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RESPONSE OF CORN GROWN ON HAITIAN HIGH LIME SOILS TO ZINC FERTILIZATION

RESPONSE OF CORN GROWN ON HAITIAN HIGH LIME SOILS TO ZINC FERTILIZATION

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By

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INTRODUCTION

Haiti occupies the western third of the island of Hispaniola. This island is second in size of the Caribbean islands with a population of about 12 million people and an area of 78,250 km^2. Two thirds of the island is composed of hills with steep slopes. Soil erosion is a serious problem. The island is divided into two republics: the Haitian Republic with 28,250 km^2 and six million people, and the Dominican Republic with 50,000 km^2 and 6.5 million people. Haiti is located between 17 and 20 degrees latitude north and between 72 and 74 degrees longititude west.

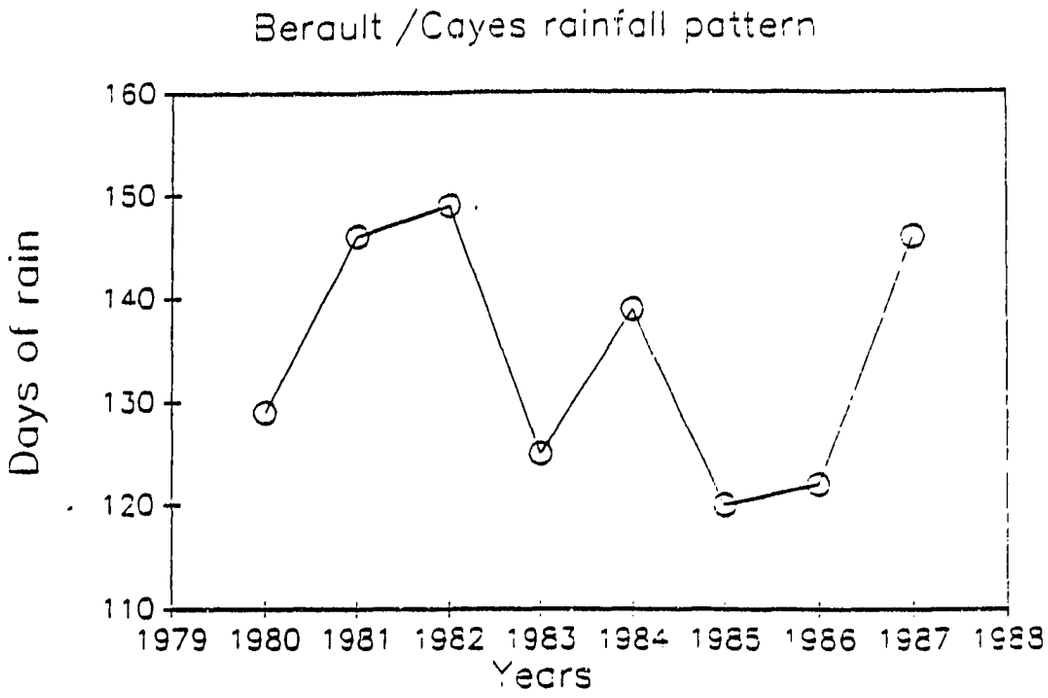
The Haitian Republic is one of the poorest countries of the Western Hemisphere with a gross national product per person of $320.00 U.S per year, and a child mortality rate of 17 per 1000. About 63 percent of the population is engaged in agriculture on a cash crop basis.

Average annual precipitation in southwestern Haiti is 1250 mm and is distributed mainly during May-June and September-October. The average daily temperature varies from 20 and 35°C in January and July, respectively. Most of the soils in the southern part of the country have developed from calcareous parent material, have a high calcium content and a pH greater than 7.2. Soil erosion is severe on the hillsides, aggravated by the continuous cutting of the young trees as a wood fuel supply for home cooking, oil-processing

factories, dry-cleaning establishments, charcoal manufacturing and for lumber.

The field experiments for this thesis were carried out at Berault in the Plain Les Cayes in southwestern Haiti. Berault is a rural area 18 km northwest of the city of Les Cayes at an average elevation not exceeding 60 m above sea level. Berault is irrigated mainly by the Torbeck River and by the main canal of the Acul Dubreuil irrigation system, although various secondary streams cross the plain. In general, the Berault area has the same rainfall pattern as Les Cayes, which is described above, although there are some important rains there in February. Rainfall data for the different locations of Berault over the last 20 years are not available; however, records have been kept by the Agricultural Development Support PROJECT (ADS-II) since 1984 in three locations: Macieu-Bourdet, Durocher and Gauvin-Lafosse. Figure 1 shows the precipitation data for the whole rural section of Berault from 1980 to 1987. The peak recorded in 1986 is due to a heavy three-day flood that happened in May of the same year.

According to Douglas C. Brown (1978), Berault soils are expected to be fertile. These are young soils, Entisols and Inceptisoils on a broad scale, relatively deep (60-70 cm), and some Mollisols with black colored surface. Ninety six samples were collected from both the flat bottomland of Berault and the upland soils of Maniche in Les Cayes area of



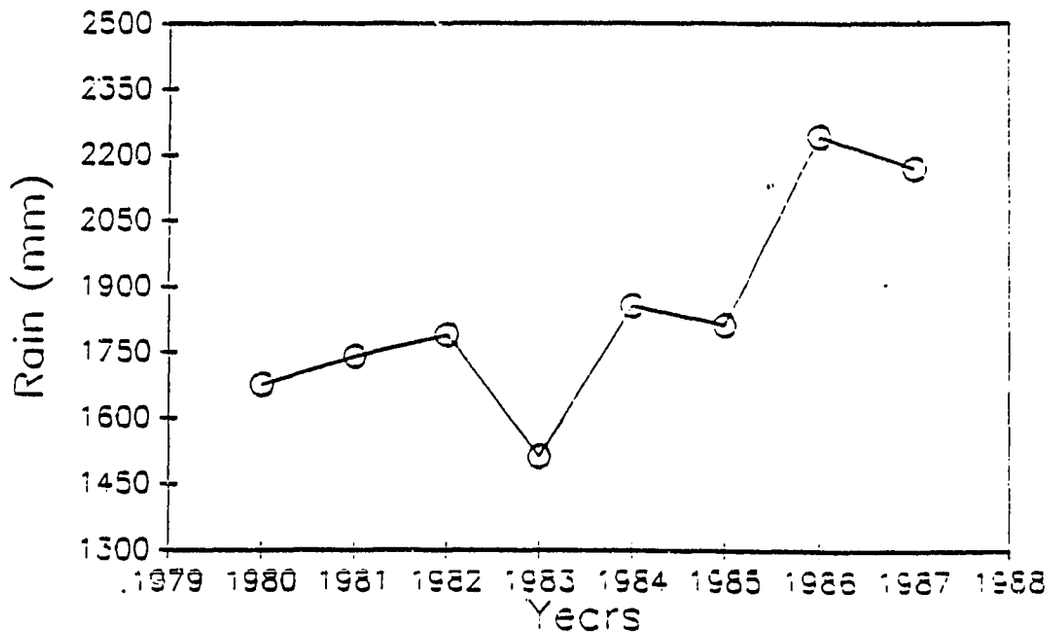


Fig. 1. Rainfall pattern of Berault in Les Cayes, Haiti, 1979-1987.

southwestern Haiti. Analyses of the 76 samples from the bottomland of Berault (Table 1) show an average pH above 7.5, an organic matter content (3.5%) and an average Ca content of 10741 kg/ha. The phosphorus (8.84 kg/ha) and the zinc (3.86 kg/ha) levels were, however, relatively low in those soils. The upland soils of Maniche (about 300 m above sea level) indicated an average pH of 7.3 with a maximum of 8.1 and a minimum of 7.2. The average organic matter content (3.83%), calcium (13820 kg/ha), phosphorus (13.90 kg/ha), potassium (372 kg/ha), sodium (127 kg/ha) and magnesium (661 kg/ha) was higher than those in the flat alluvium soils of Berault. Only the zinc (3.23 kg/ha) and the manganese (43 kg/ha) levels at Maniche were lower than those at Berault. The results from soil test analyses of soil samples from each of these 96 fields are given in Appendix Table 1.

The soils at Berault are low in phosphorus and zinc, and plants grown on them generally exhibit some nitrogen deficiency symptoms. Field plot data obtained at Berault by the CIMMYT-SERA PROJECT (Magloire et al. 1982), showed that nitrogen was one of the most limiting factors for corn (Zea mays L.) production in the Plain Les Cayes. In fact, non-fertilized corn grown at Berault usually exhibits typical nitrogen deficiency symptoms as stunted plants and chlorosis of the lower leaves. Data from corn grown on experimental plots conducted by the CIMMYT-SERA PROJECT

Table 1. Some soil test parameters from 96 farmer field soils at Berault and Maniche in the Les Cayes/Haiti area.

	pH	O.M.	P[1]	K[2]	Ca[2]	Mg[2]	Na[2]	Mn[3]	Zn[3]
		%	----- kg ha^{-1}						
				Berault (76 fields)					
Max	8.2	4.0	23.5	661	20832	1411	246	183	15
Min	6.2	1.8	2.2	101	2576	168	22	12	1.3
Mean	7.5	3.5	8.8	223	10741	490	124	44	3.9
SE[4]	0.06	0.06	0.6	11.2	315.5	26.5	4.8	3.5	0.3
				Maniche (20 fields)					
Max	8.1	4.0	28.0	907	17808	896	168	74	7.0
Min	7.2	2.4	6.7	235	9968	336	56	17	0.7
Mean	7.3	3.8	13.9	372	13821	661	127	43	3.2
SE[4]	0.05	0.09	1.2	32	478	35	7.3	3	0.3

1/ Available (Bray #1) P extraction.

2/ Extracted by neutral, normal NH_4OAc.

3/ Extracted by diethylenetriamine-pentaacetic acid (DTPA).

4/ Standard error of the mean.

indicated good agronomic response on both a local and an improved variety to 80 kg of nitrogen supplied in split applications, and an economic response to 40 kg of nitrogen per hectare (Magloire et al. 1982). Statistically significant yield increases at the 5% level of probability were also obtained using 80 kg of nitrogen applied as urea in split applications with the local Chicken-Corn variety and the improved La Maquina cultivar from Guatemala. These data were obtained from the Pre-vulgarisation plots established by ADS-II PROJECT at Berault (Agricultural Development Support Project, ADS-II. 1984).

LITERATURE REVIEW

Zinc soil fertility

The zinc content of the world's agricultural soils varies between 10 and 300 parts per million (Sillanpaa, 1979). Soil zinc is often found in such mineral forms as sphalerite (ZnS), smithsonite ($ZnCO_3$) and hemimorphite ($Zn_4Si_2O_7(OH)_2.H_2O$]. The zinc sources usually involved in plant nutrition are generally concentrated in the soil surface (Follet et al. 1981). Zinc is adsorbed on the surface of clays, on oxide minerals, and by organic matter. Tisdale et al. (1985) indicated that zinc can be adsorbed on clay minerals such as illite, montmorillonite, and bentonite. Particular emphasis is put on the adsorption by the latter because it can adsorb the micronutrient beyond its cation exchange capacity in neutral and alkaline soils, which indicates how the efficiency of soils and fertilizers in providing plants with zinc can be markedly impaired. One mechanism of this zinc fixation is the substitution of zinc for magnesium in some mineral structures since both elements have the same ionic radius of 0.83A^{o} (Mengel and Kirby, 1979). There are, however, some zinc ions which are reversibly bound to silicate clays and are potentially available to plants.

