MICRONUTRIENT NUTRITION OF MAIZE (*Zea mays* L.) AS INFLUENCED BY FERTILIZERS, HYBRIDS, IRRIGATION AND PLANT POPULATION DENSITY

by

© J.J.N POLIUS

A THESIS SUBMITTED TO THE FACULTY OF GRADUATE STUDIES
AND RESEARCH IN PARTIAL FULFILLMENT OF THE
REQUIREMENTS FOR THE DEGREE OF
MASTER OF SCIENCE

DEPARTMENT OF RENEWABLE RESOURCES
MACDONALD COLLEGE, McGILL UNIVERSITY
STE. ANNE DE BELLEVUE, PQ, CANADA

JANUARY 1987

Suggested short title:

MICRONUTRIENTS AND MAIZE PRODUCTION IN QUEBEC

J.J.N POLIUS

ABSTRACT

M.Sc. J.J.N. Polius Renewable Resources

Micronutrient nutrition of Maize (*Zea mays* L.) as influenced by fertilizers, hybrids, irrigation and plant population.

A field study was carried out to assess the effect of applied fertilizers, hybrids, irrigation and plant densities on the uptake of Cu, Zn and Mn in maize in Québec. A growth chamber experiment was conducted to investigate the effect of added N, P, $Ca(OH)_2$ and chelated micronutrients on Cu, Zn and Mn uptake by maize plants grown in surface samples of three Québec soils.

The field study showed that higher fertilization rates decreased soil pH and soil test Cu, and increased soil test Zn and Mn. Fertilization also increased plant uptake of Zn and Mn. Higher plant populations and higher yielding hybrids had higher uptake of Cu, Zn and Mn.

Irrigation was found to decrease uptake of micronutrients, and some leaching of micronutrients under irrigation may have occurred. In spite of high concentrations of micronutrients found in plants, especially at high fertilization, no toxicities were found.

The growth bench experiment demonstrated that chelates were able to maintain levels of available micronutrients in the three soils studied. Applied N and P did not decrease soil pH, but increased available Cu, Zn and Mn probably through physiological or soil exchange effects.

Fertilization effects were mainly due to N, and there were no adverse P x micronutrients interactions in plants.

RESUME

M.Sc. J.J.N. Polius Ressources renouvelables

La nutrition du maïs (*Zea mays* L.) en oligo-éléments influencée par les hybrides, la densité des plantes, la fertilisation et l'irrigation.

Une étude au champ a été établie afin d'évaluer l'effet des hybrides, de la densité des plantes, du taux de fertilisation et de l'irrigation, sur les prélèvements en Cu, Zn et Mn pour le maïs cultivé au Québec. Egalement, une expérience en chambre de croissance a été conduite afin d'établir l'effet de N, P, $Ca(OH)_2$ et des oligo-éléments sous forme de chélates sur l'utilisation du Cu, Zn et Mn par le maïs semé dans des échantillons de trois sols du Québec.

L'étude au champ a démontré que la fertilisation a décru le pH du sol et les niveaux de Cu, et a accru les niveaux de Zn et Mn disponibles. La fertilisation a également accru les prélèvements en Cu, Zn et Mn. Une forte densité des plantes ainsi que les hybrides à haut rendement ont enregistré des prélèvements élevés en Cu, Zn et Mn.

L'irrigation a décru les prélèvements en oligo-éléments, et il est possible que des pertes par lessivage aient eu lieu. En dépit des hautes concentrations d'éléments mineurs retrouvés dans les plantes, principalement en présence de fertilisation élevée, une nutrition équilibrée a néanmoins été obtenue sans toxicité visible.

L'expérience en chambre de croissance a démontré que les chélates ont pu maintenir constants les niveaux d'oligo-éléments disponibles dans

les trois sols étudiés. L'application de N et P n'ont pas décru le pH du sol mais a toutefois contribué à accroître les niveaux de Cu, Zn et Mn disponibles possiblement dû à un accroissement de la minéralisation de la matière organique.

Les effets de la fertilisation étaient surtout dûs à l'azote; les interactions P x éléments mineurs n'ont pas été néfastes pour les plantes.

ACKNOWLEDGEMENTS

The author expresses his deep appreciation to Dr. A.F. MacKenzie, Professor of Soil Science, Department of Renewable Resources, under whose direction this study was carried out, for invaluable assistance and guidance during the preparation of this thesis.

The author also thanks Peter Kirby, Brian Purcell, Marie Surprenant and Eddy St. George for their help and co-operation during the conduct of the field and growth chamber experiments; and Michel Rémillard, fellow graduate student, for his support and assistance during the course of the study.

The author is grateful to the Canadian Commonwealth Scholarship and Fellowship Committee for financial support by way of a scholarship and to the government and people of St. Lucia for granting him study leave.

Special thanks go to my wife Glenda and my parents for their love, moral support and encouragement especially during the crucial periods of my study in Canada.

FOREWORD

This thesis contains an overall introduction and literature review. The results are presented in two sections, the field work in chapter 2 and the growth chamber study in chapter 3. A combined summary and conclusion for both studies is presented in chapter 4.

TABLE OF CONTENTS

Table of Contents (cont'd)

Table of Contents (cont'd)

LIST OF TABLES

List of Tables (cont'd)

List of Tables (cont'd)

List of Tables (cont'd)

List of Tables (cont'd)

List of Tables (cont d)

List of Tables (cont'd)

List of Tables (cont'd)

LIST OF FIGURES

INTRODUCTION

Tisdale et al. (1985) describe maximum yield research as the study on the effect of one or more variables and their interactions in a multidisciplinary system that strives for the highest yield possible for the soil and climate of the research site. They also view maximum yield as a constantly moving target because of continuing technological advances.

Maximum yield studies in maize (*Zea mays* L.) can provide farmers with information as regards the yields that can be reached. Such maximum crop yields can be attained only if adequate amounts of plant nutrients, proper varieties, adequate water supply, optimum plant density and overall good management are provided within the production system. Inadequacies in any of the components could give rise to significantly reduced yields.

Maximum yield studies on maize in Canada are relatively new, with the first experiments conducted near Chatham, Ontario (Stevenson and Nuttall 1982). In 1984, maximum yield plots were established at Macdonald College, Ste. Anne de Bellevue, Quebec, and some aspects of this study will be reported here.

In the study, fertilizer level, plant population densities, plant varieties and irrigation were studied in an effort to obtain the maximum grain maize yield. The higher fertilizer rates are likely to increase the probability of nutrient imbalances. High fertilizer rates, especially where acid forming fertilizers are used, can result in a decrease in soil pH and a consequent increase in Al and Mn availability (Pierre et al. 1971; Kluthcouski and Nelson 1979).

Many investigators have noted that the application of high amounts of phosphate fertilizer depresses the uptake of Zn by maize. The more effectively the applied P is utilized by the plant, the more severe the induced Zn deficiency (Burleson et al. 1961). Excessive phosphate fertilizer has been found to reduce the availability of Cu, and increase that of Mn to maize plants (Bingham 1963).

Low soil moisture may induce or aggravate deficiences of Mn, while Zn deficiences are often associated with high soil moisture (Tisdale et al. 1985).

In responses to the above concerns, a study was undertaken with the following objectives.

(i) to assess the effect of applied fertilizers, hybrids, irrigation and plant densities on the Cu, Zn and Mn nutrition of maize plants, and

(ii) to determine if there is a depletion of soil micronutrient reserves under the maximum yield system.

This study is presented in four chapters. Chapter 1 discusses the relevant literature. Chapter 2 is concerned with the effect of hybrids, fertilizer rate, plant population and irrigation on the uptake and concentration of Cu, Zn and Mn; and the status of these nutrients in the soil. Chapter 3 deals with the effect of added N and P, chelated micronutrients and $Ca(OH)_2$ on the uptake of micronutrients in young maize plants grown on surface samples of three Quebec soils. Chapter 4 is a brief summary and conclusions of the study.

CHAPTER 1

LITERATURE REVIEW

1.1. Micronutrients in Plant Nutrition

1.1.1 Role of Cu, Zn and Mn in plant physiology

Micronutrients, though required in relatively small quantities by the plant, are nevertheless essential. Excellent reviews on the roles of Cu, Zn and Mn in plant nutrition have been given elsewhere (Mengel and Kirkby 1982; Price et al. 1972; and Tisdale et al. 1985), hence an exhaustive review will not be done.

Copper is a constituent of the chloroplast protein which forms part of the electron transport chain linking the two photochemical systems of photosynthesis (Boardman 1975), which affects starch production in the plant.

Zinc in plants is mainly involved in enzymatic reactions. It has been found to be required for the synthesis of tryptophan, an amino acid and precursor of indole acetic acid (Tsui 1948). Further evidence of the necessity of Zn was shown in the elimination of Zn deficiency symptoms by the addition of Zn or tryptophan to the nutrient medium of growing maize plants (Salami and Kenefick 1970). The total content of lysine and tryptophan were found to be significantly increased by the application of Zn (Orabi and Abdel-Aziz 1982).

Manganese functions in the plant by bridging ATP with some enzyme complexes (Lehninger 1975), and is also involved in the oxidation-reduction process in the photosynthetic electron transport system

(Cheniae 1970; Bishop 1971). Manganese at toxic levels is known to interfere with nitrate reductase activity in the root (Przemeck and Schrader 1981).

Thus these elements play a vital role in the biochemical processes and their uptake in the required amounts is crucial to healthy crop growth.

1.1.2 Uptake and translocation of Cu, Zn and Mn.

Copper is taken up by the plant in small quantities. The Cu content of most plants is generally between 2-20 mg kg^{-1} in the dry plant material with probable deficiencies when Cu levels fall below 4 mg kg^{-1} (Mengel and Kirkby 1982; Tisdale et al. 1985). Copper uptake appears to be a metabolically mediated process and there is evidence that Cu strongly inhibits the uptake of Zn and vice versa (Bowen 1969). However, the uptake of Cu is largely independent of competitive effects and relates primarily to the levels of available Cu in the soil. Copper is not readily mobile in the plant although it can be translocated from older to younger leaves. Results of Loneragan (1975) show that the movement of Cu is strongly dependent on the Cu status of the plant. In wheat plants well supplied with Cu, movement from the leaves to the grain readily occur, but in deficient plants Cu is relatively immobile. Generally, Cu deficiency in crops grown on mineral soils is not common. In corn, the youngest leaves become yellow and stunted, and as the deficiency becomes more severe, young leaves pale and older leaves die back.

The Zn requirement of most plants is small. The normal concentration range is 25 to 150 mg kg^{-1} in dry matter of plants.

Deficiencies of Zn are usually associated with concentrations of less than 20 mg kg^{-1} and toxicities will occur when the level exceeds 400 mg kg^{-1} (Tisdale et al. 1985). The uptake of Zn has been considered in a review by Loneragan (1975). However, it appears that there is considerable disagreement in the literature as to whether Zn uptake is active or passive. Moore (1972) held the view that on balance the evidence suggests that Zn uptake, like Cu, is metabolically controlled. The mobility of Zn in plants is not great. Zinc accumulates in root tissues especially when Zn supply is high. In older leaves Zn can become very immobile (Rinne and Langston 1960). The rate of Zn movement to younger tissues, like that of Cu, is particularly depressed in Zn deficient plants (Loneragan 1975).

Like the other micronutrients, the Mn requirement of plants is quite low. Normal concentrations of this element in plants are typically from 20 to 500 mg kg^{-1}. Deficiencies of Mn are usually associated with levels of between 15 and 20 mg kg^{-1} in the dry matter of upper plant parts (Mengel and Kirkby 1982). The uptake of Mn is also metabolically mediated (Moore 1972). In a similar way to other divalent cations species, Mn^{2+} participates in cation competition. Magnesium and Ca may depress Mn uptake through competition effects (Lohnis 1960; Maas et al. 1969). In the plant, Mn is relatively immobile and as such deficiency symptoms will appear in the young tissue. Most soils contain adequate levels of available Mn. However, on acid soils high in available Mn, plants can take up considerable amounts of Mn so that levels in the order of 1000 mg kg^{-1} in the dry matter are not uncommom (Mengel and Kirkby 1982). On such soils Mn toxicity is often observed and is aggravated by reducing soil conditions.

1.1.3 Foliar analyses for diagnostic purposes.

Monitoring the nutrient status of maize by means of foliar analysis is becoming an essential practice in modern production systems. The large amounts of fertilizer used with their high cost make foliar analysis an important tool in efficient fertilizer use. At the moment interpretation of foliar analysis data can be made according to the Critical Nutrient Level (CNL) approach or the Diagnosis and Recommendation Integrated System (DRIS) (Melsted et al. 1969; Sumner 1979)

The critical level of a nutrient has been defined as that concentration in a specific plant part at a specific stage of growth at which a 5 or 10 % reduction in yield occurs, or that concentration which is associated with the breaking point of the nutrient response curve, or that concentration which is at the transition between deficiency and sufficiency levels (Ulrich and Hills 1973). Though widely used, the CNL approach has some constraints, the most serious of which is its inability to deal adequately with variation in nutrient concentration on a dry matter basis with age.

