

All pots were fertilized at the rate of 50 kg N/ha as NH_4NO_3 and one of five rates of Zn; 0, 3, 6, 12, or 24 kg Zn/ha as $ZnSO_4$. These

fertilizers were mixed with the soil in a twin-shell rotary blender for five minutes at a rotation speed of 30 revolutions per minute.

Three corn cultivars (Zea mays L.) were selected for the experiment; a long season white corn, Funk's G-795W-1; a medium season yellow, Pioneer 3369-A; and a short season yellow, DeKalb XL-44. Five seeds were planted per pot, and thinned to three plants approximately five days after emergence.

The treatments were replicated three times, and a 3 x 5 complete factorial arrangement of treatments was used for each environment. Treatment means were separated by Duncan's New Multiple Range Test (17) at the 5% level of probability.

The environments were chosen to represent a cool wet, and a warm dry month of May in Tennessee. Based on climatological data from the U.S. Weather Bureau (57), the warm environment was set for a 30 C day and 18 C night temperature, the cool environment was set for a 21 C day and 12 C night temperature. The experiment was conducted in an environmental growth chamber. The unit provided 2200 foot candles of light at the soil surface, and the day length was set for 14 hours. The pots were watered to field capacity every four days. The corn seedlings were allowed to grow 21 days after emergence and then all aerial plant parts were harvested.

Laboratory Plant Analyses

The harvested corn was dried at 70 C. The tissue was then weighed, ground in a Wiley mill having a stainless steel screen, and stored in plastic bags. Approximately a one-half gram sample was accurately weighed into a porcelain dish and ashed at 550 C for four

hours. The ash was wetted with a small amount of deionized water and the free salts were dissolved in 10 ml of 3N HCl. The material was filtered through Whatman #40 filter paper and the filtrate was collected in 25 ml volumetric flasks. The solution was brought to volume with deionized water, and the Zn concentration was determined on a Perkin-Elmer 303 atomic absorption spectrophotometer. Phosphorus was determined by the ammonium vandate colorimetric procedure with a Technicon Auto Analyzer. All glassware was washed, rinsed in distilled water, rinsed in 0.1N HCl, and rinsed in deionized water.

Laboratory Soil Analyses

Soil samples were taken from each pot with a soil sampling tube. The samples were air dried, ground with a mortar and pestle, and stored in plastic bags at room temperature for two to three weeks.

Four different extracts were used for determining "available" soil Zn. They were 0.1N HCl (62), double acid (0.025N H_2SO_4 + 0.05N HCl) (46), EDTA (0.01M EDTA in 1M $(NH_4)_2CO_3$) (57), and that used by the Tennessee State Soil Testing Laboratory (0.05N H_2SO_4 in 1% w/w $(NH_4)_2SO_4$) (53). Twenty milliliters of the extractants were shaken with five grams of each soil sample for five minutes, with the exception of EDTA which was shaken with ten grams of soil. The samples were shaken in 40 ml centrifuge tubes in a reciprocating shaker at a speed of four cycles per second. The suspension was filtered through Whatman #40 filter paper and the extract collected in 25 ml erlenmeyer flasks. Zinc concentrations were determined on a Perkin-Elmer 303 atomic absorption spectrophotometer. The standards for each set of determinations were made up in the extracting solution used. Phosphorus was determined in

the Tennessee extractant by the ammonium vandate colorimetric procedure with a Technicon Auto Analyzer. All glassware and centrifuge tubes were cleaned by a wash, a rinse in distilled water, a rinse in 0.1N HCl, and a final rinse with deionized water.

CHAPTER IV

RESULTS

Environments

As shown by the data in Table I, yield was increased in the warmer environment. Zinc concentration of the plants did not change, but total Zn uptake did increase at the higher temperatures. Phosphorus concentration decreased while P uptake increased when the plants were grown in the warmer environment. Also, the number of pots with Zn deficient plants were greater in the cool environment.