It has been observed that this plant availability of

the water soluble Zn^{++} ion generally decreases as the soil pH increases; the decrease may be 100 fold for each unit increase in the soil pH. Lindsay (1972) reported that he has studied a soil containing 6.5 ppm of soluble zinc and a pH of 5.0. When the soil was limed to a pH of 8.0, the soil zinc concentration declined to 7 parts per trillion. Many studies have also mentioned zinc deficiency problems on calcareous soils having pH values above 7.3. Research with corn indicates that the optimum soil pH range for this crop is approximately 5.6 to 7.3 and that corn yields decrease as the soil pH increases above 7.3. One influence on this yield reduction is the unavailability of the zinc to the plants, a fact which is closely related to the conditions of high soil pH. In fact, above a pH value of approximately 7.3, the solubility of the soil zinc is reduced considerably, concomitant with the formation of zinc hydroxides [$Zn(OH)_2$], and zinc carbonates ($ZnCO_3$) and bicarbonates [$Zn(HCO_3)_2$] which are less soluble in the soil solution and less available to the corn plants than the common zinc fertilizer sources.

Plant metabolism of zinc

Among field crops, corn is considered one of the most sensitive species to zinc deficiency (Safaya and Gupta, 1979). Zinc plays an important role in several physiological processes of corn plants: in the biosynthesis of the corn plant auxin, indole-3-acetic acid; in the activation of several enzymes; and in protein synthesis. In fact, it is an essential component of various dehydrogenases (alcohol pyridine nucleotide, glucose-6-phosphate and trio phosphate), several proteinases and peptidases (Shkolnik, 1984). It promotes cytochrome-c synthesis and stabilizes ribosomal fractions. It acts in auxin metabolism (tryptophane synthetase and tryptamine metabolism). Zinc is also found in plant cells as metalloenzymes which form stable covalent bonds with nitrogen and sulfur ligands. The majority of Zn^{2+} reaches the plant root system by diffusion from the soil solution as the Zn++ cation although mass flow accounts for some of the Zn^{2+} reaching the roots. Generally, the mechanism of absorption is considered as active rather than passive, although some scientists have largely emphasized the latter method. It can also be directly absorbed through the leaves following foliar application, through the seeds from seed coated zinc, and through the stem of plants by direct injection (fruit trees). The uptake and metabolic physiology of zinc is

affected by zinc interactions with other nutrients such as phosphorus, iron, manganese, nitrogen and sulfur; by the soils' characteristics; and by the availability of the element to specific plant species.

Zinc Deficiency

The physiology of zinc nutrition in plants depends, to a great extent, upon species (Follett et al. 1981). The same researchers reported that within some species, significant differences exist among varieties in terms of Zn deficiency susceptibility. Lucas and Knezek (1972) indicated that some crops like corn (*Zea mays* L.), sorghum (*Sorghum bicolor* L. Moench), beans (*Phaseolus vulgaris* L.), and some fruit trees such as apples (*Malus domestica* L.), peaches (*Prunus persica* L.), and oranges (*Citrus aurantifolia* L.) are sensitive and highly responsive to zinc fertilization. Others like rice (*Oryza sativa* L.), soybean (*Glycine max* L.), potato (*Solanum tuberosum* L.), barley (*Hordeum vulgaris* L.), and sugar beet (*Beta vulgaris* L.) moderately respond to the micronutrient, while wheat (*Triticum aestivum* L.), grapes (*Vitis viniflora* L.), lettuce (*Lactuca sativa* L.), and carrots (*Daucus carota* L.) usually show low response to zinc fertilization. As a general rule, zinc deficiency reduces plant growth and results in stunting, internodal shortening, interveinal chlorosis on leaves, and very often yield reductions.

Specifically, zinc deficiency on corn is characterized by leaf discoloration and abnormally high nitrogen and phosphorus content. In this regard, Bayens (1967) stated that zinc-deficient plants accumulate manganese, iron, and nitrates in their leaves. It appears that zinc plays a role in nitrate reduction.

Zinc deficiency may result both in the reduction of vegetative shoot growth and root tip elongation in corn plants. Auxin production is reduced and the growth of auxiliary buds is inhibited. Even grain formation may be affected negatively.

Plants sometimes may also suffer from insufficient zinc without showing the deficiency symptoms immediately, i.e., "hidden hunger", but with marked yield reductions. The plants may respond to a fertilizer application, but if the hidden hunger is not properly corrected the zinc deficiency may become more and more severe as the growing season progresses.

Zinc is the most heavily used trace element in U.S. agriculture, and most of it is used on corn in the Corn Belt. Response to zinc fertilizers has also been obtained with rice (Oryza sativa L.), and grain sorghum (Sorghum bicolor L. Moench) in many regions (Follet et al. 1981). Zinc deficiency is being encountered with increasing frequency in some parts of the U.S.A. as a result of increased use of limestone, large applications of pure high

analysis fertilizers, and the high yields obtained from productive hybrids with improved cultural practices (Arnon, 1975). According to Thompson (1962), zinc deficiency has been mapped along the Pacific Coast of the U.S.A., throughout the Cotton Belt and in Wisconsin. He suggested that non-alkaline soils may be directly fertilized with zinc sulfate while sprays are more effective on alkaline soils and on very sandy soils. In an extensive investigation of zinc deficiencies in the Adour basin in France, Dartigues and Lubet (1967), have established that there is a high probability of maize plants exhibiting zinc deficiency when grown on soil with pH higher than 6.4 and a zinc content less than 40 ppm (total reserve) or 3.3 ppm of extractable zinc. Zinc deficient soils are often associated with loss of organic matter by erosion, or following land grading for irrigation or soil conservation purposes. For example, zinc deficiencies in maize in certain areas of North Dakota have been reported when the crop was grown on land levelled for surface irrigation.

Zinc Sources, Methods, and Rates.

Brown and Krantz (1966) found that zinc uptake by corn from $ZnSO_4$ and from zinc ethylenediamine tetraacetate (ZnEDTA) was comparable when the zinc sources were mixed

into the soil, but when banded under the seeds the Zn from the EDTA source was utilized more readily than from the SO_4 source. Mortvedt (1979) reported from a greenhouse experiment with corn that ZnEDTA was superior to $ZnSO_4$ when mixed into a soil having a pH of 7.5. Hergert et al. (1984) indicated that ZnEDTA was more efficient than $ZnSO_4$, $Zn(NO_3)_2$, or ZnO + $Zn(NO_3)_2$ when these fertilizers were banded near corn grown on a sandy soil. Prasad and Sinha (1981) concluded from a study on zinc uptake by corn in an alkaline soil that zinc chelate was superior to $ZnSO_4$ in enhancing the uptake of both soil zinc and applied zinc. Boawn (1973), comparing zinc sulfate and ZnEDTA as zinc fertilizer sources, found that zinc applied as a chelate (ZnEDTA) was more effective in terms of zinc accumulation by plants than a similar quantity of zinc applied as an inorganic salt. The plant availability of Zn from ZnEDTA was found to be as twice as high as that of Zn from $ZnSO_4$. In an earlier study, Boawn et al. (1957) reported on the greater efficiency of ZnEDTA to supply the micronutrient than $ZnSO_4$. They explained that the ZnEDTA complex remains completely dissolved in the soil solution and can be absorbed and translocated into the tops of plants. The soluble $ZnSO_4$ salt was only partially available for root absorption because the zinc cations were subject to being bound to the clay particles. The ZnEDTA, they concluded, has the advantage of moving with the soil solution to all

parts of the soil mass. Sese (1976) obtained a greater efficiency from ZnEDTA than from inorganic zinc with corn grown on alkaline soil. However, Bansal et al. (1978), evaluating various zinc sources for corn and wheat, noticed in a greenhouse experiment that $ZnSO_4$ at 2.5 ppm was the best source of zinc when compared with ZnO. Dev and Shukla (1980) indicated that $ZnSO_4$ applied with N, as urea, gave a significant increase in shoot dry matter production of corn grown on a zinc deficient loamy sand soil having a pH of 8.4. They suggested that N application resulted in greater growth of the plant, and consequently in greater utilization of both soil and fertilizer zinc. Brown et al. (1962), in a study on plant uptake and the fate of soil applied zinc, concluded that $ZnSO_4$ may have a residual effect lasting for several years and does not move downward as a result of leaching. They found a significant increase in zinc concentration of the leaf samples of the plant material due to the $ZnSO_4$ application.

Generally depending upon alkalinity of the soil and the form of zinc applied, recommended rates have ranged from 1.12 to 22.40 kg /ha for inorganic salts, and 0.56 to 4.48 kg /ha for organic sources, respectively. Bayens (1967) stated that 1.23 kg/ha appears to be the critical level for available zinc in the soil, and with that concentration zinc application increased corn yield up to 200%. Janiron et al. (1968) used 1.12 and 2.24 kg/ha of zinc and did not find an

advantage for ZnEDTA over $ZnSO_4$ with corn when both sources were applied as a band treatment at seeding. Bayens (1967) also believed that a 5 to 6 kg per hectare zinc application would result in optimum corn yields for four years. Pierre et al. (1966) suggested 11.2 to 22.4 kg/ha of zinc from inorganic sources, and 2.24 to 4.48 kg/ha of organic materials to control zinc deficiency on crops. Wallace and Romney (1970) reported a greater efficiency from ZnEDTA than from $ZnSO_4$ at the rates of 12 and 24 kg/ha of zinc on sweet corn. Safaya and Gupta (1979) recommended 20 to 40 kg/ha of $ZnSO_4$ to correct zinc deficiency problems for corn grown on an alkaline soil. Tisdale et al. (1985) stated that 3.36 to 22.40 kg/ha of zinc are recommended when inorganic zinc salts are banded or broadcast for corn, depending upon the soil pH. The higher the soil pH, the higher the rate of zinc needed; Tisdale et al. (1985) suggested 0.56 to 2.24 kg/ha of Zn when the source was a chelate or an organic complex.

Seed coatings have been used for several years to improve the survival of Rhizobia inoculents under favorable conditions; to control birds, rodents, insects, fungus and bacterial diseases (Waldon, 1975); and to reduce the amount of limestone needed for legumes grown in Australian acid soils with a pH 5.0-5.5 (Anderson, 1956). The University of New England in Armidale, N.S.W. (Scott et al. 1986a) reported that preliminary work with nutrient coatings on

perennial ryegrass seed showed existing commercial coatings to be effective in supplying sulfur but relatively ineffective in supplying adequate levels of P and N. Fertilizer seed coatings can have a variable effect, dependent on the element, its rates, and the plant species involved. For example, seed coatings containing soluble forms of phosphorus were found to be relatively safe to germinating phalaris seed but caused a severe reduction in the germination of lucerne seed. When compared to drilled or broadcast applications of phosphorus, seed coatings were more effective per unit of P in promoting early seedling growth (Scott et al. 1986a). Fungicides and herbicides have been incorporated together in coating some pasture seeds in field trials (Scott et al. 1986a). Work has shown that 5 kg P/ha applied to wheat seed can produce early root growth equivalent to that produced with 40 kg P/ha applied as a drilled application (Jessop et al. 1986). Research starting in 1986 (Ascher et al. 1986; Scott et al. 1986b) has been carried out recently to evaluate:

a) the interaction between herbicide seed coatings and sowing method.

b) the combinations of herbicide and nutrient coatings.

c) the nutrient seed coatings containing either, or both, N and P applied to a wide range of legumes and grass species.

d) the efficiency of fertilizer seed coatings compared

with conventional fertilizer applications to study fertilizer injury mechanisms and to develop techniques for seed protection.