To overcome this disadvantage three (3) approaches have been adopted. In the first, a set of critical values for different stages of growth has been proposed (Lockman 1972; Geraldson et al. 1973). In the second, the accumulation of dry matter with age is monitored in order to correct the nutrient concentration for increasing dry matter (Melsted et al. 1969). In the third, sufficiency ranges have been proposed such that the lower limit represents roughly the critical level while the upper is set at a value corresponding to an unusually high or toxic concentration (Geraldson et al. 1973; Jones and Eck 1973; Ward et al. 1973). Although sufficiency ranges are supposed to improve flexibility in diagnosis, they, in fact, decrease diagnostic precision because the limits are often too wide (Sumner 1979).

The DRIS is a relatively new approach that uses the principle of nutrient interrelationships in determining the order in which nutrients are most limiting, and such a diagnosis can be made at any stage of the crops development (Sumner 1982). A data base of approximately 10,000 observations of leaf nutrient (N, P, K, Ca, Mg, S, Fe, Mn, Zn, Cu, and B) concentrations and yield of maize grown in several U.S. states was used to establish the norms on corn leaves (Elwali et al. 1985). It would appear that once norms have been correctly established they are universally applicable, although increased precision can be obtained by limiting the development of norms to similar geographical regions (Escano et al. 1981). Comparisons of diagnostic precision between the two systems were made, and overall, DRIS was found to be superior to the critical value approach in that it was able to make valid diagnosis more frequently because variations due to tissue were taken into account (Sumner 1979).

1.2. Chemistry of Micronutrients in the Soil

The micronutrient content of a soil is dependent almost entirely on that of the rocks from which the soil parent material was derived and on the processes of weathering, both geochemical and pedochemical, to which the soil-forming materials have been subjected (Mitchell 1964).

Early workers recognised that although the total supply of trace elements in soils has a definite bearing on the amount delivered to the plant, factors which influence the available state, such as pH, mineral form, and solubility are more important in regulating absorption (Prince 1957).

1.2.1 Copper

Copper in soils is probably present chiefly as adsorbed Cu^{2+} and in soil solutions as the ions and various complexes (Krauskopf 1972). The solubility of soil Cu is influenced by the pH of the soil solution, and it increases 100-fold for each unit decrease in pH (Tisdale et al. 1985). Below pH 7.3 Cu^{2+} predominates while above this pH, $CuOH^{+}$ is most abundant (Lindsay 1971). Copper concentrations in soil solutions are generally much too low to be controlled by the solubility of copper minerals occuring in soils. Rather, solubility is believed to be governed both by adsorption reactions of Cu on the surfaces of Fe, Al, and Mn oxides and by bonding with organic matter (Tisdale et al. 1985). With the exception of Pb^{2+}, Cu^{2+} is the most strongly adsorbed of all the divalent transition and heavy metals on Fe and Al oxides and oxy-hydroxides.

Soil organic matter forms very stable complexes with Cu. Details of the reactions are extensively covered in other reviews (Hodgson 1963; Schnitzer 1969). The quantity of Cu held in solution phase against the strong adsorption effects of clay and organic matter is controlled by processes of chelation and complexation. It has been shown by Hodgson et al. (1966) that more than 98 % of the Cu in solution was in an organic complexed form, suggesting that in neutral soils very small quantities of free or aquated Cu^{2+} were available for adsorption reactions. As a result of this organic bonding, there is more dissolved Cu in the soil solution than normally occurs in the absence of organics. These soluble complexing agents, some from root exudates, also contribute to the mobility of Cu in soils and to the Cu flux by mass-flow and diffusion to plant roots (Nielsen 1976). Complexing agents are believed to aid Cu uptake by plants under conditions of low availability, such as high pH.

1.2.2 Zinc

The chemistry of Zn is simpler than that of Cu in that it shows only a simple valence in natural materials. In comparison to Cu, Zn migrates further from its source in soil, rocks and streams, and because of this behavior it is known as one of the most mobile of the heavy metals (Krauskopf 1972). Weathering of Zn minerals gives Zn^{2+} in solution. Unlike Cu^{2+}, the simple ion remains dominant to pH values of about 9. Not only are common Zn compounds soluble, but complex ions that might form with the inorganic anions usually present are too unstable to influence Zn solubility (Chester 1965). In basic solutions $Zn(OH)_2$ precipitates if the concentration of Zn^{2+} is high; this compound shows a minimum solubility at pH 9.5 and dissolves at higher pH values to form zincate ion, $Zn(OH)_4^{-}$.

Lindsay (1972), in a review on ionic equilibria, noted that the solubility of Zn^{2+} is highly pH dependent and decreases 100-fold for each unit increase in pH. Jahiruddin et al. (1985) suggest that Zn is held in a stable organically complexed form at elevated pH. In the absence of excess of a divalent cation such as Ca, increased solubility or dispersion of organic matter increases the amount of Zn in solution. Calcium addition however reprecipitates or flocculates the organic matter, along with associated complexed Zn. Jahiruddin et al. (1985) further suggest that Ca usually prevents significant organic matter solubilization, so that added Zn is very strongly absorbed by soil organic matter in the solid phase, increasingly so with increasing soil pH.

Zinc deficiencies induced in acid soils by over liming can be easily explained by this pH dependent relationship. According to Norvell and Lindsay (1970) the naturally occuring mineral compounds in the soil are sufficiently soluble so as not to have an effect on the small concentrations of Zn found in most soil solutions. Adsorption on clay minerals, hydrous oxides, and organic matter seems a much more likely control mechanism at pH 5-7 (McBride and Blasiak 1979). Because Zn^{2+} retains its double charge even to fairly high pH values, Zn should seemingly be more strongly adsorbed than Cu, which in near neutral solution exists as single-charged complexes like $CuOH^{+}$. On the other hand, the covalent bonds that hold Zn^{2+} to an adsorbing surface are less strong than the bonds that hold Cu^{2+} (Krauskopf 1972). It is then relatively easy to remove Zn from adsorbing surfaces, making it quite mobile. The transportation of Zn in solution is not a problem except in solutions containing sulphide ion. The solubility of Zn is also not affected by changes in redox potential. In soils Zn probably exists for the most part as the single ion adsorbed on fine-grained constituents.

1.2.3 Manganese

In its naturally occuring compounds Mn shows three valences (2^+, 3^+, 4^+). In reducing environments the most stable Mn compounds are those of Mn^{2+} and in strongly oxidizing environment the most stable compound is the dioxide, MnO_2 or pyrolusite (Krauskopf 1972). Manganese in soil usually exist as exchangeable Mn^{2+}. There is water soluble and insoluble organically bound Mn, easily reducible Mn, and various Mn oxides (Ghanem et al. 1971). These various forms are in a state of equilibrium with one another and they differ in their degree of availability to plants. The processes involved in maintaining this cycle are oxidation-reduction and production and decomposition of natural chelating agents that can complex manganese in both soluble and insoluble forms. General factors influencing the solubility of soil manganese include pH, redox potential, and complexation. Soil moisture, aeration, and microbial activity influence redox potential, while complexation is affected by organic matter and microbial activity.

In the soil solution, the principle ion species is Mn^{2+} and its concentration decreases 100-fold for each unit increase in pH (Lindsay 1971). Decreasing pH has been shown to enhance the conversion of reducible Mn to water soluble plus exchangeable Mn (Gotoh and Patrick 1972). Concentrations of Mn^{2+} measured in the soil solution of acid and neutral soil were found to vary from less than 0.01 mg kg^{-1} to almost 13 mg kg^{-1}, with levels commonly in the range 0.01 to 1 mg kg^{-1} (Krauskopf 1972). Because of the sensitivity of Mn^{2+} concentrations to pH, management practices that change soil pH will also influence the levels of soluble Mn. Organic matter reactions with Mn were important in acid and neutral soils since between 84 and 99 % of the Mn^{2+} was complexed (Krauskopf 1972).

Page (1962) suggested that the formation of complexes of Mn with organic matter in the soil may account for the observed relationship of Mn and pH. Part of the soluble Mn^{2+} can also be adsorbed on to clay and organic matter fractions in the soil. Mandal (1961) found that under reducing conditions Mn^{2+} ions were increased in solubility to the point where they become adsorbed as exchangeable ions. The early works of Heintze and Mann (1947, 1949) provide some evidence of Mn adsorption by soil organic matter, but there have since been few studies on adsorption reactions of Mn due perhaps to the fact that precipitation reactions exert control on Mn levels in the soil solution.

1.3. Macronutrient - Micronutrient Interactions

Adequate nutrition of plants with micronutrients depends on several factors other than the ability of the soil to supply these elements. Important growth factors include the rate of nutrient absorption, distribution of nutrients to functional sites and mobility in the plant. Interactions occur between the micronutrients as well as with some macronutrients in the soil-plant system. Some of these interactions are important since they modify the nutrition of crop plants. Macronutrient-micronutrient interactions have been reviewed by Olsen (1972), hence only selected interactions that affect Cu, Zn or Mn utilization, will be considered.

1.3.1 Zinc - phosphorus

The interaction of Zn and P has been one of the most extensively studied of the known nutrient interactions. Usually, the interaction is designated as a P-induced Zn deficiency. This disorder in plant growth is commonly associated with high levels of available P or with application of P to the soil. Olsen's (1972) review of P-Zn interactions surveyed results from many experiments conducted between 1936 and 1970. Numerous contradictions were found in the results leaving the impression that a true "cause and effect" mechanism for this phenomenon had not been found. It has been firmly established that P-induced Zn deficiency is not a result of precipitaion of $Zn_3(PO_4)_2$ in the soil or on roots, as such a precipitate was found to be more soluble than soil-Zn (Jurinak and Inouye 1962; Lindsay 1972; MacLean 1974; Racz and Haluschak 1974).

Some workers attribute Zn deficiency to a dilution effect due to increased growth resulting from applied P (Brown et al. 1970; Warnock 1970), but often no deficiency was found (Smilde 1973; Racz and Haluschak 1974; Armbruster et al. 1975). The lack of clear evidence had some workers suggesting that the manifestation of Zn-P interactions is influenced by other growth factors, such as genetic makeup (Giordano and Mortverdt 1969), Fe content of plant tissue (Warnock 1970) and metabolic rate of plant growth (Ganiron et al. 1969). Stukenholtz et al. (1966) suggested that P-related Zn deficiency was a metabolic malfunction of some sort, whereby P interfered with Zn translocation. However Smilde (1973) found no such evidence.

In recent times, the works of Loneragan et al. (1982) and Christensen and Jackson (1981) suggest that soil Zn deficiency interferes with P metabolism enhancing the amounts of P absorbed by roots and transported to tops. Thus under conditions of high P supply and low Zn, P accumulates to toxic levels in leaves inducing or accentuating symptoms resembling Zn deficiency.

1.3.2 Zinc - nitrogen

The application of high rates of N fertilizer can stimulate plant growth and increase Zn requirements beyond available supply. Viets et al. (1957) were able to separate the effects of N carrier on soil pH and total amount of plant growth. They found that pH exerted a greater and more consistent effect on Zn concentration and uptake by plants than the total amount of plant growth. Boawn et al. (1960) also confirmed a similar effect of pH on Zn concentration and uptake for sorghum and potatoes. Langin et al. (1962) observed that, generally, N fertilizer enhanced uptake of Zn despite substantial dilution caused by yield increases from N.

1.3.3 Copper - phosphorus

Phosphate applications in general were found to decrease Cu concentration in corn tissue (Safaya 1976). Bingham and Garber (1960) and Spencer (1966) reported similar effects of P on Cu concentration in some citrus species. Racz and Haluschak (1974) found P reduced Cu uptake by wheat seedlings in most soils, even though the water-extracted Cu content of the soil was increased by $NH_4H_2PO_4$ additions. The results of Safaya (1976) suggested that the effect of applied P on Cu may be an indirect one. A strong P x Zn interaction effect was apparent on the total uptake of Cu. At low P levels Zn reduced Cu uptake, whereas at high P levels Zn increased Cu uptake significantly.

1.3.4 Manganese - nitrogen

Fertilizer N has long been recognised to have maximum stimulative action on plant growth by reason of the numerous N functions related to growth. Thus uptake of most nutrients will be enhanced by N application. Nitrogen fertilizer is also associated with a lowering of soil pH and this frequently induces or intensifies Mn uptake and toxicity (Nelson 1977).

1.3.5 Manganese - phosphorus

Phosphate fertilizer will increase the level of soil-solution Mn in some soils, probably because of the acidic reactions of dissolved superphosphate or because of the acidity produced by the nitrification of NH_4-phosphate. Increasing amounts of water-extractable Mn tended to accompany increasing rates of $Ca(H_2PO_4)_2$, especially on non-calcareous soils (Bingham and Garber 1960; Racz and Haluschak 1974).

1.4. Influence of Some Agronomic Factors on Micronutrient Nutrition of Plants

1.4.1 Hybrid effect

Within a given environment, one hybrid or variety may produce a greater response to applied or indigenous nutrients than another hybrid or variety. The superior yield ability of a given hybrid or variety may be determined in part by its greater efficiency in absorbing and utilizing certain nutrients from the soil (Murphy et al. 1981; Hatlitligil et al., 1984). Terman et al. (1975) noted that differences in nutrient absorption among maize hybrids appear to be greatly influenced through genetic effects on growth rates and yield potentials.

1.4.2 Plant population effects

There is limited information on the effect of plant population on the micronutrient nutrition of plants. However, one can assume that the associated greater root mass at high population densities would result in a greater demand on soil nutrients, leading to possible deficiencies. One study (Godo and Reisenauer 1980) noted that there was an effect of root exudates in increasing soil Mn solubility through reduction of MnO_2 and complexing the divalent Mn released. Hence it is possible to have a higher uptake of Mn under high plant populations.