TABLE I

YIELD, Zn AND P CONCENTRATION AND UPTAKE AS AFFECTED BY ENVIRONMENT

Environment	Yield (g/pot)	Zn (ppm)	Zn uptake (mg)	P (ppm)	P uptake (mg)
Cool	1.24a*	29.6a	.038a	2824a	3.50a
Warm	2.39b	29.3a	.076b	1770b	4.62b

*Means followed by the same letter in the same column are not different at the 5% level of probability.

Table II shows the effect of these environments on the available soil P as measured by the extracting solution used by the Tennessee State Soil Testing Laboratory (53), and on the available soil Zn as

measured by the four different extractants. The available P was reduced by the warmer temperatures while the available Zn remained unchanged as measured by three of the four soil tests. Only the 0.1N HCl extractant measured an increase with the warm condition.

TABLE II

MEANS OF FOUR SOIL TESTS FOR Zn AND ONE FOR P AS AFFECTED BY TWO ENVIRONMENTS

		Zn (ppm)			
Environment	P (ppm)	HCL	Double Acid	EDTA	Tenn.
Cool	59.8a*	1.82a	3.89a	3.20a	4.30a
Warm	52.5b	2.42b	3.91a	3.19a	4.34a

*Means followed by the same letter in the same column are not different at the 5% level of probability.

Cultivars

The measurements of yield, plant P concentration, plant Zn concentration, and visual deficiency symptoms among the three cultivars used in the experiment are shown in Table III. The only difference among the cultivars was the yield of Pioneer 3369-A, which was higher than the other two. The cultivars did not affect soil test values.

Zinc Rates

The rates of applied Zn fertilizer did not change the yield or the concentration of plant P, but did alter the concentration of Zn in the plant tissue (Table IV).

TABLE III

YIELD, P AND Zn CONCENTRATIONS OF THREE CORN CULTIVARS

Cultivar	Yield (g/pot)	Zn (ppm)	P (ppm)
Dekalb XL-44	1.69a*	27.0a	2427a
Pioneer 3369-A	2.02b	34.1a	2357a
Funks G-795W-1	1.73a	27.3a	2062a

*Means followed by the same letter in the same column are not different at the 5% level of probability.

TABLE IV

YIELD, P AND Zn CONCENTRATIONS AS AFFECTED BY Zn RATES

Zn Rate (kg/ha)	Yield (g/pot)	Zn (ppm)	P (ppm)
0	1.77a*	15.5a	2515a
3	1.73a	19.1a	2301a
6	1.89a	31.1b	2239a
12	1.87a	32.7b	2270a
24	1.81a	48.8c	2164a

*Means followed by the same letter in the same column were not different at the 5% level of probability.

Table V shows the effect of Zn rates on available soil P and available Zn as measured by each of the four extracting solutions. Each of the extractants detected the added Zn at all levels. Available P was not changed by additions of Zn.

TABLE V

MEANS OF FOUR SOIL TESTS FOR Zn AND ONE TEST FOR P AS AFFECTED BY Zn RATES

Zn Rate (kg/ha)	P (ppm)	Zn(ppm) HCl	Double Acid	EDTA	Tenn.
0	54.4a*	.94a	1.55a	1.25a	1.78a
3	57.1a	1.23b	2.40b	1.83b	2.52b
6	57.3a	1.84c	3.35c	2.78c	3.81c
12	55.3a	2.71d	4.83d	4.19d	5.38d
24	56.6a	3.83e	7.38e	5.92e	8.10e

*Means followed by the same letter in the same column are not different at the 5% level of probability.

Soil Tests

Correlation coefficients were obtained for plant Zn concentrations and Zn deficiency symptoms with each of the soil tests. These coefficients are listed in Tables VI and VII, respectively. Also the tables contain these same correlation coefficients on five subsets of the data, each of the two environments and each of the three varieties.

Table VIII lists the number of pots with Zn deficient plants as affected by the treatments of the experiment. The warm environment had fewer deficiencies than the cool environment. The trend was to decrease deficiencies as rates of Zn increased, but there were wide variations due to cultivars.