A study carried out on methods of correcting zinc deficiency in rice showed higher yield performance from zinc-coated rice seeds as compared with ZnO mixed with the soil before planting (Centro Internacional de Agricultura Tropical, CIAT. 1972). Seed coating methods of supplying zinc have been tested recently, but little research has been conducted with corn in this regard. Investigations on such parameters as seed size, coating rate and coating methods still deserve great attention. Singh et al. (1983) mentioned that grain yield and zinc uptake decreased when $ZnSO_4$, ZnO, and Zn phosphate were used as coatings for seeds of corn and rice. Conversely, Edwards and Kramprath (1974) stressed that the zinc content of the seeds is the main zinc source for young corn seedlings growing under low light intensity, and they noted that there is only a slight accumulation of zinc in the roots from the soil solution at 14 to 28°C. Shukla and Prasad (1974) found that zinc coated on seeds helped seed germination. Sese (1976) obtained no significant plant differences in the field when corn seeds were coated with zinc at rates of 0.25 and 0.50 mg/kg of soil as ZnO, or from zinc lignosulfonate in a greenhouse experiment. However, he observed a better rate of survival from the plants that emerged from zinc coated seeds. The

same observations were made in a field experiment. Beeler (1974) reported that seed coating may result in some advantages such as:

a) improvement of germination under adverse conditions.

b) supplying immediately available quantities of trace elements for healthy seedling growth.

c) protection of seeds and seedlings against attack by diseases and pests.

On corn, foliar applications of zinc have been investigated to a greater extent than zinc seed coatings. According to Viets et al. (1954) alfalfa and potatoes respond to foliage applications of $ZnSO_4$ without initially showing symptoms that are specific to Zn deficiency. Pierre et al. (1966) estimated that a 1% $ZnSO_4$ solution in water at the rate of 190 liters per hectare would give good results on corn. Tisdale et al. (1985) indicated that up to 5.08 kg/ha of $ZnSO_4$ in 190 liters of water can be applied directly to the foliage of growing crops. Viets et al. (1953) reported that applications of $ZnSO_4$ sprayed to corn in central Washington stimulated growth but had little effect on yields. Murphy and Walsh (1972) mentioned that Duncan observed good control of zinc deficiency symptoms on corn by spraying with a 1.5% solution of $ZnSO_4$, starting five weeks after emergence. Lingle and Holmberg (1957), after evaluating foliar applications of zinc on sweet corn, concluded that two spray applications of 9 kg per hectare of

a 0.5% $ZnSO_4$ solution gave better results than did an application of 1.2 kg $ZnSO_4$ per hectare soil applied. These results were ascribed to the greater efficiency of the corn plant to use the zinc fertilizer applied directly to the leaves which resulted in its rapid translocation to all plant parts. When the zinc fertilizer was soil-applied, a relative slow translocation of the trace element from roots to tops of plants was obtained because of the immobility of the micronutrient in the soil under the calcareous soil conditions of the experiment.

Zinc Interactions with other Nutrients.

Zinc-phosphorus interactions.

Researchers have reported that the application of phosphorus may adversely affect the uptake of zinc by plants. Bingham and Garber (1960) stated that this effect is observed mainly on soils with high levels of native phosphorus, on calcareous soils and on exposed subsoils having free limestone. They also suggested that low soil temperature and poor soil aeration reduce zinc absorption by plants and that the application of phosphorus fertilizers under those circumstances will reduce maize yields only if the available soil zinc is at a very low level. Zinc applied at higher

rates can correct the depressant effect of phosphorus. Burleson et al. (1961) established that the phosphorus-zinc interactions take place because of the $Zn_3(PO_4)_2 \cdot 4H_2O$ precipitation in soils which depress the available zinc concentration to a marginal level. Langin et al. (1962) found that the phosphorus-zinc relations are aggravated by high clay and low organic matter content of the subsoil, by soil compaction, by excessive soil moisture and by low levels of available Zn++ in high pH soils which are high in native phosphorus. They explained the problem in two ways:

a) Abnormally high concentrations of phosphorus in the plant immobilize the micronutrient within the plant.

b) The zinc within the soil system is immobilized by the excessive phosphorus in the soil water-solution.

Brown et al. (1970), evaluating the zinc-phosphorus interaction in corn, found that applications of P accentuated zinc deficiency symptoms on corn plants that did not receive any zinc fertilization. They also observed that applied zinc caused a reduction in phosphorus concentration in the corn plants due to a dilution effect, and tended to accentuate P deficiency symptoms. The deficiency symptoms, in any case, were readily corrected by applying the appropriate element. However, Shukla and Morris (1967) reported that phosphorus fertilization increased soil zinc availability. They also suggested that the possible adverse effect of phosphorus on zinc utilization by corn is largely

physiological at the plant level rather than a zinc phosphate precipitation phenomenon occuring at the soil solution level. Phosphorus will have a depressant effect on zinc uptake by plants when the micronutrient is immobilized within the plant by abnormally high concentrations of P in that plant.

Olsen (1977) finally revised the zinc-phosphorus interaction concept and concluded these four possible explanations:

a) Phosphorus-zinc interactions: The more effectively the phosphorus applied is utilized by the plant, the more severe is the zinc deficiency.

b) A slower rate of translocation of zinc from the roots to the tops: High concentrations of phosphorus in plants were found by Stukenholtz et al. (1966) to depress the translocation of zinc from the roots to the tops of the corn plants.

c) A dilution effect on zinc concentration in the tops of plants due to an increased growth as a response to phosphorus: When the rate of corn growth exceeds the rate of zinc uptake, the zinc concentration in the corn nodal and internodal tissues will be reduced, causing the plants to exhibit zinc deficiency symptoms.

d) A metabolic disorder within the plant cells due to an imbalance between phosphorus and zinc, or an excessive concentration of phosphorus interfering with the

physiological role of zinc in the cells.

However the depressing effect of phosphorus on zinc can be counteracted. Bingham and Garber (1960) reported that nitrogen applied with phosphorus promotes zinc uptake and improves phosphorus utilization. The nitrogen increased the growth of the corn plants with a subsequent increase in the need of phosphorus and zinc. They also stated that the application of potassium fertilizers will reduce the phosphorus-induced zinc deficicency symptoms by a depressant action of K on P and possibly by an increase in the manganese uptake which in turn is beneficial to zinc utilization.

Zinc-iron interactions.

Zinc-iron interactions were shown to be of importance for several crops such as sugar beets, corn, soybean, rice, and navy bean where addition of zinc had caused a reduction of iron concentration in plants (Sese 1976). Adriano et al. (1971), studying the P-Fe and the P-Zn relationships in corn seedlings, concluded that iron and zinc are mutually antagonistic and interact more markedly than the other nutrients. At high Fe levels zinc deficiency was accentuated, and conversely Fe deficiency was induced more readily by zinc than by manganese as had been reported by Hewitt (1953). Watanabe et al. (1965) reported that the

addition of zinc at a medium level to corn grown in a calcareous solution culture increased iron deficiency symptoms and reduced dry matter production: the corn yield was lowered twofold as the plant zinc concentration was increased from 0.75 to 2.25 um when the Fe treatment was 40 um as FeEDDHA. They ascribed the depressing effect on corn productivity to a reduction of the Fe/Zn ratio but not to the Fe concentration in the plant. It was also noticed that the antagonistic effect of Fe on Zn resulted in reduced dry matter production when the Fe/Zn ratio in the tissues had dropped below 1:5. However, they concluded that additions of Zn had corrected the adverse effect of Zn on the corn dry matter production.

Zinc-potassium interactions.

Potassium fertilizers can reduce the P-induced zinc deficiency. Some scientists reported that the higher the percent K saturation of a soil the lower the effect of P fertilizers in reducing Zn uptake (Stuckenholtz et al. 1966; Ward et al. 1963). However field experiments conducted with corn grown on a dark-brown clay by Thompson (1962) suggested that zinc deficiency can be aggravated by either a deficiency or an excess of potassium.

JUSTIFICATIONS

Pierre et al.(1966) have indicated that zinc deficiency is probably the most extensive of any of the secondary or micronutrient deficiencies for corn production in the U.S. Corn Belt. Research conducted since their report has shown that response of corn grown on high lime soils having high pH values is influenced by the specific soil pH, the zinc fertilizer sources used, and by the methods and rates of zinc fertilizer applications.

In southwestern Haiti, corn is the most widely grown crop for human consumption; it is grown both in a monoculture, and in association with other crops (Brown, 1978). Approximately 50% of the cultivated area in both the hillsides and the flat bottomlands are planted to this crop. The soils which, for the most part, have been developed from calcareous parent material have suffered severe surface erosion losses resulting in the relatively low yields of 1.5 to 2.0 m tons of grain per hectare (Agricultural Development Support Project, ADS-II. 1984). This situation would indicate that corn grown on these calcareous soils might well respond to zinc fertilization. Such a response could provide a subsequent increase in food production for the 63% of the Haitian population which rely mainly on agriculture for their livelihood. Moreover, as a staple food, corn is largely consumed in the daily Haitian diet. It is cooked as

are rice and sorghum and it is used to prepare a non-alcoholic beverage locally called akassan. Corn is an active ingredient of swine feed and it is also used to prepare a corn oil used as a cooking oil in the Haitian kitchen.

Given the large acreage devoted to corn in the Berault area, a significant yield increase in corn production may bring about an increase in the farmers' profit and subsequently an improvement in their livelihood. Besides, from the nutritional standpoint, given the enzymatic action of zinc in tryptophane synthesis, it might be expected that some increase in the tryptophane content of zinc-treated corn plants would be obtained and subsequently an increase in the protein content of those plants resulting in a higher nutritional level for a population which is markedly protein-deficient in its diet.

Other agronomic crops such as beans (*Phaseolus vulgaris* L.) and sorghum (*Sorghum bicolor* L. Moench) which rank second and third, respectively, in importance in the food-growing pattern of Haiti, are also grown on the same soils and have been shown to be markedly responsive to zinc fertilization. Thus, zinc applied to corn could also help other crops when they are later grown on these same soils, because of the residual effects of the microelement when applied at an optimum rate. In addition, the results of this investigation may be useful in Arkansas agriculture

since an increasing acreage of corn is being grown on high pH soils in this state.

OBJECTIVES

In this study a greenhouse pot experiment at the University of Arkansas, Fayetteville, and field experiments in Haiti were conducted to investigate methods, sources, and rates of Zn application with the objectives of:

a) studying the response of corn growth to three methods of application: banding, coating, and foliar spray when grown on a calcareous soil with a high pH value (greenhouse trial).

b) to compare four zinc fertilizer sources: zinc chelate (ZnEDTA), zinc sulfate ($ZnSO_4$), and two proprietary zinc fertilizers in their ability to increase growth and dry matter production of corn plants.

c) to compare two rates of application of the above zinc fertilizer sources.

d) to test, under field conditions in Haiti, the more superior treatments obtained from the greenhouse experiment.

MATERIALS AND METHODS

Greenhouse Experiment

A greenhouse experiment was established in March, 1987, at the University of Arkansas, using a bulk quantity of surface soil obtained from the A horizon of a Demopolis silty clay loam to a depth of 15 cm in June, 1986, from Hempstead county, Arkansas. This Arkansas Demopolis soil was more similar to an eroded Haitian calcareous soil than any other Arkansas soil. It was used because:

a) it was not possible to bring soil from Haiti to the U.S.A for a greenhouse experiment.

b) the Demopolis soil from the Hope area has almost the same characteristics (Table 2) as Berault soils (Table 1) in southwestern Haiti in regard to pH, $CaCO_3$, and zinc content.

The Demopolis is a member of the loamy-skeletal, carbonatic, thermic family of shallow Typic Udorthents. The Demopolis series consists of shallow, well drained, slowly permeable, gently to moderately sloping soils that formed on residuum from calcareous chalk. Slopes are three to twelve percent. The Demopolis series occurs on gullied hilltops and hillsides in the Blackland Prairie area according to the Soil Survey of Hempstead County, Arkansas (1979).

The soil was brought to the University of Arkansas and dried for several days. Samples of it were ground to pass a

Table 2. Soil test data of the Demopolis surface soil from Hempstead County, Arkansas. 1987

pH	O.M	P[1]	K[2]	Ca[2]	Mg[2]	Na[2]	Mn[3]	B[4]	Zn[3]
	%	kg ha^{-1}							
7.4	1.8	11.2	246.4	10976	156.7	190.4	5.6	0.9	2.9

1/ Available (Bray #1) P extraction, 0.03 NNH_4F in 0.025 N HCl.