1.4.3 Fertilizer application effects

The maximum yield concept is directly related to fertilizer efficiency. The higher-yielding crops, with more extensive root systems and with a greater nutrient needs, will take up more of the applied and indigenous nutrients. The use of high rates of fertilizer in order to maximize yield could create undesirable effects in the soil-plant system. Most of the reported undesirable effects of applied fertilizer refer to soil acidification and the associated toxicity of micronutrients, Al and Mn (Randall et al. 1975; Murphy et al. 1981; Hoyt and Henning 1982; Petrie and Jackson 1984a; 1984b).

1.4.4 Irrigation effects

Irrigation effects on micronutrients, would most likely result in an increased uptake due to increased plant growth. A large portion of the Cu, Zn and Mn reaching the root surface does so by mass flow and diffusion (Barber and Olson 1968). These processes would most likely be enhanced under irrigation. In the case of Mn, reducing conditions at the microsite level could give rise to high concentrations of Mn^{2+} in certain areas in the soil. Hatlitligil et al. (1984) found increased uptake of Mn and Fe by corn under higher irrigation levels quite out of proportion to observed yield increases.

As a result of this review of the literature, it seemed clear that added N and P could influence micronutrient uptake and nutrition of corn plants. Thus it was decided to undertake a study of the following hypotheses:

1. Micronutrient imbalance will arise in maize treated with high rates of N and P.
2. Interactions of N and P with micronutrients will cause deficiencies in plant Cu and Zn
3. Acidification of soil by NH_4 containing fertilizer may cause Mn toxicity in plants.

CHAPTER 2

EFFECTS OF HYBRID, PLANT POPULATION, FERTILIZER RATE AND IRRIGATION ON ZINC, COPPER, AND MANGANESE IN SOIL~~, AND~~ PLANT TISSUE OF MAIZE (*Zea mays* L.)

2.1 INTRODUCTION

Generally micronutrient disorder symptoms in maize production in Quebec are not widespread. However, the possibility that micronutrients might be limiting in maximum yield corn production has been indicated by the work of Roy Flannery (1982) in the USA where significant yield responses to micronutrients occured at high fertility levels. Also, most nutrients were found to be well above concentration levels now considered adequate for good yields, suggesting that higher critical levels may be needed for higher yields. Stevenson and Nuttall (1984) also found higher concentrations of micronutrients at high fertility.

The purpose of the work reported here was to provide information on the effect of fertilizer rate, population density, hybrid and irrigation on the Cu, Zn and Mn uptake of the maize crop.

2.2. MATERIALS AND METHODS

Procedures used in the field have been detailed elsewhere (M. Remillard, 1986. Maximum yield studies with corn in Quebec. M Sc. thesis. Faculty of Graduate Studies and Research, McGill Univ.), but some of the most important procedures are noted here for the convenience of the reader.

2.2.1 Field Experiment

2.2.1.1 Site description

The experimental site was located at the Macdonald College farm on the Chicot soil series, a sandy clay loam (Gleyed melanic brunisol).

2.2.1.2 Experiment design

The experiment was a 2x2x2x2 factorial in a randomized complete block design with treatments of 2 hybrids, 2 plant populations, 2 fertilizer rates and 2 soil moisture regimes. The 16 treatment combinations were replicated 4 times for a total of 64 experimental units. The treatments and levels were as follows:-

Hybrid:-

In 1984 the hybrids used were Pioneer 3925 and Pioneer 3949. In 1985 Pioneer 3949 was replaced by Co-op 2645.

Plant populations:-

Two plant populations were used, 90000 and 65000 plants per hectare (pph).

Fertilizer rates:-

Nitrogen (N), phosphorus (P_2O_5), and potassium (K_2O) were applied at a normal rate of 170 - 100 - 170 kg/ha (N-P_2O_5-K_2O) and a high rate of 400 - 300 - 400 kg/ha (N - P_2O_5-K_2O).

Irrigation:-

The water regimes were irrigation and no irrigation. Irrigation water was applied using bi-wall drip irrigation tubing and drip tape tubing in 1984 and 1985 respectively. Irrigation scheduling was done using tensiometers at two depths, 15cm and 30cm. Irrigation was normally scheduled when tensiometer readings reached).015 MPa.

2.2.1.3 Site establishment and management

2.2.1.3.1 Land preparation

The site was ploughed with a moldboard plow in the fall of 1983 and 1984 at a depth of 20 and 25 cm respectively. Secondary tillage in the spring consisted of two passages of a disk harrow at a depth of 10cm followed by one passage of a spring tooth harrow.

2.2.1.3.2 Seeding and thinning.

The plots were seeded on May 7 in 1984 and May 2 in 1985. In 1984, maize was seeded at a depth of 5 cm using an International Harvester 2 row planter with row widths of 37.5 cm. A Gaspardo planter with 4 adjustable planters was used in 1985, with row width and seeding depth the same as in 1984.

All plots were seeded at rate of 270,000 seeds per hectare and later thinned to plant populations of 65000 and 90000 when the corn reached the three to four leaf stage.

2.2.1.3.3 Weed control

Quackgrass (Agropyron repens L.) infestation was controlled by the application of glyphosate at the rate of 2.1 kg/ha prior to secondary tillage in the two years. In 1984, broadleaf weeds were controlled with an application of 4.3 kg/ha of Alachlor (9 l/ha of Lasso, Monsanto Ltd) and 1.75 kg/ha of atrazine (3.5 l/ha of liquid atrazine), preplant incorporated. Post-emergence weed control was done with an additional 1.75 kg/ha of atrazine together with two sessions of hand hoeing. In 1985, broadleaf weeds were controlled with an application of 5.6 kg/ha Butylate (7.0 l/ha of Sutan, Stauffer Co.) and 1.75 kg/ha of atrazine (3.5 l/ha of liquid atrazine), preplant incorporated. Post emergence weed control was not necessary in 1985.

2.2.1.3.4 Pest control

In 1985 0.05 g per linear meter of Dyfonate (Stauffer Co.) was applied to the soil at seeding to prevent corn root worm (*Diabrotica barberi* SL.) damage; none was applied in 1984 and corn root worm damage did not occur. On June 22, 1984, 100 g/ha of Permethrin (Ambush, Chipman & Co) was sprayed on the corn plants to control cut worm damage; there was no such damage in 1985 and therefore no treatment was applied. On July 20, 1984, 15 kg/ha of Furadan 10G (Chemagro Ltd.) was applied to control European corn borer (*Ostrinia nubilalis* HBN.). In 1985, two separate applications of 12 kg/ha of Ambush 1G (Chipman) were made on July 4 and 12 to control European corn borer.

2.2.1.4 Fertilizers and amendments

2.2.1.4.1 Fertilizer application

Fertilizer application rates, nutrient carriers, and method and time of application for 1984 and 1985 are summarized in Tables 2.1 and 2.2 respectively. Micronutrients were applied over the experiment site before secondary tillage, and disked into the soil surface. The micronutrient carriers and rates of application in 1984 and 1985 are presented in Table 2.3.

Table 2.1. Types and amounts of fertilizer materials with time of application for the 1984 growing season.

NORMAL RATE								
N	P_2O_5	K_2O	Mg	S		Carrier	Rate	Method and time of application
kg/ha							kg/ha	
149	0	0	0	0		Urea[1]	324	SPPI[5]
21	100	0	0	0		MAP[2]	190	Banded[6]
0	0	140	0	0		Potash[3]	233	SPPI
0	0	30	15	30		PMS[4]	136	SPPI
170	100	170	15	30	Total			

HIGH RATE								
N	P_2O_5	K_2O	Mg	S		Carrier	Rate	Method and time of application
kg/ha							kg/ha	
358	0	0	0	0		Urea	788	SPPI
0	100	0	0	0		TSP[7]	217	SPPI
42	200	0	0	0		MAP	380	Banded
0	0	370	0	0		Potash	617	SPPI
0	0	30	15	30		PMS	136	SPPI
400	300	400	15	30	Total			

1) Urea (46% N)
2) MAP = monoammonium phosphate (11% N and 52% P_2O_5)
3) Potash = potassium chloride (60% K_2O)
4) PMS = potassium magnesium sulphate (22% K_2O 11% Mg and 22% S)
5) SPPI = spring preplant incorporated
6) Banded = 5 cm besides and 5 cm below seed at planting.
7) TSP = triple super phosphate (46% P_2O_5)

Table 2.2. Types and amounts of fertilizer material with time of application for the 1985 growing season.

NORMAL RATE

N	P_2O_5	K_2O	Mg	S		Carrier	Rate	Method and time of application
-----------	kg/ha	------------					--kg/ha--	
149	0	0	0	0		Urea[1]	324	SPPI[7]
21	100	0	0	0		MAP[2]	190	Banded[8]
0	0	140	0	0		Potash[3]	233	SPPI
0	0	30	15	30		PMS[4]	136	SPPI
170	100	170	15	30	Total			

HIGH RATE

N	P_2O_5	K_2O	Mg	S		Carrier	Rate	Method and time of application
-----------	kg/ha	------------					--kg/ha--	
0	100	0	0	0		TSP[5]	217	FPPI[9]
0	0	100	0	0		Potash	167	FPPI
149	0	0	0	0		Urea	324	SPPI
42	200	0	0	0		MAP	380	Banded
0	0	270	0	0		Potash	450	SPPI
0	0	30	15	30		PMS	136	SPPI
105	0	0	0	0		AN[6]	308	SD[10] (June 10)
52	0	0	0	0		AN	153	SD (July 8)
52	0	0	0	0		AN	153	SD (July 30)
400	300	400	15	30	Total			

1) Urea (47% N)
2) MAP = monoammonium phosphate (11% N and 52% P_2O_5)
3) Potash = potassium chloride (60% K_2O)
4) PMS = potassium magnesium sulphate (22% K_2O 11% Mg and 22% S)
5) TSP = triple superphosphate (46% P_2O_5)
6) AN = ammonium nitrate (34% N)
7) SPPI = spring perplant incorporated
8) Banded = 5 cm beside and 5 cm below seed at planting
9) FPPI = fall preplant incorporated
10) SD = side-dressed

Table 2.3 Boron, zinc and manganese rates and carriers used in 1984 and 1985.

Micronutrient	Element rate	Carrier rate	Carrier
	---kg/ha---	---l/ha---	
B	0.361	2.57	Sodium Borate[1] (10% B)
Zn	0.412	5.00	Zinc chelate[2] (7% Zn)
Mn	0.12	2.00	Mn Chelate[3]. (5% Mn)

1) Sodium borate carrier weighed 1.28 kg/l
2) Zinc chelate weighed 1.18 kg/l (Oligosol Ltd)
3) Manganese chelate weighed 1.20 kg/l (Oligosol Ltd)

2.2.1.4.2 Liming

The site was limed in spring of 1985 on a plot by plot basis in order to obtain a pH of 6.0. Calcium hydroxide ($Ca(OH)_2$, as the liming material, was hand applied and disked in with the fertilizer to a depth of 10 cm. Rates of liming material were based on laboratory incubation studies which followed the procedures of Shoemaker et al (1961).

2.2.1.4.3 Manure application

In the fall of 1984, cattle manure was applied and plowed down. Manure was applied with a conventional farm-type manure spreader transversely on a replicate by replicate basis. The rate of manure application is given in Table 2.4.

Table 2.4. Rate of application of cattle manure applied in November 1984

Replicate	Rate of application (DMB)[1]
	--------Mg ha^{-1}--------
1	2.81
2	4.41
3	4.74
4	4.48

1) DMB=dry matter basis

2.2.1.5 Sampling

2.2.1.5.2 Soils

Soils were sampled for chemical analysis in the spring prior to fertilizer application and in fall after harvesting, at a depth of 0-25 cm using a T-sampler.

2.2.1.5.2 Plants

Tissue was sampled at different growth stages as defined by Hanway (1963). Plant parts and the growth stage at which tissues were sampled in both years are presented in Table 2.5. In both years, grain was sampled when physiological maturity was reached, which corresponds to Hanway's growth stage 10, using the kernel milk line and black layers as maturity indicators (Crookston and Afuakwa 1983). Grain and stover were harvested according to a modification of the procedures of Stevenson (1984).

Table 2.5 Plant parts and various growth stages at which tissue was sampled in 1984 and 1985.

Growth stages		Plant parts	
1984	1985	1984	1985
2*	2	Whole plant	Whole plant
-	3	Whole plant	Whole plant
4	4	Whole plant	Leaf, stalk
5	5	Ear leaf	Ear leaf
10	10	Stover, grain	Stover, grain, leaf, stalk

2.2.2 Laboratory Procedures

2.2.2.1 Soils

Soil samples were dried at 105°C and ground to pass a 2-mm sieve prior to Cu, Zn, Mn, and pH determinations. Extractable Cu, Zn, and Mn were determined by the diethylenetriaminepentaacetic acid (DTPA) method as outined by Baker and Amacher (1982). The procedure involved the shaking, for exactly 2 hours, of 10 g of dried soil in a 125-ml flask with 20 ml of DTPA solution. The extracted micronutrients were measured on an atomic absorption spectrophotometer (Perkin-Elmer A A model 2380). Soil pH was measured using a soil:water ratio of 1:2.5 (McLean 1982).