TABLE VI

CORRELATION COEFFICIENTS OF PLANT Zn CONCENTRATIONS WITH FOUR SOIL TEST VALUES ON TOTAL DATA AND FIVE SUBSETS

	Soil Test			
Data	EDTA	Tenn.	Double Acid	HCl
All	.65*	.63	.63	.59
Cool	.74	.71	.72	.68
Warm	.61	.60	.58	.58
DeKalb XL-44	.93	.94	.89	.91
Pioneer 3369-A	.77	.76	.78	.67
Funks G-795W-1	.52	.47	.47	.47

*All coefficients in the table are different from zero at the 5% level of probability.

TABLE VII

CORRELATION COEFFICIENTS OF Zn DEFICIENCY SYMPTOMS WITH FOUR SOIL TEST VALUES ON TOTAL DATA AND FIVE SUBSETS

	Soil Test			
Data	EDTA	Tenn.	Double Acid	HCl
All	.23*	.25*	.27*	.26*
Cool	.31*	.31*	.35*	.28
Warm	.17	.20	.20	.17
DeKalb XL-44	.39*	.41*	.44*	.44*
Pioneer 3369-A	.13	.18	.17	.13
Funks G-795W-1	.27	.33	.27	.29

*Coefficient is different from zero at the 5% level of probability.

TABLE VIII

NUMBER OF POTS WITH DEFICIENT PLANTS AS INFLUENCED BY TREATMENT

Treatment	Number/Total Pots
Cool	30/45
Warm	22/45
DeKalb XL-44	8/30
Pioneer 3369-A	23/30
Funks G-795W-1	21/30
Zn(kg/ha):	
0	16/18
3	9/18
6	12/18
12	8/18
24	6/18

CHAPTER V

DISCUSSION AND CONCLUSIONS

Environments

The warm environment produced corn seedlings yielding greater amounts of dry matter than the cool environment. The primary reason for this increase might be due to the increased photosynthetic capability of the plants. The warmer temperature alone will increase the CO_2-fixation rate of plants with the C_4-dicarboxylic acid pathway (22).

A few researchers have suggested that increasing temperature increases the available soil Zn (3,23). Since this soil is deficient in Zn, the temperature effect on yield might have been due to increased available Zn. However, this argument is not supported by the fact that three of the four soil tests detected no change in soil Zn between the two growing temperatures, and that the concentration of Zn in the plant was not affected by the different environments. Furthermore, the applied Zn fertilizer, which definitely increased available Zn, had no effect on yield. Total Zn uptake did increase in the warmer temperature regime, but this might be explained by increased root growth and exploration of the soil for Zn, rather than more available soil Zn.

The number of pots having deficient plants was 30 for the cool environment as compared to 22 for the warm environment. Again the Zn concentration of the plants in both of these environments was equal, yet there was a decrease in visually deficient plants. This would suggest that the Zn metabolism of the plant is responsible for this

temperature effect rather than the supply or availability of Zn from the soil.

One difference between the two environments was the effect on P concentration in the plant, which was lowered by the warmer temperature. This could be accounted for by a "dilution" effect due to increased growth. This seems even more likely considering the fact that total P uptake increased with the temperature. However, root growth should have increased accordingly and taken up a proportionate amount of P in the warm environment. If the availability of the soil P had not changed, then it seems that the plant concentration would not have changed. The soil test values for available P did indeed decrease when plants were grown under the warmer regime. Therefore it seems that the availability of soil P was higher in the cool environment.

Boawn and Legget (6) and Watanabe, Lindsay, and Olsen (60) have demonstrated that P/Zn ratios can be used to predict deficiency symptoms. This decrease of P in the plant would cause a more favorable P/Zn ratio in the low Zn plants and could account for the decrease in the number of deficient plants.