2/ Extracted by neutral, normal NH_4OAc.

3/ Extracted by diethylenetriamine-pentaacetic acid (DTPA).

4/ Hot water extractable.

20-mesh screen and submitted to the Soil Testing and Research Laboratory of the University of Arkansas to be analyzed for pH, percent organic matter, Bray #1 available phosphorus, exchangeable potassium, calcium, sodium, and magnesium, hot water soluble boron, diethylenetriamine pentaacetic acid (DTPA) extractable zinc and manganese. These data are given in Table 2. A quantity of 3 kg air-dry weight of the soil was placed in 7-inch plastics pots for an experiment with corn.

Ninety six samples were collected in August 1986 from both the upland soils of Maniche and the flat bottomland soils of Berault, which represented the working area of the ADS-II Project in Les Cayes, southwestern Haiti (Table 1). They were analyzed for the same constituents analyzed for in the Demopolis soil. The greenhouse pot experiment was established with twenty treatments to study the response of corn to different sources, rates, and methods of zinc application. A randomized complete block design with four replications was used.

The treatments were:

Table 3. The twenty treatments of the greenhouse experiment.

Fertilizer sources	Methods of Zn application	Rates of Zn application mg g^{-1}	Amendment (Zn salt) mg /pot
1) none		none	none
Soil Treatments:	layered 2.5 cm below the soil surface		
2) $ZnSO_4$	layered 2.5 cm	5.0	37.77
3) $ZnSO_4$	layered 2.5 cm	10.0	75.44
4) Neutral zinc	layered 2.5 cm	5.0	26.15
5) Neutral zinc	layered 2.5 cm	10.0	52.30
Seed-coated Treatments:	coated onto the corn seeds		
6) ZnEDTA	seed-coated	5.0	226.70
7) ZnEDTA	seed-coated	10.0	453.40
8) NZN	seed-coated	5.0	272.20
9) NZN	seed-coated	10.0	544.40
Foliar Treatments in:			
10) none	water	none	none
11) none	0.15% Azone	none	none
12) $ZnSO_4$	water	0.069	0.53
13) $ZnSO_4$	0.15% Azone	0.069	0.53
14) ZnEDTA	water	0.069	3.17
15) ZnEDTA	0.15% Azone	0.069	3.17
16) NZN	water	0.069	3.80
17) NZN	0.15% Azone	0.069	3.80
18) Neutral zinc	water	0.069	0.36
19) Neutral zinc	0.15% Azone	0.069	0.36
20) none	0.30% Azone	none	none

Treatments 10 through 20 all contained 0.7% Tween-80 (Polyoxyethylene sorbitan mono-oleate) in the foliar spray. This is a surfactant used in order to increase the adherence of the Azone and the zinc salts to the corn plant leaves. It was mixed to the water or Azone solution.

Azone is a penetrating enhancing agent commonly used in the medical field on animal tissues (Nelson Research). The chemical and physical characteristics of Azone are described in Appendix Table 2. The NZN is the trade name of a liquid foliar fertilizer marketed by Allied Chemical Corporation containing 15% N and 5% Zn. Its chemical formula is 15-0-0-5Zn. Surfactants are not recommended to use with NZN since they may increase phytotoxicity. The Neutral Zinc "52" is a powdered fertilizer salt containing 52% Zn. It is marketed by Monterey Chemical Company of Fresno California. It is derived from zinc oxysulfate.

The Azone concentration in the foliar sprays on treatments 11, 13, 15, 17, and 19 was 0.15%. In treatment 20 the Azone concentration in the foliar spray was 0.30% thus giving two rates of Azone concentrations on the no-zinc treatments.

In treatments 2 through 9, the four zinc sources were used at two rates each: 5 and 10 ppm. The ZnEDTA and NZN were coated onto the corn seeds, while the $ZnSO_4$ and Neutral Zinc were applied directly to the soil. The seeds to be planted in each pot of treatments 6 through 9 were soaked in

dilute ZnEDTA or NZN solutions contained in closed plastics bags for 24 hours. The seeds absorbed all of the solution. The zinc concentrations of the solutions were such that, when all of it was absorbed, treatments 6, 7, 8, and 9 contained 226.70, 453.40, 272.20 and 544.40 mg per pot of ZnEDTA or NZN, respectively (Table 3).

Treatments 10 through 20 were foliar sprayed with 1.9 ml of a water, or Azone-water solutions. Treatments 12 through 19 contained 0.1 g L^{-1} of Zn in the form of $ZnSO_4$, ZnEDTA, NZN or Neutral Zinc, thus applying 0.19 mg of zinc per pot. However, from visual appearance, it is estimated that less than 20% of this foliar spray fluid was deposited on the corn plants. In contrast the 5 and 10 ppm rates of zinc applied to treatments 2 through 9 contained 13.6 and 27.2 mg of Zn, respectively, per pot.

Four corn seeds per pot were planted 2.5 cm deep, in all treatments, according to a pre-set pattern, in the pots containing 3 kg of air-dry soil. The zinc compounds used in treatments 2, 3, 4 and 5 were layed in the soil 2.5 cm deep. All treatments were planted the same day at the same depth, and in the same pattern with a corn cultivar frequently used for forage and silage: FFR 929 W, lot# 8546 from the Tennesse Farmer's Cooperative Corn Seed. It should be noted that the seeds of that variety had been treated with the fungicide, Captan (cis-N-((Trichloromethyl) thio)-4-cyclohexene-1, 2-dicarboximide) and the insecticide,

Heptaclor (1, 4, 5, 6, 7, 8, 8-Heptachloro-3a. 4. 7. 7a-tetrahydro-4, 7-methanoindene).

All treatments received a basal dressing of 50 ppm of P_2O_5 from triple superphosphate (0-45-0) fertilizer (equivalent to 0.306 g of fertilizer per pot) layered in the soil at a 10 cm depth. After seeding, all treatments were fertilized with a solution of KNO_3 and $Ca(NO_3)_2$ at the rate of 10 ml per pot so as to apply 40 ppm of N and 40 ppm of K.

The phosphorus was applied the day prior to planting. A solution of KNO_3 and $Ca(NO_3)_2$ was supplied 8 days following planting when the plants were about 10 cm high and when they had exhausted the nitrogen contained in the corn seeds. Distilled water (550 ml) was added to each pot at planting time and the pots were watered thereafter as needed.

Five days after planting, seedling emergence was recorded. Records for emergence were taken again on the 6th and 7th day. Twelve days after planting the seedlings were thinned to three plants per pot, discarding the thinnest ones. They were cut one cm from the soil surface of the pot, washed, dried in a force-draft oven at 65°C for three days and weighed for dry matter production. Four days later the seedlings of treatments 10 through 20 were foliar sprayed.

Two days following the foliar spray, some purple leaf coloration was observed on plants in several treatments and notes were recorded on these symptoms concerning the number

of plants exhibiting the purple coloration. Nine days after the foliar spray, the pots were thinned again, this time to two plants per pot. The thinned plants were cut again one cm from the soil surface of the pot, washed, dried in a force-draft oven at 65°C for three days and weighed for their dry matter production.

Twelve days following the observation of the leaf purple coloration, i.e. one month after planting, a second application of nitrogen, phosphorus and potassium was applied to all plots according to the experimental plan. A solution of 50.36 g KNO_3 and 35.0 g NH_4NO_3 dissolved in one liter of H_2O was used at the rate of 10 ml per pot so as to apply 80 ppm of nitrogen and 71 ppm of potassium. Likewise, all treatments received 10 ml of a solution of 21.63 g $Ca(H_2PO_4)_2.H_2O$ dissolved in one liter of H_2O so as to apply 50 ppm of phosphorus (P_2O_5). At this date some possible phosphorus deficiency symptoms were observed on some of the plants' leaves. Three days later, plant height measurements were taken and a visual evaluation of the phosphorus deficiency was made; the symptoms had almost disappeared in most seedlings in that the leaves had lost their previous purple coloration.

Forty days after planting the plants were harvested. They were cut one cm from the soil surface, washed immediately in a detergent solution and then rinsed twice in distilled water. They were dried in a force-draft oven at

65°C for three days and then weighed for their dry matter production. The dry matter weight of the three harvests were summed for each treatment, and the statistical analysis conducted using the GLM procedure of the Statistical Analysis System (SAS) program.

Given there was such a difference in the emergence rate per pot in the seed coated treatments as compared to that in the soil-applied and foliar treatments, it was understood that the competition for air, light, and nutrients was greater in pots with three to four seedlings than in those with only one seedling. Thus it was decided to analyze the seed coated treatments as one group; and the soil-applied and foliar Zn treatments as a second group, for the five parameters that were considered in the greenhouse experiment: emergence, leaf discoloration, phosphorus deficiency, plant height and dry matter production.

For the convenience of the analysis, the results and the ANOVA for seed coated treatments are presented first in each table, followed by a similar analysis for the soil-applied and foliar-applied Zn treatments.

Field Experiments

The relatively small size of the typical Haitian farmer's field (less than 0.5 ha), dictated that the size of these cooperative farmer field experiments be kept small. It was not possible to include all the treatments employed in the greenhouse experiment. Thus, given these circumstances, and since no statistical differences had been found between any pair of treatments from the greenhouse experiment, it was decided to limit this study to the rates of zinc using zinc sulfate as the fertilizer source on the Haitian field plots. The analyses of the field soils used are given in Table 4. The pH values varied from 6.5 to 8.1; the organic matter from 3.4 to 6.1%; phosphorus from 4.5 to 22.4 kg/ha, and the zinc from 3.4 to 11.4 kg/ha. The soil test data indicated that these soils should be good agronomic soils; their cation exchange capacity corresponds to that of a 2:1 type clay. Data from the Faculte d'Agronomie et de Medecine Veterinaire Soil laboratory at Damien, Port-au-Prince, place these soils in the clay textural class. They are dark in color, and not affected by severe erosion problems.

No corn growth response was obtained from Zn in the greenhouse experiment. The low (5 ppm) Zn rate used there is equivalent to 11.2 kg ha^{-1}. Thus, a similar (10 kg ha^{-1}) Zn rate was chosen as the high rate for the field plots.

Table 4. Some characteristics of the six field soils at Berault/Les Cayes, Haiti. 1988

F[1]	pH	O.M.	S[1]	C[1]	B[1]	P[2]	Zn[3]	K[4]	Ca[4]	Mg[4]	Na[4]	CEC[1]
		--------%	--------			kg ha^{-1}		-------cmol kg^{-1}	--------			
1	6.9	3.4	60	35	75	14.6	6.1	0.3	21.8	0.8	2.0	33
2	8.1	4.0	40	50	126	4.5	3.4	0.6	41.5	0.4	1.9	35
3	6.5	4.3	45	50	108	22.4	11.4	0.5	30.3	2.0	1.6	32
4	7.7	5.3	40	55	87	14.6	4.4	2.0	41.0	0.8	1.8	52
5	7.7	6.1	35	55	42	15.7	4.4	0.9	18.5	2.0	1.9	55
6	6.5	4.4	40	50	82	16.8	5.1	0.4	26.3	1.5	1.9	37

1/ texture was determined by the Bouycouos method. F stands for field number; S is sand; C is clay; CEC is cation exchange capacity and B is base saturation.

2/ available (Bray #1) P extracted by 0.03 N NH_4F in 0.025 N HCl.

3/ zinc was extracted by diethylenetriamine-pentaacetic acid (DTPA).

4/ exchangeable cations extracted by neutral, normal NH_4OAc.