2.2.2.2 Plants

Tissue samples were dried at 70°C and ground using a macro- and micro-Wiley mill to pass a 20-mesh screen. Plant parts were weighed and the dry matter yields were determined. A sub-sample of 0.5 g was digested in a block digestor using hydrogen peroxide (30% H_2O_2) and concentrated H_2SO_4 (Thomas et al. 1967). The digests were diluted to a known weight (50 g) with deionized water, and the amounts of Cu, Zn, Mn, Ca, and Mg in solution were measured with an atomic absorption spectrophotometer (Perkin-Elmer A A model 2380). The "Technicon" auto-analyser (Technicon Inc., Tarrytown NY) was used to measure NH_4-N by the alkaline phenolhypochlorite test described by O'Brien and Fiore (1962), and P by a modification of the chloro-stannous-reduced molybdophosphoric blue colour technique of Jackson (1962). Potassium was measured with a "Technicon" flame photometer.

2.2.3 Use of the Diagnosis and Recommendation Integrated System (DRIS)

The tissue analysis results for concentrations of N, P, K, Ca, Mg, Cu, Zn and Mn in the whole plant or leaves were used in calculating nutrient indices for the DRIS approach to diagnosing nutrient insufficiences and imbalances. The procedures for calculating DRIS have been outlined by Cornforth and Steele (1981), Elwali and Gascho (1984) and Sumner (1977a; 1977b). A computer programme developed by Letzsch and Sumner (1983) was used. The Nutritional Balance Index (NBI) was calculated by adding values of DRIS indices irrespective of sign. The larger the value of the NBI, the greater was the intensity of imbalances among nutrients at the time of sampling.

2.2.4 Terminology

The term "concentration" will denote a mass ratio such as milligrams per kilogram. Further, "uptake" will be used when referring to the total quantity of nutrient in the plant, either in the above-ground portion of the plant, or some tissue such as leaves, grain, stalks or stover.

2.2.5 Statistical Analysis

Analysis of variance of the results were performed using the Statistical Analysis System (SAS) (Barr et al. 1979). Differences among means was obtained using Duncan's new multiple range test (DMR) for main effects and the Least Significant Difference (LSD) test for interaction effects (Steel and Torrie 1980). Letters were used to differentiate means where analysis of variance was carried out on data sets with unequal numbers of replicates. Where replicates were equal, LSD values were used. Correlation and regression analyses were done using the GLM procedures of the Statistical Analysis System (SAS) (Barr et al. 1979)

2.3. RESULTS

2.3.1 Soil Effects

A summary of the probabilities associated with the F-statistic of some of the treatment effects on DTPA-extractable Cu, Zn, Mn, and soil pH at the end of the growing season in 1984 and 1985 is presented in Appendix I

2.3.1.1 Soil pH

Results showed that at normal fertilizer rate in 1984 there were no differences in soil pH with or without irrigation (Table 2.6). However, at the high rate of fertilizer the pH was lower where irrigation was absent. In 1985, the high fertilizer rate was associated with significantly lower soil pH.

2.3.1.2 Soil Cu

There was a significant hybrid - plant population effect on DTPA-extractable soil Cu in 1985 (Table 2.7), in that at high plant populations of Pioneer 3925 the soil Cu level was reduced.

2.3.1.3 Soil Zn

In 1984 there was a hybrid - fertilizer rate effect on soil Zn. The nature of the interaction was not consistent, with the hybrids having differing effects at each fertilizer rate (Table 2.8). There was no siginificant effect of treatments on soil test Zn in 1985.

2.3.1.4 Soil Mn

In 1985 there was a hybrid - plant population effect on soil test Mn (Table 2.9). Pioneer 3925 plots were lower in Mn at high populations. In

1985 there was a plant population - fertilizer - irrigation effect on soil test Mn (Table 2.10). Under high plant populations, high fertilizer rates and irrigation, there was a significantly higher value of soil test Mn than with non-irrigated or low plant populations. However, under high plant population and at high fertilizer rate, soil test Mn value under irrigation was higher than under non-irrigated conditions.

Table 2.6. Effect of fertilizer - irrigation and fertilizer on the pH of surface soil in fall of 1984 and 1985 respectively.

$N - P_2O_5 - K_2O$ Rates (kg/ha)	1984 Irrigation: Yes	1984 Irrigation: No	1985
	-------pH-------		--pH--
170 - 100 - 170	5.07a+	5.05a	5.68a
400 - 300 - 400	5.13a	4.83b	5.53b
CV(%)	4.98		3.47

+ means for each year, having a common letter are not significantly different (p=0.05) according to the LSD test.

Table 2.7. Effect of hybrid - plant population on the DTPA-extractable copper from surface soil sampled in fall 1985.

Hybrid	Plant Population (pph): 65000	90000
	------mg/kg------	
Pioneer 3925	1.03a+	0.76b
Co-op 2645	0.98a	1.00a
CV(%)=29.9		

+ means in the body of the table, having a common letter are not significantly different (p=0.05) according to the LSD test

Table 2.8. Effect of hybrid - fertilizer on the DTPA-extractable zinc of surface soil sampled in fall 1984.

Hybrid	N - P_2O_5 - K_2O Rates (kg/ha) 170 - 100 - 170	400 - 300 - 400
	--------mg/kg--------	
Pioneer 3925	1.53ab	1.37b
Pioneer 3949	1.27b	1.66a*
CV(%)=26.2		

* means in the body of the table, having a common letter are not significantly different (p=0.05) according to the LSD test.

Table 2.9. Effect of hybrid -plant population on DTPA-extractable manganese from surface soils sampled in fall of 1985.

Hybrid	Plant Population (pph) 65000	90000
	--------mg/kg--------	
Pioneer 3925	31.7a*	26.4b
Co-op 2645	29.3ab	31.3a
CV(%)=18.3		

* means in the body of the table, having a common letter are not significantly different (p=0.05) according to the LSD test.

Table 2.10. Effect of plant population - fertilizer - irrigation on DTPA-extractable manganese in surface soils in fall of 1985.

Plant Population	$N - P_2O_5 - K_2O$ Rates (kg/ha)			
	170 - 100 - 170 Irrigation		400 - 300 - 400 Irrigation	
	Yes	No	Yes	No
---pph----	------mg/kg------			
65000	32.3	29.6	28.9	31.3
90000	26.3	27.0	34.5	27.4

CV(%)=18.3 $LSD_{0.05}$=5.5 mg/kg

2.3.2 Plant Growth Responses

The probabilities associated with the F-statistic of the treatment effect on dry matter yields, and content and uptake of Cu, Zn, and Mn at the various growth stages in 1984 and 1985 are presented in Appendix II

2.3.2.1 Dry matter accumulation during the growing seasons.

In general, the total accumulation and rate of dry matter accumulation was greater in 1985 than 1984. The rate of dry matter accumulation was highest during the period between 40 and 80 days after emergence in both years (Figures 1, 2, 3 and 4). Treatment differences, within any one season, and between seasons, were noticeable when plants passed stage 4, about 80 days after emergence.