Cultivars

The three cultivars proved to be a good example of the importance of considering genetics when conducting soil fertility experiments. Pioneer 3369-A gave a higher yield than the other two cultivars, and had the most Zn deficient pots, 23 of 30. DeKalb XL-44 showed the fewest visual deficiency symptoms with only 8 of the 30 pots displaying the symptoms, while Funks G-795W-1 had 21. Apparently the DeKalb cultivar has a lower requirement for Zn than the other two. Phosphorus

concentration in the tissue was approximately equal for all cultivars. As can be seen, (Table III, page 14, Table VIII, page 17), the measurable nutrient concentrations of these cultivars were similar yet they had wide variations in showing deficiencies. This conclusion again indicates plant metabolism to be very important in Zn nutrition, particularly on soils with low and borderline Zn levels. The increased yield of Pioneer 3369-A over the other two varieties is probably due to seedling vigor. Even though this variety appears to be less tolerant of low levels of Zn than the others, the 3-week growing period was not sufficient time for the chlorotic symptoms to affect the growing ability of the young plants. Also, the adverse effect of this condition will be less because the plants are confined to small pots in a low-light intensity growth chamber.

Zinc Rates

None of the five rates of fertilizer Zn applied to the soil had any affect on P concentration of the tissue, the available soil P, or the yield of the seedlings. Thus, the Zn did not have an antagonistic effect on P metabolism as reported by some (5,50), but does support the work of other researchers (4,45). It would be expected that fertilizer Zn would increase yield of corn growing on Zn deficient soils. The reason for no yield response in this experiment is similar to that just discussed concerning the cultivar differences. The growing period was relatively short and conditions are far from natural.

The number of pots with deficient plants had a tendency to decrease as the rate of applied Zn increased (Table VIII, page 17) dropping from 16 at the zero rate to 6 at the 24 kg/ha rate. The trend

was for P concentration in the tissue to decrease as Zn rates increased. As expected, Zn concentrations increased as Zn rates increased. This increase in Zn along with a decrease in P resulted in a better balance of P and Zn in the plant, which accounts for fewer pots containing Zn deficient plants.

One unexpected observation was made concerning the rates of fertilizer Zn. Despite the trend for the number of deficient pots to decrease as rates increased, there was no correlation between plant Zn and deficiency symptoms. The correlation coefficient for this relationship was 0.097, which is not significant. When considering each cultivar individually the following coefficients were determined: DeKalb LX-44, 0.38 (significant); Pioneer 3369-A, 0.26 (non-significant); Funks G-795W-1, .003 (non-significant). Although these coefficients are all quite low, there is a wide variation among them which illustrates the importance of genetic control. It would seem that there should be a greater relationship between concentration of Zn in the plant and the development of deficiency symptoms.

One possible explanation arises from the fact that Zn has low mobility within the plant. In this experiment the entire plant was harvested. The seedlings received adequate Zn from the seed in the early stages of growth. If the roots grew and could not find sufficient Zn, the young tissue developed chlorotic symptoms. With the short growing time, there may have been enough Zn in the older tissue to mask the low concentration in the young tissue. When the entire plant was harvested, ground, and mixed, the overall effect was apparently normal levels of plant Zn. Variations in growth, Zn content of the seed, and

other factors may have resulted in the lack of a relationship between the measured concentration of Zn in the plant and early deficiency signs. Supporting this explanation is the fact that in all cases except one, the soil tests for available Zn correlated better with deficiency symptoms than did plant Zn concentrations. This would indicate that the available Zn does affect deficiency symptoms. It is suggested that had the plants been allowed a longer growing time, the association between Zn concentration and deficiency symptoms would increase.

Interactions

The analysis of variance shows that there were no significant interactions at the 5% level of probability on any of the variables. This indicates that each of the environments affected all three cultivars, and all levels of Zn fertilizer in the same manner. Likewise, each cultivar responded to the five Zn rates in a similar fashion.

Soil Tests

All four soil tests correlated well with concentrations of Zn in the tissue. The correlation coefficients were so similar (Table VI, page 16) that it would be misleading to rank the tests. Correlation coefficients were also determined between the tests and visual deficiency symptoms (Table VII, page 16). These coefficients were again similar among the soil tests but much lower than those for plant Zn. It is reasonable to conclude that the four soil tests were equally effective in relating to the Zn nutrition of the seedlings.