Data from the literature were also taken into consideration and 2.5, 5.0, and 10.0 kg of Zn per hectare were selected, along with a check, as the four treatments of the field experiments. The Zn treatments and their designations are:

Treatment 1 = 0.0 kg of Zn/ha

Treatment 2 = 2.5 kg of Zn/ha

Treatment 3 = 5.0 kg of Zn/ha

Treatment 4 = 10.0 kg of Zn/ha

The experimental design was a randomized complete block (RCB) with four replications. The local corn variety, "Chicken Corn", was used to plant the six trials at six different locations at Berault; the zinc source was zinc sulfate ($ZnSO_4$) fertilizer containing 36% Zn.

Three kernels of corn were planted per hill 0.50 m apart within the row. The rows were 0.75 m apart; this calculates to 80,000 plants per ha. Soon after emergence the plants were thinned to two per hill. Each plot consisted of six rows six m long. The corn was planted by hand as is the custom on Haitian farms, and a basic nitrogen and phosphorus fertilization was applied to all treatments at the rate of 80 kg N ha^{-1} from urea, and 45 kg ha^{-1} of P_2O_5 from triple superphosphate (0-45-0). Half the nitrogen was applied at planting time along with the triple superphosphate, while the remainder 40 kg of nitrogen was applied 22 days after plant emergence. The zinc sulfate was also applied at

planting at rates indicated above. All three fertilizers were locally placed together 6 cm from the corn seeds and 5 cm deep. The maize kernels were planted about 6 cm deep in an 18 cm ridge; the fertilizers were placed 6 cm deep to the side and below the corn kernels so that they could be easily solubilized by the irrigation water, and consequently rendered available to the corn plants.

It should be noted that soil preparation had been done according to the traditional systems, i.e. two cultivations and one harrowing, using an oxen-drawn plough which usually goes some 15 to 20 cm deep in medium texture soils.

Each plot containing a treatment comprised 6 m X 0.75 m X 6 rows, which is an area of 27 m^2; each field experiment on an individual farm was 504 m^2, i.e. 28 m X 18 m, and the planted area was 432 m^2, i.e. 6 m X 18 m X 4 replications. Two alleys of 1 m width and one central alley, 2 m wide , separated the replications of each trial.

Seven days after planting emergence counts were made. At least a 92% emergence in each treatment was recorded in all plots. Within 15 to 22 days of emergence, the first weeding was performed, followed immediately by a visual search for zinc deficiency symptoms on the plants. No visual zinc deficiency symptoms were seen on the corn plants on this first observation in any treatment of the six trials.

Two days following that observation, the plants were

thinned to two per hill, theoretically reducing the density to 53,333 plants per ha. A second weeding was accomplished one to two days following plant thinning, concomitant with the second urea application (40 kg of N/ha) which was applied in the same manner as the first, manually, by local workers of the area.

The trials were irrigated as needed, four times on the average, during the vegetative growth stage. Irrigation was provided mainly during the first growing stages of the crop; but not during silking and early maturation which occurred during the rainy season. The plots were sprayed twice, using a 57% wettable powder solution of Sevin (1-Naphthyl N-methylcarbamate) to control corn stemborer infestations; photographs were taken of the corn at different growth stages, from planting to harvest. Data regarding plant and ear height were recorded two weeks after 50% of the plants of each trial had flowered. Height from the ground to top leaf, and height from the ground to the uppermost ear, were also recorded. These data were collected from ten randomly selected plants in each treatment of each trial. Averages of these data such as the influence of zinc application on plant and ear height, etc. were calculated.

Leaf samples were taken from each treatment of each trial at silking for protein and zinc content analyses. The leaves were collected from each treatment, one per plant from ten randomly selected plants. The leaf opposite and

just below the uppermost ear of the plant, and time of sampling, were considered in order to meet the following criteria stated by Hanway (Arnon, 1975):

a) The standard position of the leaf to be analyzed is easily defined at that stage of growth.

b) At silking, nutrient uptake is rapid, and any existing deficiencies in nutrient uptake from the soil are brought into evidence.

c) Reliable relationships between leaf composition and yield response to fertilizers have been established at this growth stage.

The leaf samples were dried in a force-draft oven at 65° C for three days, ground in a stainless steel mill, weighed, and analyzed for protein and zinc content in the chemistry laboratory of the school of Agriculture at Port-au-Prince in Haiti. The protein was determined by the micro-Kjeldahl method and computed as 6.25 X N obtained from the Kjeldahl analysis. The zinc was determined by atomic absorption spectrophotometry.

Within 115 to 120 days of the planting time, all the plots were harvested according to the following procedure: plants from the four central rows of each treatment were picked, discarding the two final hills on each end of the row to avoid the border effect. In other words, 11 hills having two plants each, that is 22 plants per row and thus 88 plants per treatment, were harvested. The two outside

lateral rows of each treatment were not harvested so as to reduce border effect contamination from one treatment to another. The number of plants harvested and ears collected, the weight and moisture of the corn harvested for each treatment, and the yield per hectare at 15% moisture were calculated using the following formula:

$$\text{Yield (kg)} = \frac{\text{trt wt} \times 10{,}000\ m^2}{\text{trt area}} \times \frac{100-\text{H.R.}}{85} \times 0.9$$

trt wt = weight of ears harvested in kg.

trt area = the area harvested per each treatment in m^2.

H.R. = moisture content of the grain in each treatment at harvest.

0.9 = the weight ratio of grain/ear for the "chicken corn" variety.

Rainfall data for the Berault area were recorded during the vegetative growth period of the crop, showing the following amounts: 21.1 mm for February; 72.4 mm for March; 36.4 mm for April; 258.5 mm for May; and 228.0 mm for June. These figures reflect the general rainfall pattern of Berault during the last decade, starting from 1980 (Figure 1).

RESULTS AND DISCUSSION

GREENHOUSE EXPERIMENT/University of Arkansas, 1987.

1. Emergence.

Five days after planting, only one seedling per pot had emerged in most pots of the seed coated treatments while the other treatments showed three to four seedlings per pot. Six days after planting, there still was no increase in the emergence rate of those four treatments or even seven days after planting although temperature and moisture conditions were favorable.

Analysis of variance of emergence counts for both groups of treatments are shown in Table 5. No statistical differences were found among the seed coated treatments at the 5% level of probability. The very low emergence rate of those treatments was ascribed to the zinc coating used. The corn seeds apparently were damaged by zinc salt toxicity during the 24-hour period of soaking because their germination was markedly depressed . Similar adverse effects of zinc were not observed in the soil-applied or foliar-applied zinc treatments.

Plant emergence in the soil-applied and foliar-applied Zn treatments did not show statistical differences among the treatments (Table 5). However it should be noted that the highest rates of emergence were obtained in treatments which

were not zinc-treated: those being #1, #14, #15, #17, and #20 (foliar Zn had not yet been applied to treatments 12 through 19). Normally, it would be expected that an increased amount of zinc around the corn seeds would contribute to the synthesis of more auxin which in turn would promote the elongation of the stems and roots of the corn, thus giving a higher germination rate (Shukla and Prasad, 1974), but that was not the case. The seed coating method did not show the advantages and results that Beeler (1974), and Shukla and Prasad (1974) mentioned, being:

a) improvement of germination against adverse conditions.

b) supply of immediately available quantity of trace-elements for healthy seedlings.

c) protection of seeds and seedlings against pest and disease attacks.

It is possible that a lower rate of seed-coated zinc could have proved beneficial.

Table 5. Effects of sources, methods, and rates of zinc application on corn emergence. Counts made seven days following planting.

Fertilizer sources	Methods of application	Rates of Zn application	Emergence counts
		ug g^{-1}	plants/pot
Seed-Coated Treatments			
6) ZnEDTA	seed coated	5.0	1.50NS
7) ZnEDTA	seed coated	10.0	1.50NS
8) NZN	seed coated	5.0	0.75NS
9) NZN	seed coated	10.0	0.75NS

ANOVA

Source	DF	SS	F	PR>F
TRT	3	2.25	1.42	0.2995
Error	9	4.75		

$LSD_{0.05}$ = 1.16 C.V.= 64.57

1) check		none	4.00
Soil Treatments	layered 2.5 cm deep		
2) ZnSO4	layered 2.5 cm	5.0	3.75NS
3) ZnSO4	layered 2.5 cm	10.0	3.50NS
4)Neutral Zinc	layered 2.5 cm	5.0	3.50NS
5)Neutral Zinc	layered 2.5 cm	10.0	3.75NS
FoliarTreatments	in:		
10) none	water	none	3.50NS
11) none	0.15% Azone	none	3.25NS
12) ZnSO4	water	0.069	3.50NS
13) ZnSO4	0.15% Azone	0.069	3.75NS
14) ZnEDTA	water	0.069	4.00NS
15) ZnEDTA	0.15% Azone	0.069	4.00NS
16) NZN	water	0.069	3.50NS
17) NZN	0.15% Azone	0.069	4.00NS
18) Neutral zinc	water	0.069	3.25NS
19) Neutral zinc	0.15% Azone	0.069	3.75NS
20) none	0.30% Azone	none	4.00NS

ANOVA

Source	DF	SS	F	PR>F
TRT	15	4.8593	1.13	0.3628
Error	45	12.9531		

$LSD_{0.05}$ = 0.7641 C.V. = 14.61

2) Leaf Discoloration

Two days following the zinc foliar application, (i.e. about three weeks after planting), some leaf purpling was observed on several plants. None was severe and in general the symptoms were a slight purple coloration of the margins of the lower leaves, starting from the tip of the blades. None resembled an initial stage of zinc deficiency, or zinc toxicity. Plants in some of the zinc treated soils and in some of the zinc seed coated treatments exhibited the same symptoms. The discoloration appeared to be evidence of soil phosphorus deficiency caused by the low available soil P and the high soil pH (Table 2) which could convert soluble phosphorus to the very insoluble $Ca_3(PO_4)_2$ (Tisdale et al. 1985). Rating the P deficiency symptoms from one to three with one the lowest level of discoloration , a statistical analysis appropriate to discrete ranked data was performed separetely for the seed coated treatments, and for the soil-applied and foliar-applied treatments. The F-test used to compare the treatments was equivalent to Friedman's nonparametric test for randomized complete block analysis using ranks. There were no statistically significant differences in the level of leaf discoloration among seed coated treatments (Table 6). The same results were also found when considering the F-test for soil-applied and foliar-applied treatments. It would have been possible to obtain more precise results if the leaf discoloration was

rated in a wider range such as one to ten, or if the level of discoloration was expressed in percent of number of leaves affected by the discoloration, in order to reduce the large variability obtained by the visual rating from one to three.

Twelve days following this first leaf discoloration observation, a second application of N, P, and K was applied in order to correct the P deficiency symptoms and supply the remaining part of the nitrogen and potassium recommended in the fertilization plan. At that growth stage, additional plants exhibited purple discoloration. Some leaves had 75% of their blade affected, starting from the tip; but no necrosis was noticed. Rating from one to three again, records were taken on the intensity of the purple discoloration of the young leaves four days after the second fertilization application. Performing the same type of analysis of variance and F-test as described previously, there were again no statistically significant differences in the level of affectation of both groups of treatments by the P deficiency symptoms (Table 7).

Table 6. The relationship of sources, methods, and rates of zinc application to corn leaf phosphorus deficiency coloration. Leaf discoloration ratings made 18 days after planting, and 2 days following foliar spray application to treatments 10 through 20.

Treatments and zinc sources	Methods of application	Rates application	Leaf discoloration
		ug^{-1}	
Seed-Coated Treatments			
6) ZnEDTA	seed coated	5.0	1.25NS
7) ZnEDTA	seed coated	10.0	1.00NS
8) NZN	seed coated	5.0	1.33NS
9) NZN	seed coated	10.0	1.00NS

ANOVA

Source	DF	SS	F *	PR>F
TRT	3	1.25	1.06	0.4245
Error	7	2.75		

* This F-test is equivalent to Friedman's nonparametric test for randomized complete block analysis using ranks.