Figure 1. Dry matter accumulation over growing season

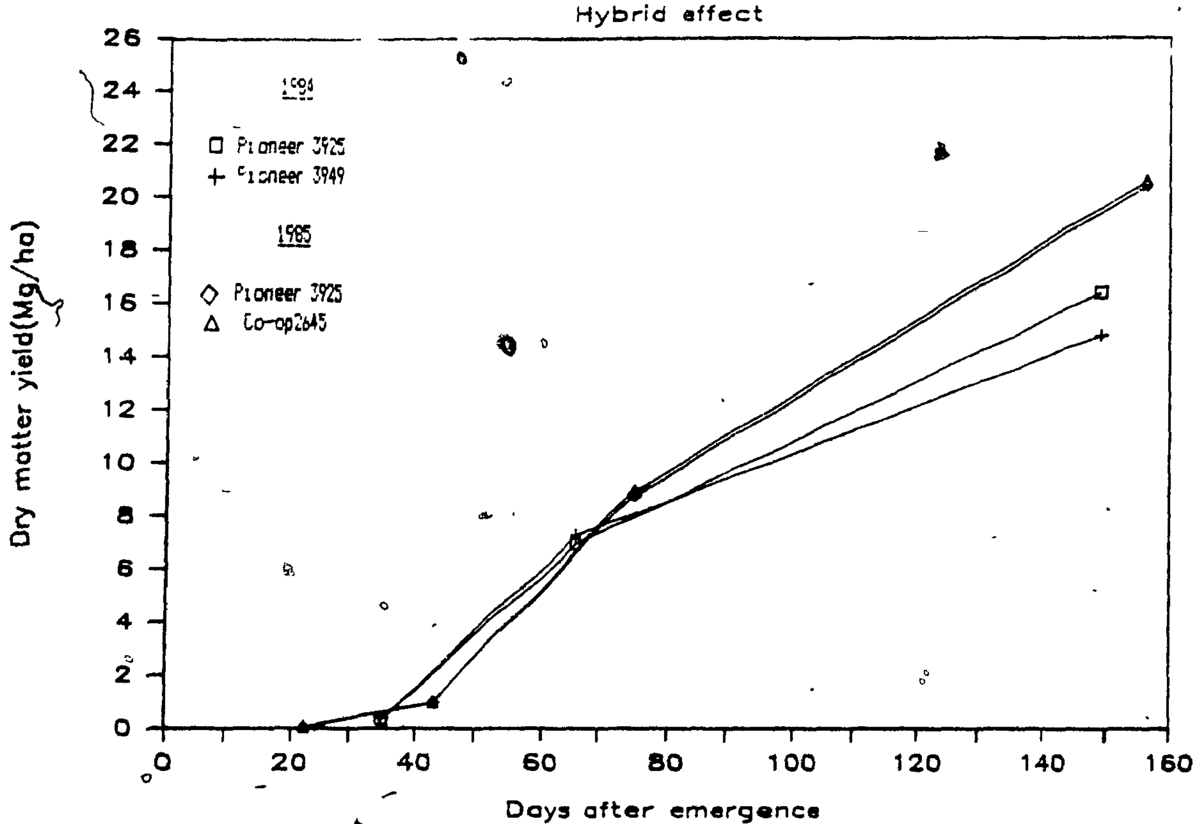


Figure 2. Dry matter accumulation over growing season

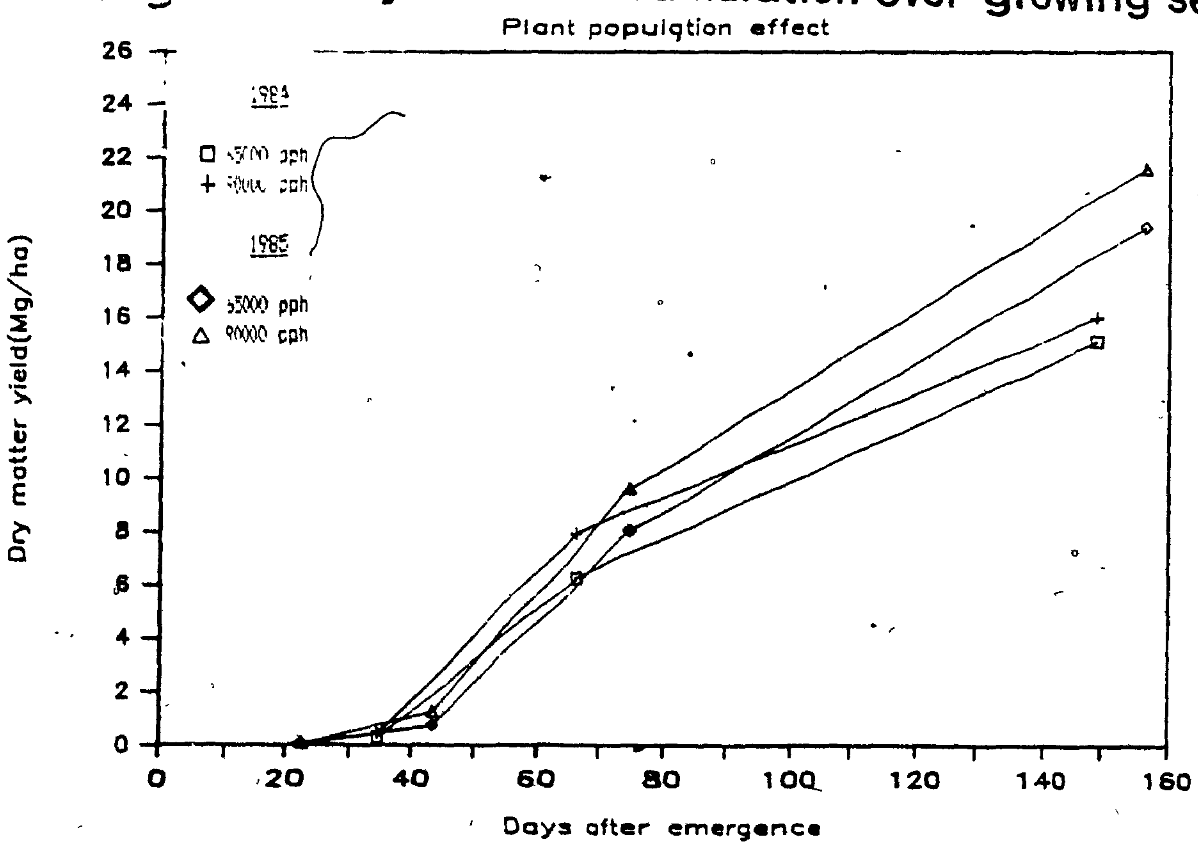


Figure [illegible]. Dry matter accumulation over growing season

Fertilizer effect

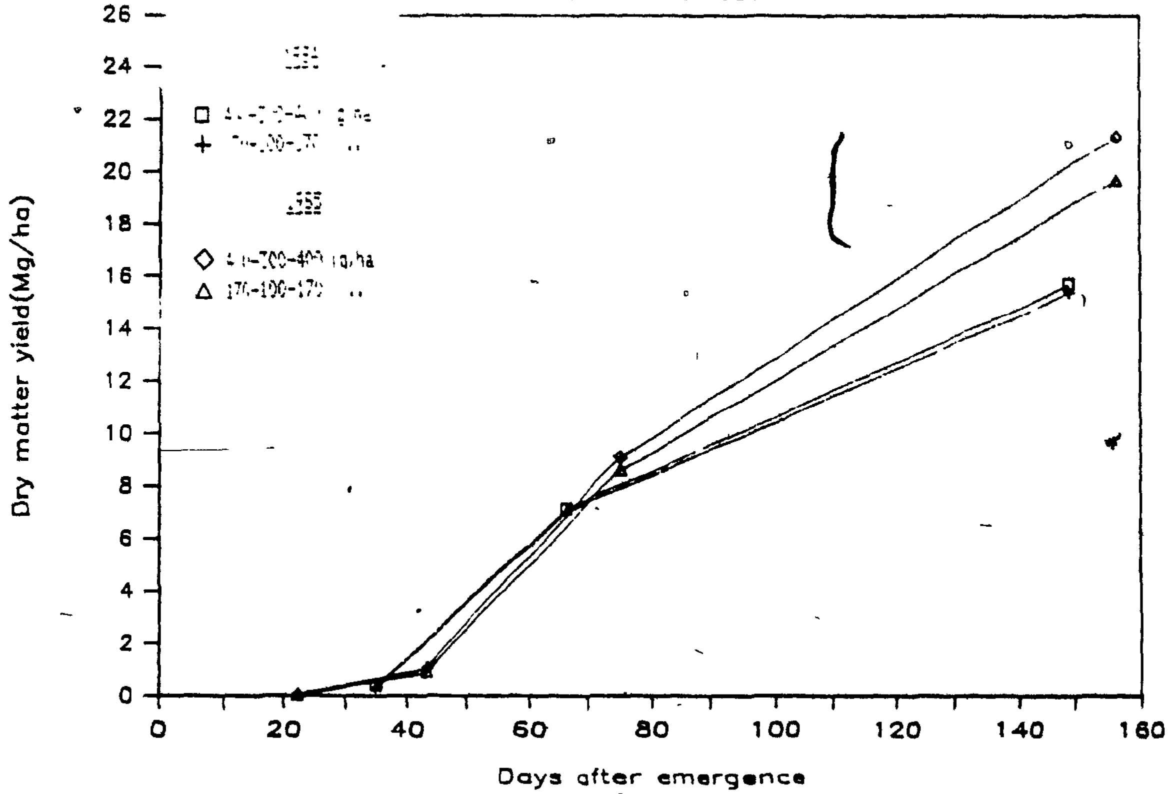
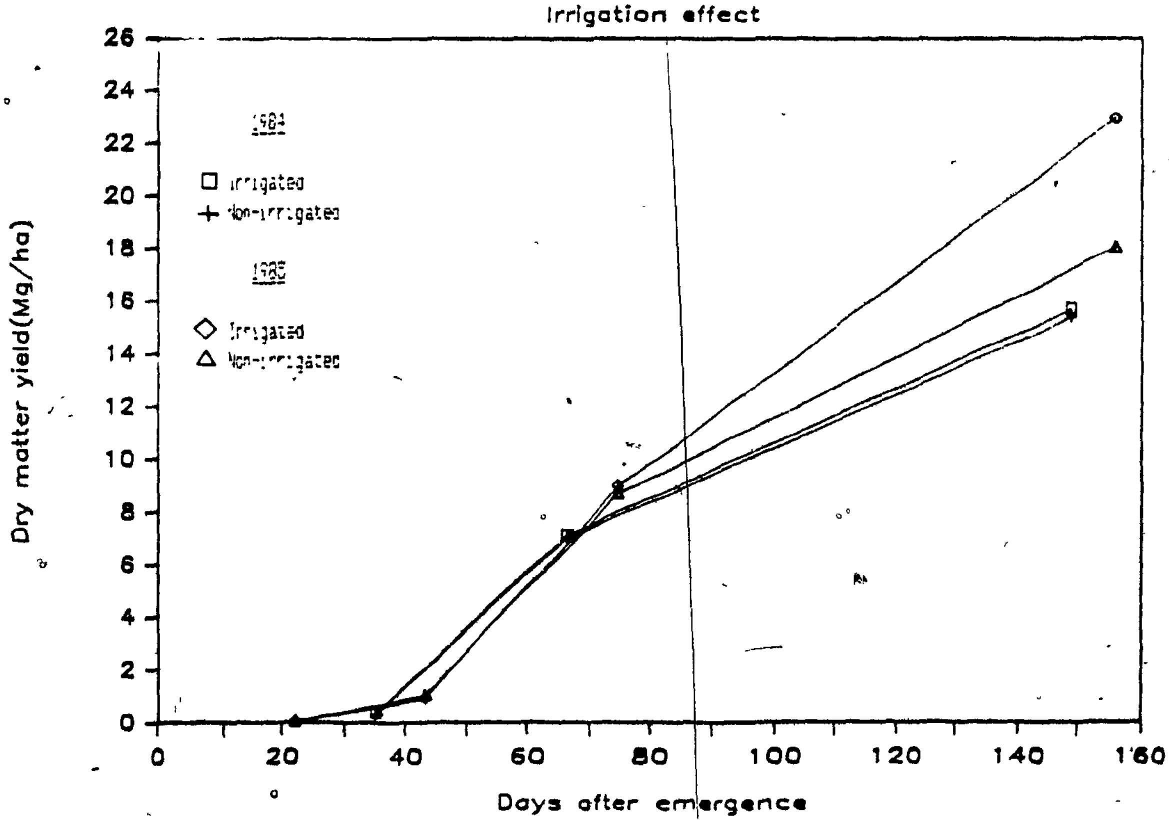


Figure 4. Dry matter accumulation over growing season

Irrigation effect



2.3.2.2 Plant tissue copper

In general, uptake of Cu with time as a function of hybrid, population density, fertilizer rate and irrigation followed a sigmodial curve (Figures. 5, 6, 7, and 8)

2.3.2.2.1 Growing season 1984

High plant population resulted in a greater uptake of Cu by the whole plant at growth stage 2+ and 4 only (Table 2.11). At growth stage 4, Pioneer 3949 had a lower concentration and uptake of Cu in the whole plant when irrigated (Table 2.12). At growth stage 5 the Cu concentration in the ear-leaf was found to be lower where high fertilizer rates were used, compared to the normal rate; and Cu was lower with irrigated than non-irrigated plants (Table 2.13). At harvest in 1984, Cu concentration in the grain of plants at low population and normal fertilizer rate, was increased by irrigation (Table 2.14).