As noted in Tables VI and VII, the data were divided into five subsets, i.e., each of the two environments and each of the three

cultivars. The cool environment (21 C day and 12 C night) demonstrated a greater correlation with Zn concentrations and deficiency symptoms than did the warm environment. Because Zn deficiencies are more prominent in cool seasons, it is more important for the cool environment to correlate well than for the warm environment. This indicates that the soil tests are most efficient when most needed.

The other subsets of the data, those for each cultivar, showed tremendously different correlations between Zn concentration of the plants and soil tests. The Tennessee method, for example, had a coefficient for DeKalb XL-44 of 0.94, for Pioneer 3379-A, 0.76, and Funks G-795W-1, 0.47. Despite these wide variations, all are different from zero. Correlation of deficiency symptoms and the Tennessee soil test for the cultivars were 0.41, 0.18, and 0.33, respectively. Only the coefficient for DeKalb XL-44 is significant. If three separate experiments had been conducted with each using one of these varieties, the results would have been very different, and by themselves misleading. Once again the importance of genetic control in nutrition is demonstrated.

The extracting solution of the Tennessee state laboratory had not previously been used as a Zn soil test. However, it has been just as effective as three established Zn soil tests on the one soil used in this experiment. Further studies on numerous Tennessee soils could provide needed information concerning the effectiveness of this test. If results similar to these were obtained, the laboratory could conveniently determine Zn on their routine extractions, without having to incorporate another system and extracting solution for Zn tests.

CHAPTER VI

SUMMARY

Three corn cultivars (Zea mays L.) were grown under two environmental conditions for 21 days in a growth chamber. They were grown in three kg of soil in number 10 cans lined with plastic bags. The soil used was a Zn deficient Bradyville silt loam which had been treated with five rates of Zn fertilizer. Laboratory measurements were made of plant Zn and P concentrations by dry ashing procedures, of available soil P by the Tennessee State Soil Testing Laboratory extracting solution, and available soil Zn by four different extracting solutions. These were 0.1N HCl, a double acid mixture of 0.05N HCl and 0.025N H_2SO_4, 0.05M EDTA in 1M NH_4CO_3, and 0.05N H_2SO_4 in 1% NH_4SO_4 (Tennessee Soil Testing extractant, same as used for soil P).

There were no differences in dry weight yield due to the Zn rates. This was probably due to the short, unnatural growing time and conditions. Yield differences did occur between environments and among cultivars. These differences may be due to increased photosynthetic rates at the warmer temperature and the differences in seedling vigor.

Phosphorus concentrations in the plants decreased in the warmer environment. As supported by the soil test values, this was thought to be due to reduced availability of P in the warmer soils. Other treatments had no significant effect on P concentration or available soil P.

Zinc concentrations in the plants increased as applied Zn fertilizer increased. These concentrations did not vary among the cultivars or between environments.

The number of pots with Zn deficient plants in the warm environment was fewer than in the cool environment. A better P/Zn balance was determined to exist in the plants grown in the warm condition. Deficiencies generally decreased as Zn rates increased. This was probably due to increased Zn in the plants, and also a more balanced P/Zn ratio. There were wide variations in the number of deficiencies among the cultivars. This demonstrates the influence of plant genetics on Zn requirements and metabolism.

Correlation coefficients were determined between plant Zn and each of the four soil test values, and between deficiency symptoms and the soil test values. These coefficients were reasonably high for plant Zn correlations, but rather low for the deficiency symptoms correlations. Correlations were better when made with only cool environment data than with warm environment. These correlations indicate that the tests are more efficient when Zn shortages are likely to occur. Also, wide variations occurred when considering each of the cultivars separately, and again demonstrates the importance of genetic control.

All four soil tests were equally effective in detecting applied Zn, and the above correlation coefficients were approximately the same for each of the soil tests. The Tennessee extractant, although previously not used for soil Zn determinations, was as effective on this one soil as were the other three established extracting solutions.

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