1) check		none	1.00
Soil Treatments	layered 2.5cm deep		
2) $ZnSO_4$	layered 2.5 cm	5.0	1.25NS
3) $ZnSO_4$	layered 2.5 cm	10.0	1.25NS
4) Neutral zinc	layered 2.5 cm	5.0	1.50NS
5) Neutral zinc	layered 2.5 cm	10.0	1.25NS
Foliar Treatments	in:		
10) none	water	none	1.25NS
11) none	0.15% Azone	none	1.00NS
12) $ZnSO_4$	water	0.069	1.25NS
13) ZnSO4	0.15% Azone	0.069	2.25NS
14) ZnEDTA	water	0.069	1.50NS
15) ZnEDTA	0.15% Azone	0.069	1.25NS
16) NZN	water	0.069	1.75NS
17) NZN	0.15% Azone	0.069	1.25NS
18) Neutral zinc	water	0.069	1.50NS
19) Neutral zinc	0.15% Azone	0.069	1.50NS
20) none	0.30% Azone	none	1.00NS

ANOVA

Source	DF	SS	F*	PR>F
TRT	15	308.875	1.79	0.0675
Error	45	518.625		

This F-test is equivalent to Friedman's test using ranks.

Table 7. Effects of sources, methods, and rates of zinc application on corn leaf phosphorus deficiency discoloration, 34 days after planting.

Treatments and zinc sources	Methods of application	Rates of Zn application	Leaf discoloration
		ug g^{-1}	mean of rating
Seed-Coated Treatments			
6) ZnEDTA	seed coated	5.0	2.25NS
7) ZnEDTA	seed coated	10.0	1.75NS
8) NZN	seed coated	5.0	1.67NS
9) NZN	seed coated	10.0	2.33NS

ANOVA

Source	DF	SS	F*	PR>F
TRT	3	1.25	1.06	0.4245
Error	7	2.75		

This F-test is equivalent to the Friedman's nonparametric test for randomized complete block analysis using ranks.

1) check		none	2.75
<u>Soil Treatments</u>	layered 2.5 cm deep		
2) $ZnSO_4$	layered	5.0	2.75NS
3) ZnSO4	layered	10.0	2.50NS
4) Neutral zinc	layered	5.0	3.00NS
5) Neutral zinc	layered	10.0	3.00NS
<u>Foliar Treatments</u>	in:		
10) none	water	none	2.50NS
11) none	0.15% Azone	none	3.00NS
12) $ZnSO_4$	water	0.069	2.50NS
13) $ZnSO_4$	0.15% Azone	0.069	3.00NS
14) ZnEDTA	water	0.069	2.50NS
15) ZnEDTA	0.15% Azone	0.069	2.25NS
16) NZN	water	0.069	2.50NS
17) NZN	0.15% Azone	0.069	2.50NS
18) Neutral zinc	water	0.069	2.50NS
19) Neutral zinc	0.15% Azone	0.069	2.00NS
20) none	0.30% Azone	none	2.25NS

ANOVA

Source	DF	SS	F*	PR>FRT
TRT	15	313.875	1.82	0.0617
Error	45	517.625		

*This F-test is equivalent to the Friedman's test for ranks.

3) Plant height

Thirty four days after planting, plant height measurements were taken to determine if corn growth was affected by the different sources, methods, and rates of zinc fertilization. A randomized complete block analysis using Proc GLM of the SAS program did not show any statistically significant differences among the treatments of the seed coated treatments, nor among those of the soil-applied and foliar-applied Zn treatments. The ANOVA is presented in Table 8. It should be noted, however, that in the second group of treatments, the $ZnSO_4$ soil-applied at 5 and 10 ppm, and the Neutral zinc-Azone foliar treatments tended to be the shortest, while the NZN-Azone and foliar, $ZnSO_4$-water treatments tended to be the tallest, although not statistically different from the check. The non-significant differences obtained from this statistical analysis are contradictory to Shukla and Morris' (1967) findings, who reported an increase in corn growth from zinc on alkaline soils, which they ascribed to a significant interaction of phosphorus X zinc interaction when both elements were applied together. Also, Shukla and Prasad (1974) found that zinc increased by several fold the dry matter yield and plant height of corn grown on an alkaline soil having a pH of 9.2.

Table 8. Effects of sources, methods, and rates of zinc application on the height of corn plants. 34 days after planting.

Treatments and zinc sources	Methods of application	Rates of Zn application	Height
		ug g^{-1}	cm
Seed-Coated Treatments			
6) ZnEDTA	seed coated	5.0	79.86NS
7) ZnEDTA	seed coated	10.0	83.45NS
8) NZN	seed coated	5.0	88.67NS
9) NZN	seed coated	10.0	69.33NS

ANOVA

Source	DF	SS	F	PR>F
TRT	3	432.769	0.93	0.4768
Error	7	1091.101		

$LSD_{0.05}$ = 22.458 C.V. = 15.51

1) Check		none	67.17
<u>Soil Treatments</u>	layered 2.5 cm deep		
2) $ZnSO_4$	layered 2.5 cm	5.0	65.47NS
3) $ZnSO_4$	layered 2.5 cm	10.0	64.12NS
4) Neutral zinc	layered 2.5 cm	5.0	66.74NS
5) Neutral zinc	layered 2.5 cm	10.0	66.43NS
<u>Foliar Treatments</u>	in:		
10) none	water	none	70.89NS
11) none	0.15% Azone	none	67.92NS
12) $ZnSO_4$	water	0.069	71.95NS
13) $ZnSO_4$	0.15% Azone	0.069	67.44NS
14) ZnEDTA	water	0.069	67.13NS
15) ZnEDTA	0.15% Azone	0.069	66.21NS
16) NZN	water	0.069	75.74NS
17) NZN	0.15% Azone	0.069	72.96NS
18) Neutral zinc	water	0.069	66.40NS
19) Neutral zinc	0.15% Azone	0.069	65.95NS
20) none	0.30% Azone	none	75.99NS

ANOVA

Source	DF	SS	F	PR>F
TRT	15	826.083	0.76	0.7149
Error	45	3273.484		

$LSD_{0.05}$ = 12.15 C.V. = 12.43

4) Dry matter production

The results obtained from the analysis of variance of the dry matter weight of the corn plants did not show statistically significant differences among the seed coated treatments or among the soil-applied and the foliar-applied treatments (Table 9). Looking at Tables 5 and 9, the adverse effect of Zn seed-coating did not bring about a significant reduction in the dry matter production of the seed coated treatments considered together. In the second group of treatments, the highest dry matter weights were obtained in decreasing order, from Azone applied at 0.30% rate, NZN foliar spray in water, NZN foliar spray in Azone, $ZnSO_4$ soil-applied at 5 ppm and ZnEDTA foliar spray in Azone. When considering the soil-applied treatments, the 5 ppm rate of zinc tended to yield slightly better than the 10 ppm. Likewise, the foliar spray treatments generally tended to exhibit a better performance than the soil-applied ones. The zinc-Azone treatments all tended to yield better, although not statistically different, than the check. Azone did not have any deleterious effect on the foliage of the corn plants of this experiment. This indicates that research on the rates of Azone application in agriculture still deserves attention to determine if the chemical can be a better carrier than water alone for micronutrient foliar application.

Considering Tables 7 and 9, the dry matter production of the corn plants at this growth stage did not seem to be affected by the phosphorus deficiency symptoms, since the treatments most affected by the purple coloration were not the ones which yielded the lowest dry matter production. Conversely, the treatments the least affected by the deficiency symptoms were not the ones which showed the highest dry matter yields.

One of the objectives of the greenhouse experiment was to compare the sources of zinc applied. Again, no statistical differences were observed among the several sources of zinc used in the study, considering the emergence rate, the plant growth 34 days after planting, and particularly the dry matter production 40 days after planting . Several scientists had reported on the effectiveness of the organic chelates to the inorganic zinc sources (Boawn, 1973; Mortvedt, 1979; Prasad and Sinha, 1981; Hergert et al. 1984). Moreover, the rates of zinc application did not cause yield differences, which is contradictory to previous data reported by several researchers (Pierre et al. 1966; Safaya and Gupta, 1979; Tisdale et al. 1985). The methods of zinc application, soil-applied and foliar-applied, showed to be equally effective in this study. In short, there was no positive response from the corn variety used to zinc fertilization on the Demopolis silty clay loam , although the native zinc in

the soil was considered to be low. The chemical reactions of zinc with the heavy rate of phosphorus application may account for those results, given the antagonistic interactions of the two elements on high pH and high calcium soils (Stukenholtz et al. 1966). There is another possible explanation for the non-response of corn to the zinc application, from the dry matter production standpoint. The reduced number of plants per pot accounted for a great variability among pots and thus did not allow the statistic test to determine at 5% level of probability any possible difference due to zinc treatment effect.

Table 9. Effects of souces, methods, and rates of zinc application on corn dry matter production.

Forty days after planting

Treatments and zinc sources	Methods of Application	Rates of Application	Dry matter yield
		ug g^{-1}	mean, g pot^{-1}
Seed-Coated Treatments			
6) ZnEDTA	seed coated	5.0	3.48NS
7) ZnEDTA	seed coated	10.0	4.46NS
8) NZN	seed coated	5.0	3.86NS
9) NZN	seed coated	10.0	2.28NS

ANOVA

Source	DF	SS	F	PR>F
TRT	3	10.348	1.76	0.2415
Error	7	13.700		

$LSD_{0.05}$ = 2.526 C.V. = 39.02

1) Check		none	3.98
Soil Treatments	layered 2.5 cm deep		
2) $ZnSO_4$	layered 2.5 cm	5.0	4.86NS
3) $ZnSO_4$	layered 2.5 cm	10.0	3.37NS
4) Neutral zinc	layered 2.5 cm	5.0	4.29NS
5) Neutral zinc	layered 2.5 cm	10.0	4.09NS
foliar Treatments	in:		
10) none	water	none	4.26NS
11) none	0.15% Azone	none	4.29NS
12) $ZnSO_4$	water	0.069	4.38NS
13) $ZnSO_4$	0.15% Azone	0.069	4.04NS
14) ZnEDTA	water	0.069	3.96NS
15) ZnEDTA	0.15% Azone	0.069	4.85NS
16) NZN	water	0.069	5.26NS
17) NZN	0.15% Azone	0.069	4.89NS
18) Neutral zinc	water	0.069	4.10NS
19) Neutral zinc	0.15% Azone	0.069	4.56NS
20) none	0.30% Azone	none	6.01NS

ANOVA

Source	DF	SS	F	PR>F
TRT	15	23.105	0.88	0.5901
Error	45	78.817		

$LSD_{0.05}$ = 1.884 C.V. = 29.75

CORN FIELD EXPERIMENTS IN HAITI, 1988.

Seven days after planting, plant emergence counts were made. Good emergence of the plants was obtained on all the plots with at least a 92% germination in each treatment. Within 15 to 22 days of emergence, the first weeding was performed, followed immediately by a visual observation of zinc deficiency symptoms on the plants. No visual symptoms of the micronutrient deficiency were noticed on the first observation on any treatment of the six trials 20 days after emergence.

In general, all trials had a good stand. There were no serious lodging problems, no disease symptoms at all, and no insect damage; only some light woodpecker attacks on a few ears on plots located in the vicinity of such fruit trees as mangos (*Mangifera indica* L.) and coconut (*Cocos nucifera* L.). Most of the plants were single earred, about 20% had two.