Figure 5. Cu uptake over growing season

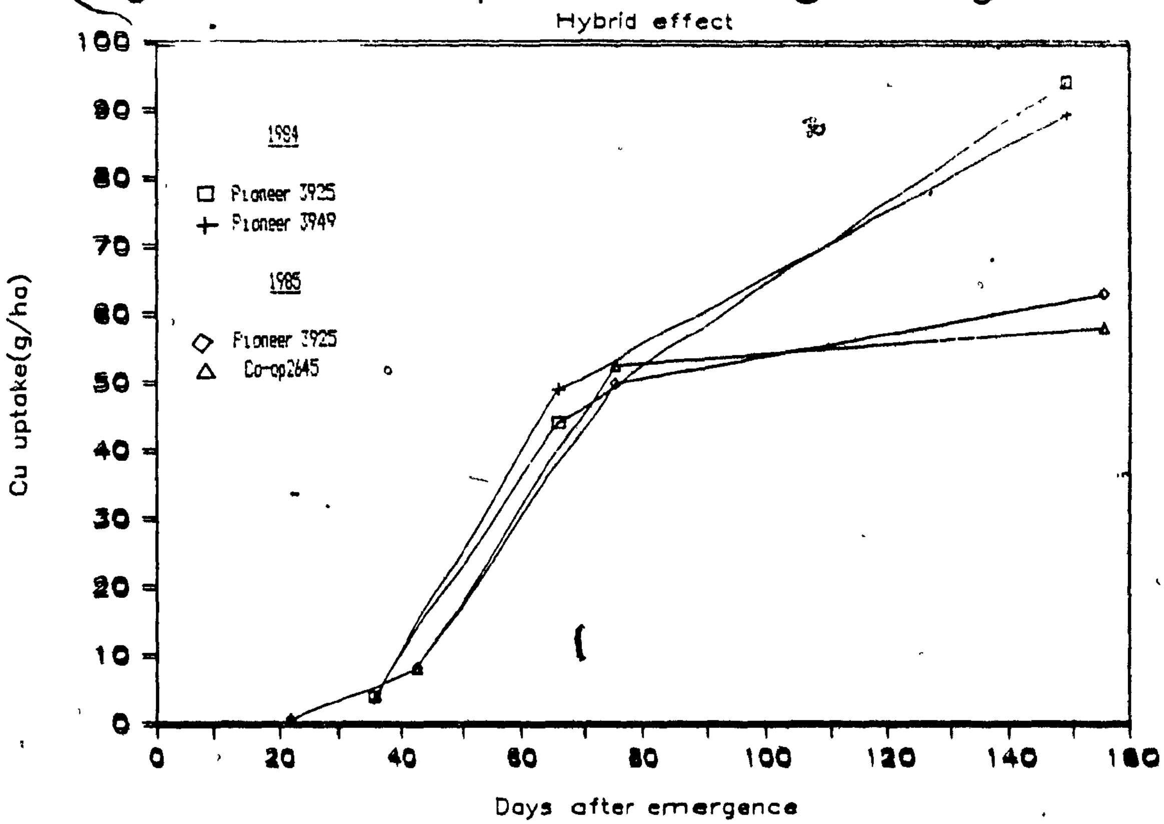


Figure 6. Cu uptake over growing season

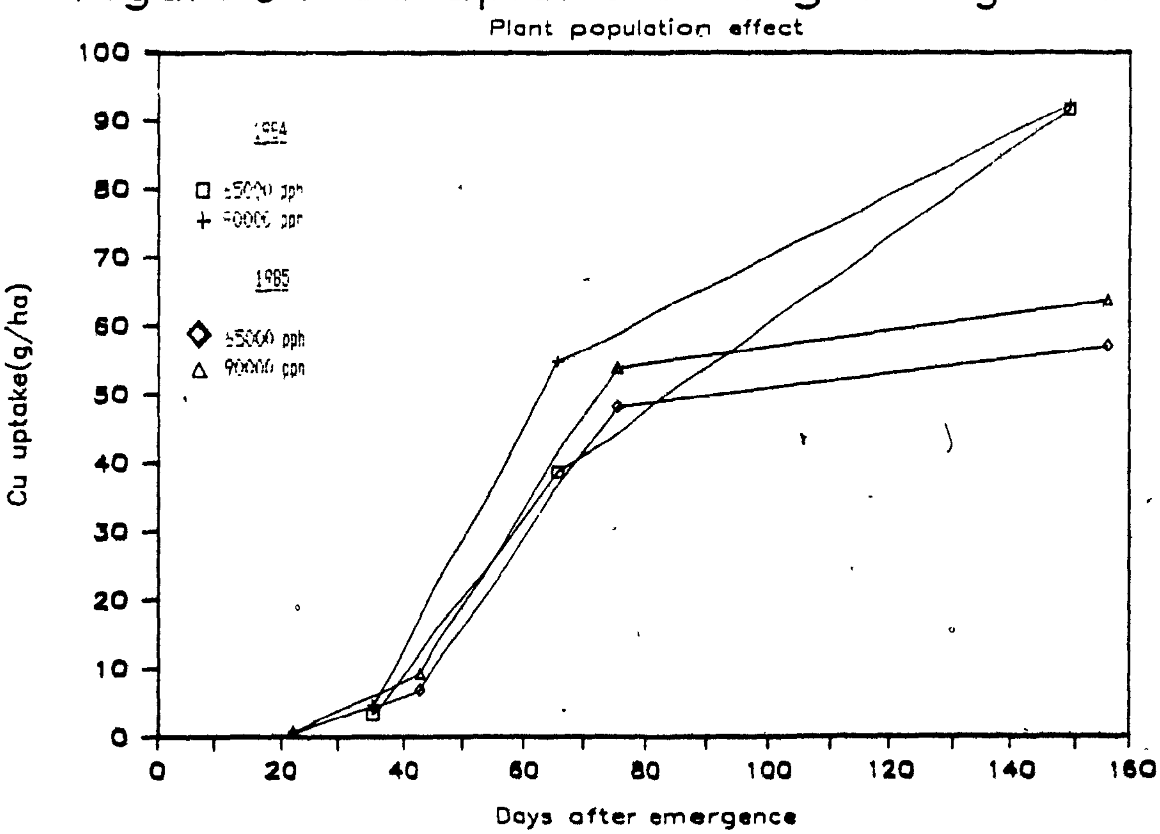


Figure 7. Cu uptake over growing season

Fertilizer effect

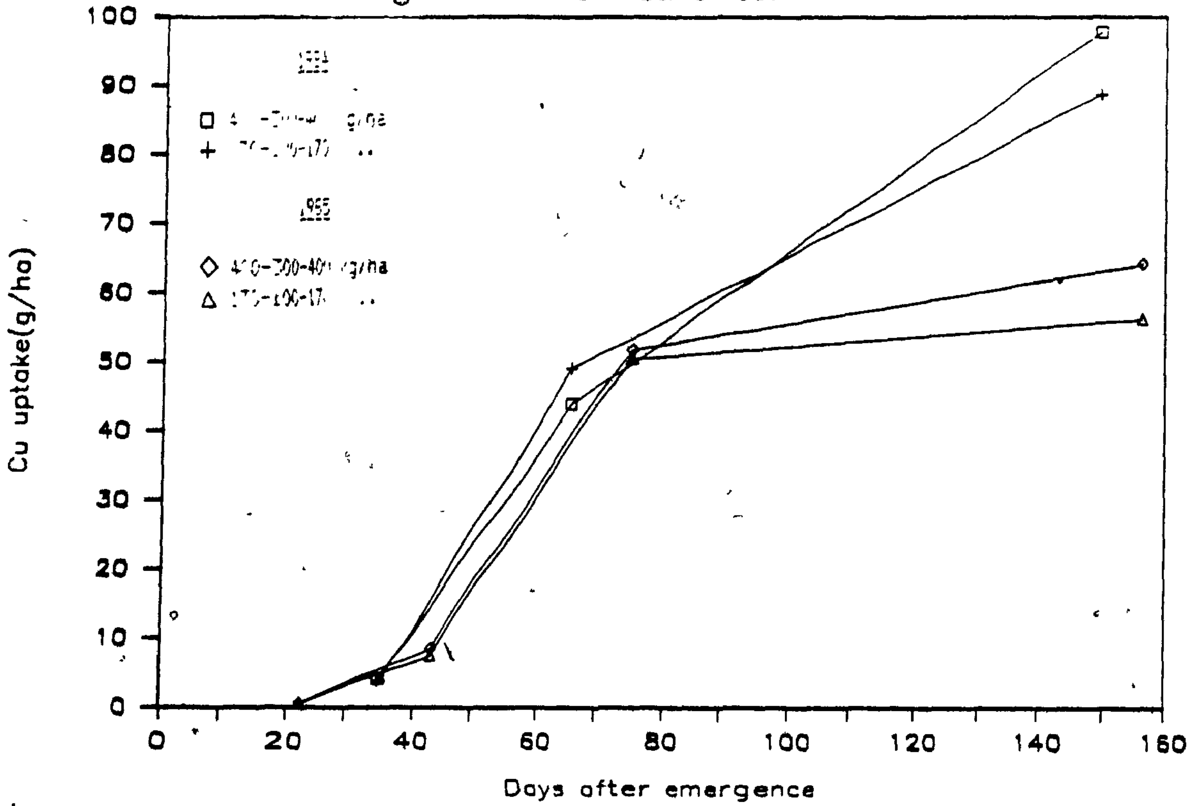


Figure 8. Cu uptake over growing season

Irrigation effect

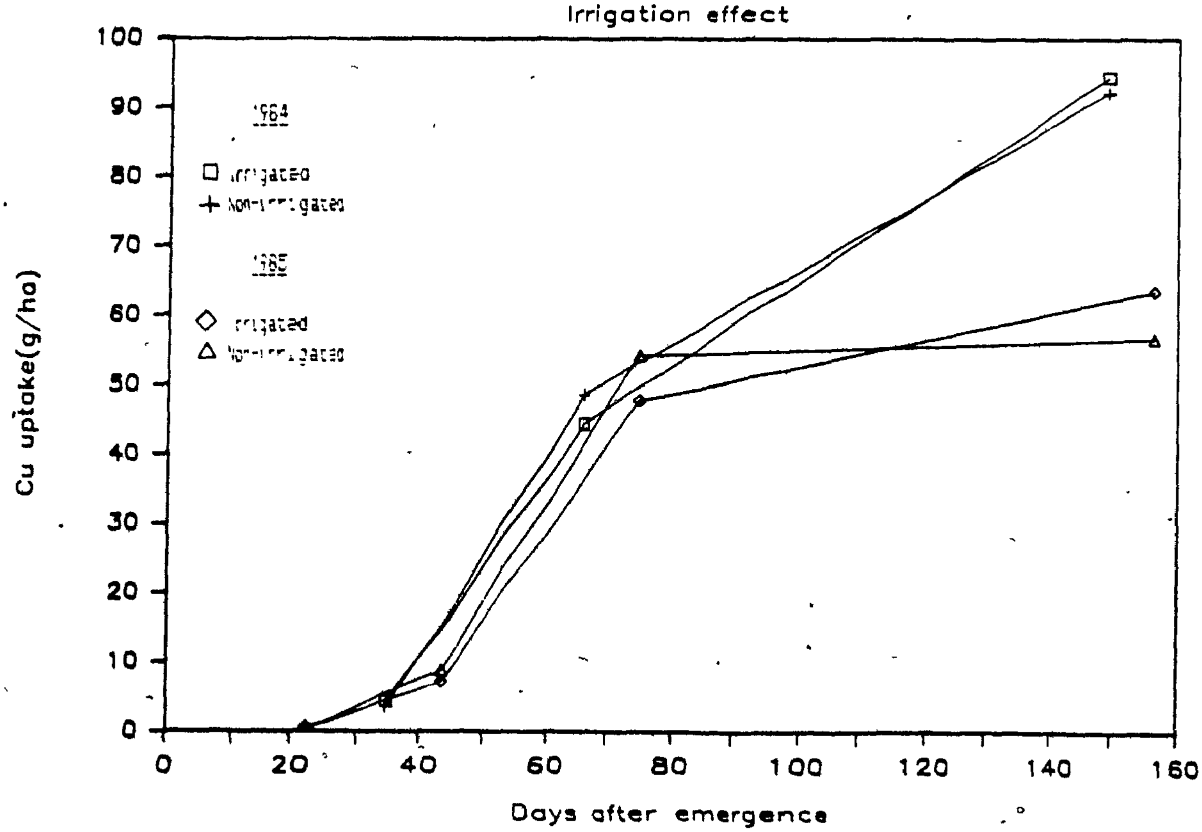


Table 2.11. Effect of plant population on copper concentration and uptake by maize shoots at growth stage 2* and 4 in 1984

Growth Stage	Plant Population	Cu Uptake	Cu Concentration	Dry Matter Yield
		---g/ha---	----mg/kg----	---Mg/ha---
2*	65000	3.46	12.5	0.31
	90000	4.76	10.8	0.45
		*		*
	CV(%)	60.0	110	37.9
4	65000	40.0	6.76	6.17
	90000	54.0	6.50	8.07
		*		*
	CV(%)	31.1	32.2	13.9

*, population differences significant at p=0.05

Table 2.12. Effect of hybrid - irrigation on copper concentration and uptake by maize plant shoot at growth stage 4 in 1984.

	Cu concentration		Cu uptake	
	Irrigation		Irrigation	
Hybrid	Yes	No	Yes	No
	----------mg/kg---------		-------------g/ha-----------	
Pioneer 3925	6.55	6.50	46.0	43.0
Pioneer 3949	5.68	7.79	43.0	54.0
	CV(%)=32.2	$LSD_{0.05}$=1.52 mg/kg	CV(%)=31.1	$LSD_{0.05}$=10.0 mg/kg

Table 2.13. Effect of fertilizer and irrigation on maize ear-leaf copper concentration at growth stage [illegible] in 1984.

Treatment	Cu content
	---mg/kg---
N - P_2O_5 - K_2O (kg/ha)	
170 - 100 - 170	13.9
400 - 300 - 400	12.5 *
Irrigation	
Yes	12.6
No	13.8 *
CV(%)	16.9

*, significantly different at p=0.05

Table 2.14. Effect of plant population-fertilizer-irrigation on copper concentration in maize grain at harvest in 1984.

	Irrigation			
	Yes N - P_2O_5 - K_2O (kg/ha)		No N - P_2O_5 - K_2O (kg/ha)	
Plant Population	170-100-170	400-300-400	170-100-170	400-300-400
---pph---	---mg/kg---			
65000	5.57	3.59	3.43	4.70
90000	4.18	5.43	4.36	4.60
CV(%)=42.1	$LSD_{0.05}$=1.99 mg/kg			

2.3.2.2.2 Growing season 1985

In 1985, there were generally more treatment effects on the content and uptake of Cu at the various growth stages than in 1984. There were a number of treatment interactions which made generalizations difficult. However, high populations, high fertilizer rates and irrigation tended to reduce Cu concentration, and Cu concentration in Co-op 2645 was generally lower than in Pioneer 3925.

There were no treatment differences with respect to effects on the concentration and uptake of Cu by plants at growth stage 2. The Cu concentration and uptake by the plant shoot at stage 3, and leaves at stage 4, were decreased under irrigation, but the Cu uptake by the grain at growth stage 10 was increased under irrigation (Table 2.15). The concentration of Cu in the plant shoot at growth stage 3, was lower at high rates of fertilizer when compared to normal rates, however, the uptake of Cu was higher; the leaves of Co-op 2645 were lower than those of Pioneer 3925 in Cu content (Table 2.16). The leaves of plants at high populations were lower than those at low population in Cu concentration, however, the uptake of Cu was higher (Table 2.16)

Copper uptake followed a similar pattern to that of dry matter yields, with increased uptake generally associated with increased dry matter yields (Table 2.17). At growth stage 4, Co-op 2645 at the high fertilizer rate, was found to have a lower concentration and uptake of Cu in the plant stalks when irrigated as against no irrigation (Table 2.18 and 2.19).

When the normal rate of fertilizer was applied, the Cu concentration in the ear-leaf of Co-op 2645 at growth stage 5, was greater at 65000 than 90000 plants per hectare; at the higher plant density Pioneer 3925 was higher than Co-op 2645 in Cu concentration in the ear-leaf. At high rates of fertilizer, the Cu concentration in the ear-leaf did not differ with plant population for Co-op 2645, but it was higher at 65000 than at 90000 plants per hectare for Pioneer 3925 (Table 2.20). Further, it was found that under high rates of fertilizer the Cu concentration was lower with irrigation regardless of plant population. At normal fertilizer rates there were no difference in Cu concentration between plant population when irrigation was applied, but in the absence of irrigation the low plant populations were associated with greater Cu concentration (Table 2.21).

At harvest the Cu concentration in the stover of non-irrigated plants of Co-op 2645 were lower at high plant population, and there were no differences when plants were irrigated (Table 2.22). A pattern of hybrid x plant population x irrigation effect on Cu uptake by the stover, similar to the effect on concentration (Table 2.22) was also observed (Table 2.23).

With respect to the leaf tissue Cu concentration at harvest, Pioneer 3925 had a greater Cu concentration than Co-op 2645 (Table 2.24). Copper concentrations in the plant stalks at harvest were lower under irrigation than non-irrigation when plants were at low population, however there were no differences in concentration between the moisture regimes at high plant populations (Table 2.25). The dry matter yield and uptake of Cu were increased only at high plant populations when the fertilizer rate was increased from normal to high (Tables 2.26 and 2.27)

Table 2.15. Effect of irrigation on copper concentration and uptake, and dry matter yield in various plant parts at different plant growth stages in 1985.

Growth stages	Plant Part	Irrigation	Cu Concentration	Cu Uptake	Dry Matter Yield
			---mg/kg---	--g/ha--	--Mg/ha--
3	plant shoots	Yes	6.88	0.713	0.958
		No	8.18	0.881	1.068
			*	*	
		CV(%)	14.0	19.7	27.5
4	leaves	Yes	10.1	28.0	2.81
		No	11.0	31.0	2.84
			*	*	
		CV(%)	11.1	15.0	11.7
10	grain	Yes	1.83	21.0	11.5
		No	1.93	16.4	8.4
				*	*
		CV(%)	38.5	42.9	8.19

*; significantly different at p=0.05

Table 2.16. Effect of fertilizer rate on copper concentration and uptake, and dry matter (DM) yield in the plant shoot at growth stage 3; effect of hybrid and plant population on copper concentration and uptake, and dry matter (DM) yield in leaf tissue at growth stage 4 in 1985.

Growth Stage	Plant Part	Treatment	Cu Concentration	Cu Uptake	DM Yield
			---mg/kg---	--g/ha--	--Mg/ha--
3	plant shoot	$N - P_2O_5 - K_2O$			
		170-100-170	7.88	7.48	0.93
		400-300-400	7.16	8.46	1.10
			*	*	*
		CV(%)	14.0	19.7	27.5
4	leaves	Hybrid			
		Pioneer 3925	10.9	29.6	2.73
		Co-op 2645	10.2	29.7	2.93
			*		*
		CV(%)	11.1	15.0	11.7
4	leaves	Population (pph)			
		65000	11.0	28.0	2.55
		90000	10.1	31.3	3.10
			*	*	*
		CV(%)	11.1	15.0	11.7

*, significantly different at $p=0.05$

Table 2.17. Effect of plant population and fertilizer on dry matter yield and copper uptake by maize shoots at growth stage 3 in 1985.

Plant Population	Dry Matter Yield N - P_2O_5 - K_2O (kg/ha) 170-100-170	400-300-400	Cu Uptake N - P_2O_5 - K_2O (kg/ha) 170-100-170	400-300-400
---pph---	----------Mg/ha----------		----------g/ha----------	
65000	0.77	0.75	6.79	6.69
90000	1.09	1.45	8.17	10.2
	CV(%)=27.5	$LSD_{0.05}$=0.20	CV(%)=19.7	$LSD_{0.05}$=1.12

Table 2.18. Effect of hybrid - fertilizer - irrigation on copper concentration in maize plant stalks at growth stage 4 in 1985.

Hybrid	N - P_2O_5 - K_2O (kg/ha) 170 - 100 - 170, Irrigation No	Yes	400 - 300 - 400, Irrigation No	Yes
	----------mg/kg----------			
Pioneer 3925	3.85	3.08	3.36	3.11
Co-op 2645	3.80	3.56	4.71	2.86
CV(%)=23.1	$LSD_{0.05}$=0.82 mg/kg			

Table 2.19. Effect of hybrid - fertilizer - irrigation on copper uptake by maize plant stalks at growth stage 4 in 1985.

	N - P_2O_5 - K_2O (kg/ha)			
	170 - 100 - 170		400 - 300 - 400	
	Irrigation		Irrigation	
Hybrid	No	Yes	No	Yes
	g/ha			
Pioneer 3925	21.0	18.0	21.0	20.0
Co-op 2645	21.0	23.0	30.0	16.0
CV(%)=28.7	$LSD_{0.05}$=6.0 g/ha			

Table 2.20. Effect of hybrid - plant population - fertilizer on maize ear-leaf copper concentration at growth stage 5 in 1985.

	N - P_2O_5 - K_2O (kg/ha)			
	170 - 100 - 170		400 - 300 - 400	
	Plant Population		Plant Population	
Hybrid	65000	90000	65000	90000
	mg/kg			
Pioneer 3925	8.88	8.84	8.78	7.65
Co-op 2645	8.71	7.09	7.76	7.85
CV(%)=12.5	$LSD_{0.05}$=1.03 mg/kg			

Table 2.21. Effect of hybrid - fertilizer - irrigation on maize ear-leaf copper concentration at growth stage 5 in 1985.

	Irrigation			
	Yes		No	
	N - P_2O_5 - K_2O (kg/ha)		N - P_2O_5 - K_2O (kg/ha)	
Plant Population	170-100-170	400-300-400	170-100-170	400-300-400
---pph---	mg/kg			
65000	7.85	7.70	9.74	8.84
90000	8.28	7.18	7.65	8.33

CV(%)=12.5 $LSD_{0.05}$=1.03 mg/kg

Tables 2.22. Effect of hybrid - plant population - irrigation on copper concentration maize stover at harvest stage in 1985.

	Plant Population (pph)			
	65000		90000	
	Irrigation		Irrigation	
Hybrid	No	Yes	No	Yes
	mg/kg			
Pioneer 3925	4.51	3.86	4.65	2.93
Co-op 2645	5.09	3.70	3.54	3.78

CV(%)=28.3 $LSD_{0.05}$=1.14 mg/kg

Table 2.23. Effect of hybrid - plant population - irrigation on the uptake of copper by maize stover in 1985.

	Plant Population (pph)			
	65000		90000	
	Irrigation		Irrigation	
Hybrid	No	Yes	No	Yes
	g/ha			
Pioneer 3925	36.0	36.0	42.0	35.0
Co-op 2645	39.0	34.0	30.0	36.0

CV(%)=25.8 $LSD_{0.05}$=9.0 g/ha

Table 2.24. Effect of hybrid - irrigation on copper content in maize leaf tissue at harvest stage in 1985.

	Irrigation	
Hybrid	Yes	No
	mg/kg	
Pioneer 3925	6.28	7.34
Co-op 2645	6.15	6.00

CV(%)=14.7 $LSD_{0.05}$=0.68 mg/kg

Table 2.25. Effect of plant population - irrigation on copper content of maize plant stalks at harvest stage in 1985.

Plant Population	Irrigation Yes	Irrigation No
----pph----	---mg/kg---	
65000	1.89	3.49
90000	2.63	2.39
CV(%)=63.3	$LSD_{0.05}$=1.17 mg/kg	

Table 2.26. Effect of plant population - fertilizer on maize leaf dry matter yield at harvest stage in 1985.

$N - P_2O_5 - K_2O$	Plant Population (pph) 65000	Plant Population (pph) 90000
----kg/ha----	---Mg/ha---	
170 - 100 - 170	3.20	3.64
400 - 300 - 400	3.22	4.16
CV(%)=11.0	$LSD_{0.05}$=0.28 Mg/ha	

Table 2.27. Effect of plant population - fertilizer on copper uptake by maize leaf tissue at harvest stage in 1985.

	Plant Population (pph)	
$N - P_2O_5 - K_2O$	65000	90000
-----kg/ha-----	--------g/ha--------	
170 - 100 - 170	22.0	23.0
400 - 300 - 400	20.0	26.0

CV(%)=20.3 $LSD_{0.05}$=3.0 g/ha

2.3.2.3 Plant tissue zinc

In general, uptake of Zn with time as a function of hybrid, population density, fertilizer rate and irrigation followed a sigmoidal pattern similar to dry matter accumulation (Figures. 9, 10, 11, and 12)

2.3.2.3.1 Growing season 1984

At growth stage 2+ there were no differences in Zn concentration in the hybrids at low plant population, but at high plant populations Pioneer 3949 was higher in Zn than Pioneer 3925 (Table 2.28). The uptake of Zn at stage 2+ was greater at high plant populations, and with high rate of fertilizer. Dry matter yields followed the same pattern (Tables 2.29 and 2.30). High plant populations had a higher Zn uptake than low populations at stage 4, and this also occurred with Zn content in the grain (Table 2.31).

High fertilizer rates were associated with a higher Zn concentration in the ear-leaf at stage 5, and with a higher Zn uptake by the grain at stage 10 (Table 2.31). Irrigation was associated with a decrease in concentration and uptake of Zn by the stover at stage 10, and a decrease in Zn concentration in the grain at the same stage (Table 2.31).