1) Leaf zinc content

The effect of zinc treatments on corn leaf zinc content at silking is shown on Table 10. No statistical differences were obtained from the treatments at 0.05 level of probability at either of the locations. These results were in agreement with those of Stout and Bennett (1983) in

northern West Virginia who did not find significant increase in the leaf zinc concent of corn plants using none, 3.36 and 6.72 kg of Zn/ha; but they were in contradiction with Shukla and Prasad's (1974) conclusions who found that increasing the zinc treatment concentration from 2.5 to 5.0 ppm significantly increased the zinc content of corn plants grown under alkaline conditions. However, the zinc content in the leaves of these corn plants tended to decrease slightly, but non-significantly, as the level of zinc application increased in fields 1 and 2 (Table 10), but they fall within the range of adequate zinc content for corn at the silking stage (20 to 70 ppm) (Sillanpaa, 1979). In other words, check plant leaves had zinc levels above the critical value generally mentioned in the literature, and contained sufficient zinc to meet the requirements of the physiological processes of the "Chicken Corn" cultivar. Secondly, given that the concentration of zinc in the leaves was adequate, the plants did not exhibit luxury consumption of the micronutrient at the levels of 2.5, 5.0, and 10.0 kg per hectare zinc rates.

Table 10. Effects of zinc treatments on leaf zinc content of corn at silking. Berault/Haiti, 1988.

Field #1

Treatments and zinc source	Methods of application	Rates of application	Zinc content
		kg ha^{-1}	ug g^{-1}
1) Check		none	58.5
2) $ZnSO_4$	layered 6 cm	2.5	55.8NS
3) $ZnSO_4$	layered 6 cm	5.0	55.3NS
4) $ZnSO_4$	layered 6 cm	10.0	49.8NS

LSD = 28.81 PR>F = 0.9169 C.V. = 32.86

Field #2

1) Check		none	55.0
2) $ZnSO_4$	layered 6 cm	2.5	49.8NS
3) $ZnSO_4$	layered 6 cm	5.0	49.0NS
4) $ZnSO_4$	layered 6 cm	10.0	49.5NS

LSD = 24.45 PR>F = 0.8525 C.V. = 30.60

LEAF PROTEIN CONTENT

The nitrogen concentration in the corn ear leaves of experimental fields 1 and 2 was determined by the micro-Kjeldahl procedure and the protein content was computed as N x 6.25 and expressed on a dry weight basis.

The protein content of the corn ear leaf at tasseling was not affected by any of the four levels of zinc applied in either field at the 0.05 level of probability as it is shown in Table 11. However, the protein content of the leaf tended to decrease as the zinc application rates increased, which was the same trend observed with ear leaf zinc in both fields (Table 10). That was probably due to the close relationship of Zn in plant metabolism. Indeed, zinc is involved in several physiological processes as a metalloenzyme, particularly in plant protein synthesis (Shkolnik, 1984; and Tisdale et al. 1985). The reduction in the zinc content of Zn-treated plant leaves (Table 10) might have brought about a subsequent reduction in the protein content of the same plant leaves.

However, it should be pointed out that the average nitrogen content of the maize ear leaves falls in the adequate range (1.0 to 3.5%) as stated by Sillanpaa (1979) for optimum corn production.

Table 11. Effects of zinc treatments on leaf protein content of corn. Berault/Les Cayes Haiti, 1988

Field #1

Treatments and zinc source	Methods of application	Rates of Zn application	Protein content
		kg ha^{-1}	g $(100g)^{-1}$
1) Check		none	12.9
2) $ZnSO_4$	layered 6 cm	2.5	12.2NS
3) $ZnSO_4$	layered 6 cm	5.0	11.9NS
4) $ZnSO_4$	layered 6 cm	10.0	10.9NS

LSD = 2.47 PR>F = 0.3914 C.V. = 12.92

Field #2

1) Check		none	11.5
2) $ZnSO_4$	layered 6 cm	2.5	11.1NS
3) $ZnSO_4$	layered 6 cm	5.0	10.8NS
4) $ZnSO_4$	layered 6 cm	10.0	9.2NS

LSD =2.41 N.S PR>F =0.2345 C.V. =14.15

3) GRAIN YIELD

Six field trials were established at Berault but one of them was harvested by the farmer. The mean grain yield for each of the five field experiments is given in Appendix Table 3.

The analysis of variance performed by using the GLM procedure of the Statistical Analysis System (SAS) showed statistically significant differences at 0.05 level of probability among the treatments of the five experiments harvested at Berault in Haiti (Table 12). The results were in agreement with reports from several studies conducted in the U.S.A. and other countries where corn was shown to be responsive to zinc banded in the soil (Bayens, 1967; Shukla and Prasad, 1974; Dev and Shukla, 1980). However the results from Haiti field experiments were contradictory to those found by Stout and Bennett (1983) in northwest Virginia; they did not find a positive response to zinc fertilization on corn from 3.36 and 6.72 kg of zinc per hectare surface applied and incorporated in the soil.

The least significant difference test (LSD) ranked the 2.5 kg/ha rate as the highest yielding followed successively by the 5.0 and the 10.0 kg rates. The check gave the lowest yield. Moreover, looking at Table 12, the yield decreased as the zinc rates increased above 2.5 kg/ha with significant differences between 2.5 and 10.0 rates; but with no

Table 12. Effects of zinc treatments on corn grain yield. Data from the five locations analyzed as a single experiment. Berault/Les Cayes, Haiti. 1988.

Treatments and zinc source	Methods of application	Rates of application	Grain yield
		kg ha^{-1}	kg ha^{-1}
1) Check		none	4634c*
2) $ZnSO_4$	layered 6 cm	2.5	5052a
3) $ZnSO_4$	layered 6 cm	5.0	4928ab
4) $ZnSO_4$	layered 6 cm	10.0	4885b

*means within a column followed by the same letter are not statistically different at the 0.05 level of probability based on LSD.

LSD = 0.1357 PR>F = 0.0039 C.V. = 7.09

significant differences between the 2.5 and 5.0 kg rates. The 5.0 kg of Zn/ha rate did not differ statistically from the 10 kg/ha rate.

After the five field experiments were harvested and the yield increases noted from the 2.5 kg ha^{-1} Zn application, yield increases were used to calculate the regression equations and the correlation coefficients that fit the yield increases versus the soil test data for pH, P, Ca, and Zn (Table 4). The regressions equations were:

$Y = -562.25 + 132.50x$ for pH

$Y = 704.04 - 20.09x$ for P

$Y = 244.21 + 5.60x$ for Ca

$Y = 621.88 - 34.73x$ for Zn

These equations will allow to calculate the predicted values of the yield increases that can be obtained on the five field plots when considering values for each of the fours factors (pH, P, Ca, Zn) in their respective range described in Table 4.

The Pearson correlation coefficients (r) between the yield increses and each of the four factors (pH, P, Ca, Zn) were found to be:

yield	vs	pH	$r = 0.5860$	with $p = 0.2986$
yield	vs	P	$r = -0.8655$	with $p = 0.0580$
yield	vs	Ca	$r = 0.4002$	with $p = 0.5004$
yield	vs	Zn	$r = -0.7490$	with $p = 0.1451$

(p) indicates the level of significance for the (r) values.

Those data indicate a positive but non-significant correlation between yield increases from Zn fertilizers and the soil test levels of pH and Ca in these five fields.

There was an inverse but non-significant relationship between yield increases from Zn fertilizers and the soil test levels of P and Zn, at 5% level of probability.

The limited number of fields, (five), probably mitigated against obtaining higher level of significance: the yield vs soil phosphorus level correlation was significant at 5.80% level of probability, while the yield vs soil Zn level correlation was significant at 14.51% level of probability.

Other correlations were also considered from these five soils. There was in these five field soils:

a) a negative and significant (at 8.96%) relationship between pH and the phosphorus soil test level.

b) an inverse and significant (at 3.00%) relationship between pH and the zinc soil test level.

c) a positive and non-significant relationship between pH and the calcium soil test level.

d) a positive and significant (at 9.52%) relationship between the phosphorus and the calcium soil test level.

e) a positive and significant (at 8.11%) relationship between the phospohorus and the zinc soil test level.

f) an inverse and non-significant relationship between the zinc and the calcium soil test level.

These relationships agree with results reported in the

literature (Tisdale et al. 1985).

From the economic standpoint, the yield increase of 418 kg/ha justifies the application of the 2.5 kg/ha of the micronutrient. Indeed, an increase of 418 kg of corn grain per hectare has an value of $84.00 in Haiti.

In short, the following assumptions should be taken into consideration for the Haitian fields:

a) The yield response of corn to zinc fertilization was not reflective of the adequate ear leaf zinc level, which would predict that corn plants would not have shown a response to a zinc application.

b) The extractable soil zinc levels which were found at Berault, and which are considered to be in the low range according to the literature, did not appear to be adequate for the "Chicken corn" cultivar production in that Berault area of southwestern Haiti.

c) Shukla and Prasad (1974) reported that zinc applications to maize are helpful if the phosphorus/zinc ratio in plants is wider than 100.

However it is estimated that this rate was not reached in the corn leaves of the Haitian fields, given the quasi immobility of phosphorus in alkaline soils and the relatively high zinc concentration of the corn plant leaves of those fields.

d) The response of "Chicken Corn", a variety locally adapted to the Berault/Les Cayes soil conditions through

many years of cultivation, would predict that introduced and high yielding varieties might show an even greater response to zinc fertilization when grown on these soils.

e) According to Tisdale et al. (1985), applications of sulfur-containing compounds to high pH and calcareous soils can partially neutralize the soil basicity and result in an increased availability of soil micronutrients. They reported a beneficial influence of soil-applied SO_2 on uptake by sorghum of P, Fe, Mn, and Zn. Tisdale et al. (1985), also suggested that, in several instances, the yield increases obtained on alkaline soils can be ascribed to the lowering of the pH by the sulfur component. On the basis of that information it appears that the sulfur from the $ZnSO_4$ could account for the yield increases obtained on the Haitian field plots. However, on the other hand, some concepts mitigate against the possible influence of sulfur. It could be thought that these soils high in organic matter would have mineralized adequate S to satisfy the plant requirements for this element. Secondly, the 2.5 kg Zn rate would have supplied only 1.25 kg/ha of S, hardly sufficient to supply the corn's sulfur requirements in a S deficient soil.

In short, it does not appear clear which of the two, S or Zn, is mainly responsible for the yield increases on the Haitian field plots. Further investigations need to be conducted to find out the reasons of those yield increases.

CONCLUSIONS

The results obtained from the greenhouse experiment at the University of Arkansas Agricultural Station allowed the following conclusions to be drawn:

a) In a geeenhouse experiment, zinc did not have an ameliorative effect on corn germination or growth in an alkaline Demopolis soil when applied at rates up to 10 ppm.

b) There were no significant increases from the methods, sources, and rates of zinc on corn dry matter production in this greenhouse experiment.

c) Seed coatings of 5 and 10 ug g^{-1} depressed the germination of the FFR 929 W lot# 8546 corn variety.

However, the results obtained from the field plots in Haiti brought up the following conclusions:

a) Corn grain yields with the local "Chicken Corn" variety were statistically increased by zinc sulfate hill applied at the rate of 2.5 kg Zn/ha, but yields tended to decrease as the rate of Zn application increased above the 2.5 kg/ha level.

b) This positive response did indicate that the extractable zinc (3.87 kg/ha) was below the critical level of zinc for this corn variety at Berault/Haiti, and that the relatively high soil pH and high Ca content of these Haitian soils caused the corn to respond to zinc fertilizers as is reported in the literature.

c) The recommended treshhold of 11.20 kg Zn/ha from the literature (Tisdale et al. 1985) was far above the critical level of zinc for corn production in Berault area of Haiti. The optimum agronomic yield was obtained with 2.5 kg of Zn/ha.

d) There was no response to zinc levels above 2.5 kg/ha from the "Chicken Corn" variety in that area.

e) Additional investigations need to be conducted with corn on these soils to determine why the 2.5 kg zinc rate was superior to the 5 and 10 kg ha^{-1} rates.

f) Other investigations will have to be conducted to test the response of corn to zinc fertilization on other high pH soils of the Plain Les Cayes.

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APPENDICES

Table 1. Some characteristics of 96 soil samples taken at Berault and Maniche in Les Cayes/Haiti. August 1986.

Field	pH	O.M.	P1	K2	Ca2	Na2	Mg2	Mn3	Zn3
		%	----------	----------	----------	----------	kg ha^{-1}	----------	----------
			Berault (fields #1 to 76)						
			Maniche (fields #77 to 96)						
#1	7.8	1.8	7.84	190.4	2576	100.8	280.0	26.88	12.55
#2	7.9	2.8	5.60	380.8	9856	145.6	358.4	28.00	2.24
#3	7.8	3.8	6.72	224.0	11648	145.6	414.4	33.60	5.15
#4	7.7	3.8	6.72	280.0	11312	123.2	436.8	33.60	2.80
#5	7.3	3.1	2.24	268.8	11424	145.6	448.0	49.28	3.36
#6	7.7	3.1	12.32	380.8	7056	134.4	582.4	79.52	3.92
#7	7.9	3.3	3.36	156.8	8848	89.6	280.0	26.88	1.35
#8	7.6	2.6	3.36	313.6	10752	123.2	380.8	31.36	1.57
#9	7.8	2.8	4.48	313.6	10416	100.8	347.2	22.40	2.69
#10	7.7	3.8	2.24	302.4	20832	112.0	414.4	30.24	3.02
#11	8.0	4.0	4.48	235.2	13216	145.6	470.4	44.80	1.57
#12	7.9	3.6	10.08	145.6	11088	100.8	392.0	39.20	2.24
#13	7.9	1.9	4.48	112.0	10528	201.6	358.4	35.84	2.02
#14	7.8	3.5	4.48	156.8	11312	212.8	392.0	40.32	2.58

#15	8.0	3.3	7.84	190.4	11648	224.0	268.8	22.40	3.03
#16	7.8	3.2	5.60	156.8	11760	212.8	336.0	24.64	2.80
#17	7.7	3.1	4.48	123.2	11088	179.2	280.0	29.12	1.46
#18	7.8	3.6	6.72	156.8	11648	168.0	291.2	29.12	3.70
#19	7.9	2.5	5.60	112.0	11088	156.8	347.2	25.76	2.35
#20	8.0	3.3	7.84	235.2	12656	112.0	336.0	34.72	1.68
#21	7.7	2.3	10.08	100.8	9632	145.6	168.0	28.00	1.68
#22	7.7	2.2	7.84	179.2	10416	179.2	324.8	24.64	2.58
#23	7.5	3.9	6.72	100.8	9632	100.8	179.2	30.24	1.68
#24	7.6	3.5	6.72	123.2	10080	112.0	235.2	21.28	1.68
#25	7.7	3.8	6.72	123.2	10416	123.2	268.8	23.52	2.24
#26	7.8	3.0	7.84	212.8	13400	179.2	291.2	16.80	1.68
#27	7.7	3.0	5.60	201.6	14112	123.2	392.0	21.28	2.35
#28	7.8	4.0	4.48	190.4	12656	134.4	369.6	24.64	3.81
#29	8.0	3.1	6.72	100.8	11088	156.8	257.6	12.32	6.05
#30	7.7	3.5	5.60	156.8	11760	145.6	369.6	12.32	2.80
#31	7.5	3.9	4.48	134.4	11200	134.4	302.4	21.28	2.13
#32	7.6	3.5	5.60	190.4	12096	89.6	414.4	20.16	2.13
#33	7.8	3.1	5.60	145.6	12096	168.0	403.2	24.64	6.27
#34	7.3	2.4	20.16	212.8	4928	112.0	504.0	70.56	11.20
#35	7.6	2.9	14.56	179.2	4816	100.8	571.2	114.24	6.05
#36	6.6	3.9	7.84	190.4	4256	1[illegible]3.2	649.6	182.56	7.50
#37	7.3	4.0	15.68	392.0	11536	78.4	862.4	45.92	6.38
#38	7.7	3.5	6.72	448.0	12656	112.0	560.0	20.16	5.60
#39	7.2	3.7	16.80	369.6	12320	100.8	560.0	24.64	5.04
#40	7.4	2.7	23.52	380.8	10752	22.4	526.4	26.88	6.61

#41	6.9	2.9	4.48	246.4	11200	89.6	324.8	22.40	3.36
#42	6.5	2.6	23.52	660.8	6160	33.6	672.0	53.76	15.23
#43	6.2	3.8	13.44	179.2	7728	134.4	548.0	0.40	11.43
#44	6.3	3.6	13.44	145.6	4368	100.8	627.2	131.04	6.61
#45	8.2	4.0	11.20	313.6	10528	168.0	392.0	24.64	2.8
#46	6.6	3.7	12.32	246.4	8624	12.0	660.8	68.32	4.37
#47	7.1	3.8	15.68	313.6	11088	67.2	672.0	43.68	4.37
#48	6.8	4.0	12.32	201.6	7392	112.0	1019.2	117.6	5.26
#49	6.4	3.8	10.08	201.6	6608	78.4	918.4	115.4	2.46
#50	6.5	4.0	10.08	313.6	11648	246.4	627.2	30.24	3.36
#51	6.3	3.6	11.20	302.4	8848	179.2	1411.2	96.32	3.58
#52	7.2	3.7	22.40	336.0	11200	112.0	918.4	13.44	11.42
#53	6.5	4.0	14.56	291.2	8288	156.8	1388.8	104.16	6.83
#54	6.2	3.8	14.56	302.4	7280	100.8	806.4	89.60	4.37
#55	6.8	3.6	20.16	268.8	6384	156.8	683.2	67.20	5.71
#56	6.9	4.0	10.08	324.8	12432	134.4	716.8	23.52	2.35
#57	7.7	4.0	8.96	280.0	11984	123.2	705.6	22.40	2.91
#58	7.4	4.0	10.08	324.8	9968	100.8	739.2	35.84	2.35
#59	7.9	4.0	5.60	179.2	13104	112.0	481.6	41.44	2.24
#60	7.8	4.0	4.48	145.6	12432	100.8	436.8	29.12	3.70
#61	7.8	4.0	6.72	145.6	12992	100.8	459.2	33.60	2.69
#62	7.3	3.3	6.72	156.8	12992	100.8	492.8	36.96	1.57
#63	7.7	4.0	5.60	123.2	12656	123.2	392.0	66.08	2.58
#64	7.5	4.0	5.60	179.2	12432	168.0	459.2	40.32	2.46
#65	7.4	3.4	10.08	302.4	10640	100.8	336.0	31.36	2.13
#66	7.8	3.4	6.72	100.8	10416	123.2	257.6	42.56	2.02

#67	7.6	4.0	14.56	145.6	12656	89.6	448.0	25.76	3.47
#68	7.7	4.0	11.20	156.8	13644	123.2	492.8	34.72	2.91
#69	7.6	4.0	6.72	201.6	13328	134.4	492.8	47.04	2.35
#70	7.8	3.6	7.84	235.2	12880	89.6	515.2	56.00	2.24
#71	7.7	4.0	3.36	179.2	12768	56.0	425.6	36.96	5.15
#72	7.8	4.0	3.36	168.0	11872	67.2	403.2	49.28	3.02
#73	7.5	4.0	5.60	134.0	12656	67.2	425.6	49.28	3.02
#74	7.8	4.0	5.60	168.0	11536	8.4	380.8	45.92	2.57
#75	7.7	2.8	6.72	156.8	11312	67.2	358.4	35.84	1.91
#76	7.9	4.0	11.20	224.0	13664	123.2	571.2	49.28	1.79
#77	7.7	4.0	23.52	907.2	10864	123.2	896.0	44.80	4.93
#78	7.5	4.0	11.20	280.0	13104	156.8	672.0	43.68	7.06
#79	8.0	3.7	10.08	268.8	11984	145.6	548.8	30.24	3.14
#80	7.9	3.7	7.84	280.0	9968	112.0	336.0	22.40	2.13
#81	7.8	4.0	8.96	324.8	14448	89.6	571.2	41.44	3.36
#82	7.7	4.0	12.32	280.0	12544	112.0	481.6	36.96	2.24
#83	7.8	3.2	10.08	369.6	11200	112.0	481.6	28.00	3.25
#84	7.7	4.0	28.00	436.8	15456	168.0	772.8	47.04	4.59
#85	7.7	2.4	15.68	425.6	15344	112.0	705.6	44.80	1.68
#86	7.2	4.0	15.68	369.6	17808	100.8	817.6	57.12	3.14
#87	7.7	4.0	17.92	414.4	16128	100.8	828.8	73.92	4.93
#88	7.9	4.0	12.32	414.4	15008	123.2	795.2	40.32	2.80
#89	7.5	4.0	16.80	336.0	15680	78.4	840.0	44.80	5.26
#90	7.7	4.0	15.68	302.4	15456	56.0	873.6	59.36	2.46
#91	7.8	4.0	10.08	313.6	14784	168.0	683.2	66.08	2.02
#92	7.9	4.0	20.16	324.8	15232	145.6	627.2	35.84	3.81

#93	7.6	4.0	10.08	235.2	13216	145.6	526.4	34.72	1.68
#94	8.1	4.0	14.56	280.0	14336	145.6	604.8	39.20	1.79
#95	7.8	4.0	10.08	492.8	13664	168.0	694.0	44.80	3.81
#96	7.5	3.5	6.72	380.8	10192	168.0	481.6	16.80	0.68

1/ Available (Bray #1) P extraction.

2/ Extracted by neutral, normal NH_4OAc.

3/ Extracted by diethylenetriamine-pentaacetic acid (DTPA).

The analyses were performed at the Soil Testing and Research Laboratory of the University of Arkansas, Fayetteville in Feb. 1987.

The soil samples were collected in August 1986 at the following locations of Berault and Maniche:

Samples #1 through 10 at Durocher /Berault

Samples #11 through 33 at Jogue /Berault

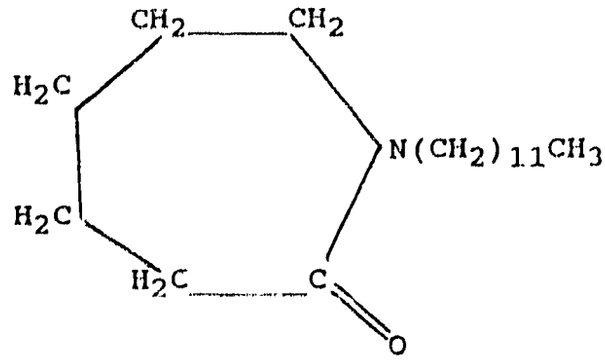
Samples #34 through 50 at Bourdet/Berault

Samples #51 through 58 at Macieu /Berault

Samples #59 through 76 at Charlette/Berault

Samples #77 through 96 at Fonds-des-Freres /Maniche

Table 2. Chemical and physical characteristics of Azone used in this study.

Chemical name	1-Dodecylazacycloheptan-2-one
Chemical structure	
Empirical formula	$C_{18}H_{35}NO$
Formula weight	281.49
Purity	99.00%
Physical form	a clear colorless liquid
Freezing point, ^{o}C	-7
Boiling point, oC	158-160°/100u
Viscosity, centipoise (cp)	45.2
Specific gravity, at 25°C (d^{25})	0.912
Surface tension, dyne per cm at 22°C (dy/cm^{22})	32.65
Flash point	100°C no flash
Miscible with	most organic solvents

Poise is the unit of viscosity and has the dimensions of one gram per centimeter-second.

Dyne is the unit of force that gives acceleration of one centimeter per second to one gram of mass.

Table 3. Effects of zinc treatments on corn grain yield. Berault/Les Cayes, Haiti. 1988.

Average yields obtained from five fields at Berault.

Rates/Zn	Field#1	Field#2	Field#3	Field#4	Field#5
Kg ha^{-1}	kg ha^{-1}				
none	4957	4232	5063	4972	3948
2.5	5473	4804	5273	5433	4276
5.0	5340	4612	5112	5428	4149
10.0	5225	4697	5227	5325	3953