Figure 9. Zn uptake over growing season

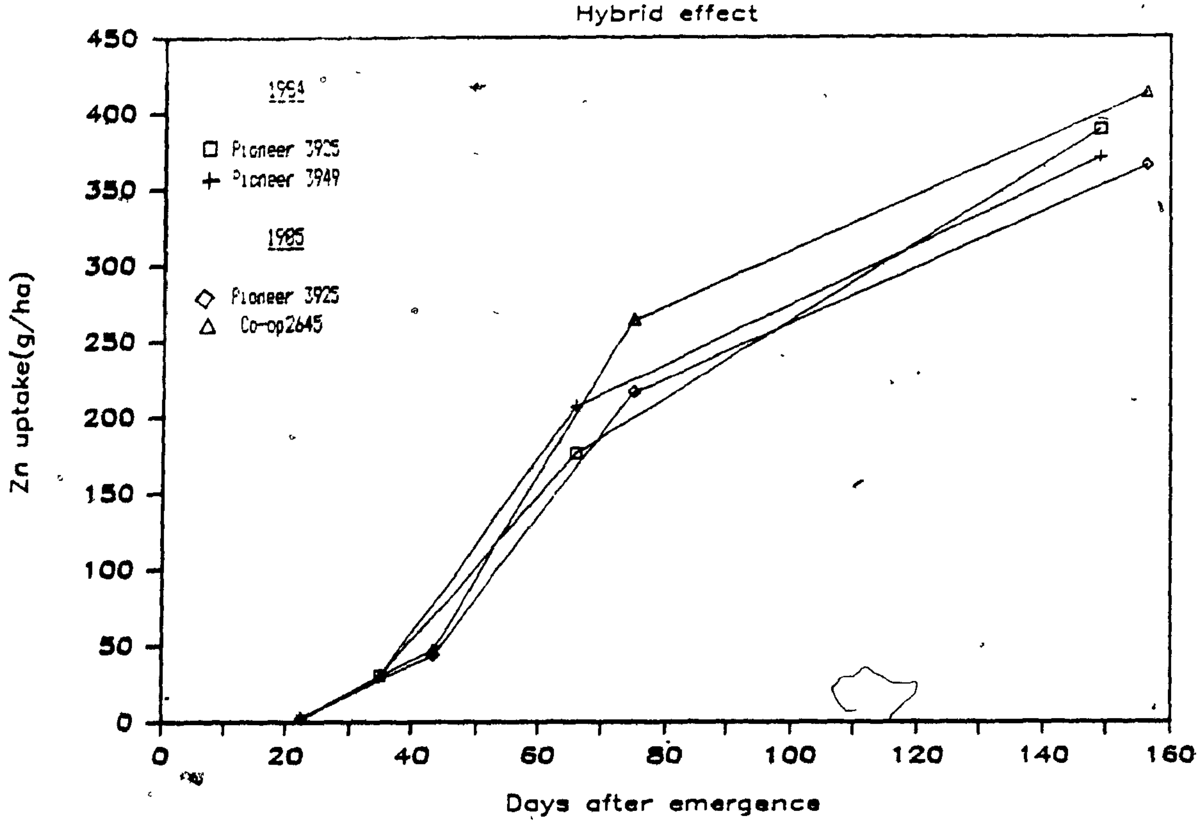


Figure 10. Zn uptake over growing season

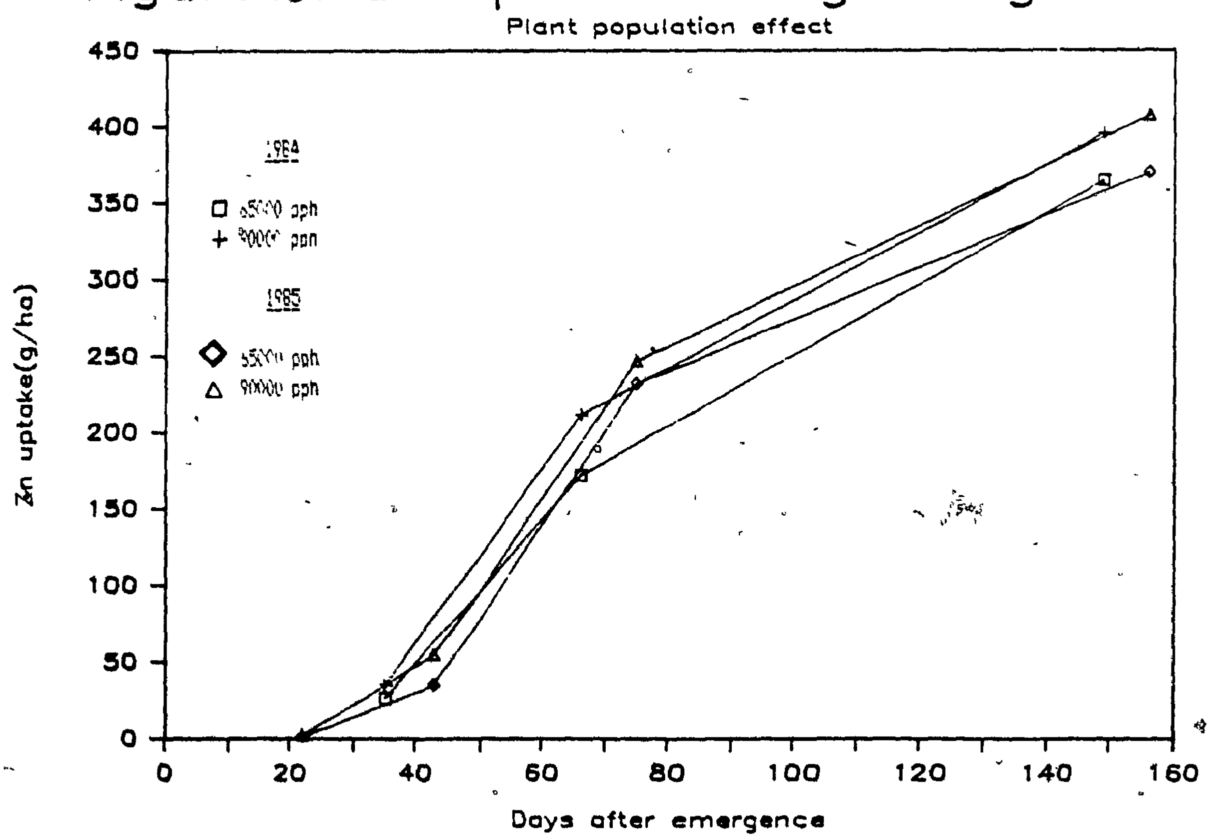


Figure 11. Zn uptake over growing season

Fertilizer effect

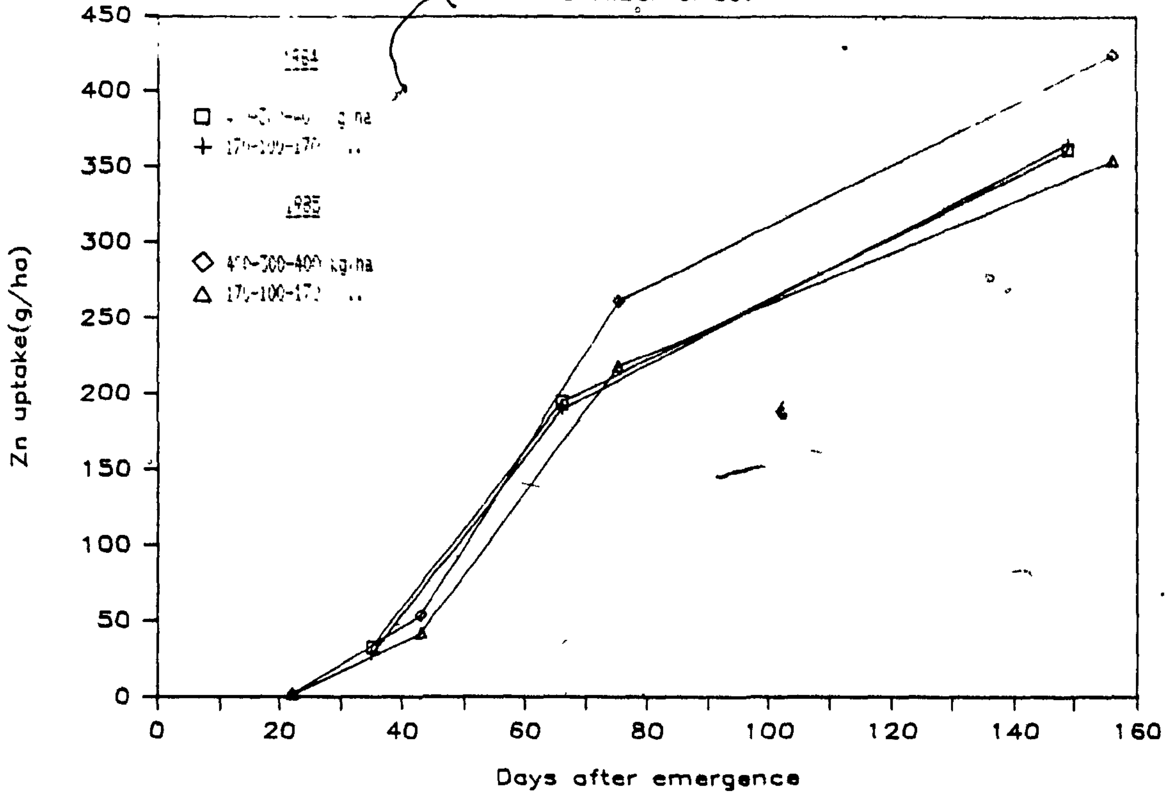


Figure 12. Zn uptake over growing season

Irrigation effect

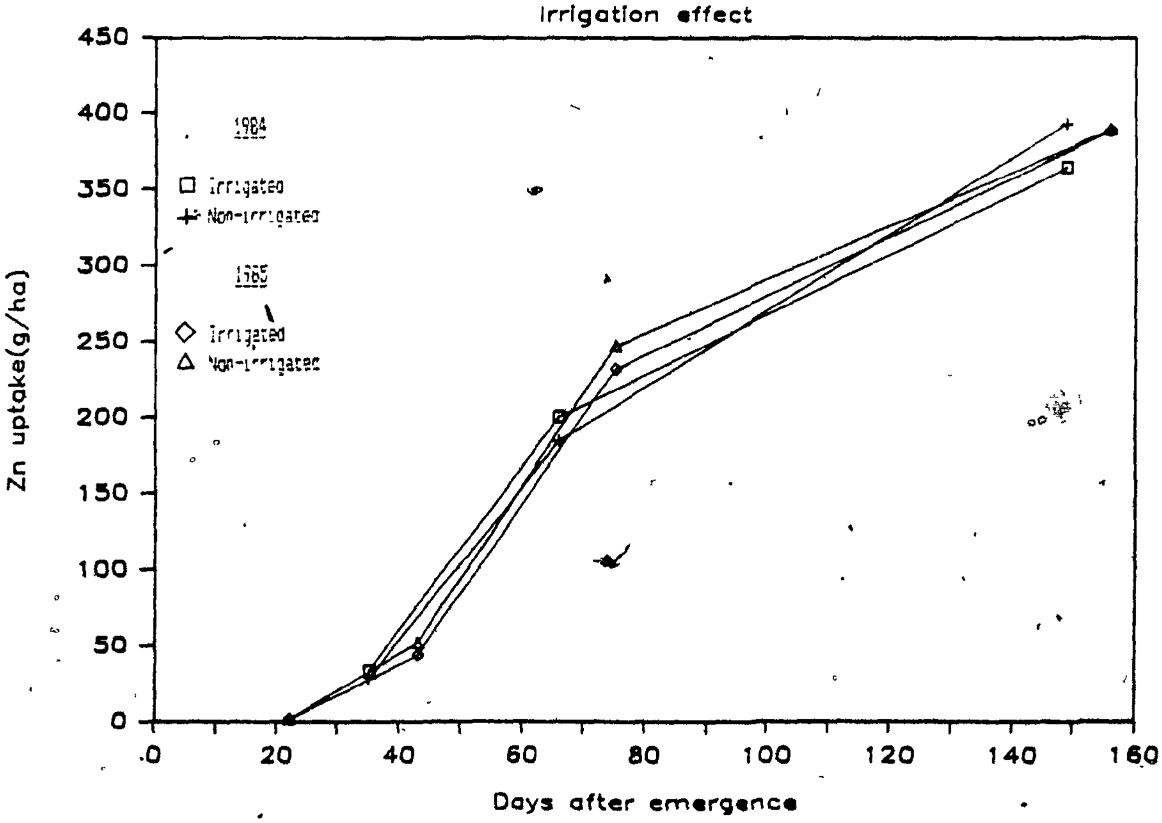


Table 2.28. Effect of hybrid - plant population on zinc content in maize plant shoots at growth stage 2⁺ in 1984.

Plant Population	Hybrid: Pioneer 3925	Hybrid: Pioneer 3949
---pph---	---mg/kg---	
65000	103.2a⁺	75.1a
90000	67.6b	79.3a
CV(%)=24.7		

⁺ means in the body of the table, having a common letter are not significantly different ($p=0.05$) according to the LSD test.

Table 2.29. Effect of plant population - fertilizer rate on zinc uptake by maize plant shoots at growth stage 2⁺ in 1984.

Plant Population	$N - P_2O_5 - K_2O$ Rates (kg/ha): 170 - 100 - 170	400 - 300 - 400
---pph---	---g/ha---	
65000	28.0	25.9
90000	29.1	42.0
CV(%)=46.5	$LSD_{0.05}$=10.2 g/ha	

Table 2.30. Effect of plant population - fertilizer rate on above ground dry matter yields of maize plants at growth stage 2* in 1984.

Plant Population	N - P_2O_5 - K_2O Rates (kg/ha) 170 - 100 - 170	400 - 300 - 400
---pph---	---kg/ha---	
65000	305	320
90000	372	527

CV(%)=37.9 $LSD_{0.05}$=102 kg/ha

Table 2.31. Effect of plant population, fertilizer rate, and irrigation on zinc uptake and concentration in various plant parts at growth stages 4, 5, and 10 in 1984.

Growth Stage	Plant Part	Treatment	Zn Concentration	Zn Uptake	DM Yield
			---mg/kg----	--g/ha--	--Mg/ha--
4	plant shoots	Population (pph)			
		65000	27.4	6.2	6.67
		90000	26.9	8.1 *	8.07 *
		CV(%)	30.2	33.1	13.9
5	ear-leaf	N - P_2O_5 - K_2O			
		170-100-170	39.9	-	-
		400-300-400	46.0 *	-	-
		CV(%)	15.0		
10	grain	Population (pph)			
		65000	30.2	242	8.18
		90000	29.6	264 *	8.85 *
		CV(%)	10.3	12.0	9.6
10	grain	N - P_2O_5 - K_2O			
		170-100-170	29.2	243	8.34
		400-300-400	30.6	262 *	8.85
		CV(%)	10.3	12.0	9.6
10	grain	Irrigation			
		Yes	27.6	250	9.03
		No	32.1 *	256	8.00 *
		CV(%)	10.3	12.0	9.6
10	stover	Irrigation			
		Yes	15.8	115	7.31
		No	19.9 *	139 *	6.87 *
		CV(%)	18.9	25.1	10.1

*, differences are significant at $p=0.05$

2.3.2.3.2 Growing season 1985

At growth stage 2, there was a hybrid x irrigation effect on the Zn concentration in the plant (Table 2.32). However this must be considered as a random effect as the irrigation treatment had not been applied by the time of sampling.

In comparing hybrids, Zn concentration and uptake in the plant shoot at stage 3, plant stalks at stage 4, and leaves at stage 10, were higher for Co-op 2645; the uptake of Zn at stage 2 was higher for Co-op 2645 than for Pioneer 3925 (Table 2.33)

Comparing plant population effects, the high plant population was associated with a higher uptake of Zn in the whole plant at growth stages 2 and 3, and in the leaves at growth stage 10 (Table 2.34).

High fertilizer rate in comparison to normal rate, was associated with a higher uptake of Zn in, the whole plant at stage 3, the leaves and stalks at stage 4, and the stalks and grain at stage 10 (Table 2.35). The Zn concentration in the ear-leaf at stage 5 was also higher at the high fertilizer rate treatment (Table 2.35).

Where plants were irrigated, in comparison to non-irrigated, the concentrations of Zn were lower in the whole plant at growth stage 3, the ear-leaf at stage 5, and the stover, ~~leaves,~~ stalks, and grain at stage 10 (Table 2.36). Irrigation also lowered the Zn uptake by plants at growth stage 3, and that by the leaves and stalks at growth stage 10, but it increased the uptake by the grain at stage 10 (Table 2.36).

There were a number of hybrid interactions with the other treatments. At growth stage 3, the hybrids did not differ in tissue Zn concentration when they were planted at low plant density, but at high density Pioneer 3925 had a lower concentration (Table 2.37); and also, Pioneer 3925 had a lower Zn concentration when at high plant population than at low population. Irrigation decreased the concentration of Zn in the maize leaves of both hybrids, but at high population and non-irrigated conditions, Co-op 2645 had a higher Zn concentration (Table 2.38)

Table 2.32. Effect of hybrid - irrigation on zinc content in maize plants at growth stage 2 in 1985.

Hybrid	Irrigation Yes	Irrigation No
	mg/kg	
Pioneer 3925	34.0	32.1
Co-op 2645	32.0	39.4
CV(%)=26.4	$LSD_{0.05}$=6.5 mg/kg	

Table 2.33. Effect of hybrid on zinc concentration uptake and dry matter (DM) yield in various plant parts at growth stages 2, 3, 4 and 10 in 1985.

Growth Stage	Plant Part	Hybrid	Zn Concentration	Zn Uptake	DM Yield
			---mg/kg----	--g/ha--	--Mg/ha--
2	plant shoot	Pioneer 3925	33.1	1.92	0.058
		Co-op 2645	35.7	2.30	0.068
				*	*
		CV(%)	26.4	37.4	16.4
3	plant shoot	Pioneer 3925	42.7	43.7	1.02
		Co-op 2645	47.4	53.0	1.01
			*	*	
		CV(%)	18.8	26.6	27.5
4	stalks	Pioneer 3925	20.6	123	6.03
		Co-op 2645	26.1	157	6.03
			*	*	
		CV(%)	31.3	31.3	9.8
10	leaves	Pioneer 3925	17.0	59.0	3.55
		Co-op 2645	22.9	82.0	3.56
			*	*	*
		CV(%)	29.4	40.3	11.0

*, significantly different at p=0.05

Table 2.34. Effect of plant population on zinc uptake and concentration, and dry matter (DM) yield in various plant parts at growth stages 2, 3 and 10 in 1985.

Growth Stage	Plant Part	Plant Population	Zn Concentration	Zn Uptake	DM Yield
		---pph---	---mg/kg----	--g/ha--	--Mg/ha--
2	plant shoot	65000	32.2	1.86	0.052
		90000	36.5	2.68	0.074
				*	*
		CV(%)	26.4	37.3	16.4
3	plant shoot	65000	46.3	41.3	0.75
		90000	43.8	55.4	1.27
				*	*
		CV(%)	18.8	26.6	27.5
10	leaves	65000	19.2	61.0	3.21
		90000	20.7	81.0	3.91
				*	*
		CV(%)	29.4	40.3	11.0

*, significantly different at p=0.05

Table 2.35. Effect of fertilizer rate on zinc concentration and uptake, and dry matter (DM) yield in various plant parts at growth stages 3, 4, 5 and 10 in 1985.

Growth Stage	Plant Part	N - P_2O_5 - K_2O Rate	Zn Concentration	Zn Uptake	DM Yield
		---Kg/ha---	---mg/kg---	--g/ha--	--Mg/ha--
3	plant shoot	170-100-170	44.0	42.5	0.93
		400-300-400	46.1	54.2	1.10
				*	*
		CV(%)	18.8	26.6	27.5
4	leaves	170-100-170	33.1	90.0	2.74
		400-300-400	37.6	110.0	2.91
				*	*
		CV(%)	33.1	37.7	11.7
4	stalks	170-100-170	22.0	128.0	5.86
		400-300-400	24.7	151.0	6.20
				*	*
		CV(%)	33.3	31.3	9.8
5	ear-leaf	170-100-170	28.1	-	-
		400-300-400	31.7	-	-
			*		
		CV(%)	34.8	-	
10	stalk	170-100-170	8.2	42.0	5.26
		400-300-400	11.6	65.0	5.80
				*	*
		CV(%)	76.9	84.1	14.7
10	grain	170-100-170	21.7	206.0	9.6
		400-300-400	23.5	242.0	10.4
			*	*	*
		CV(%)	15.3	18.3	8.2

*, significantly different at p=0.05

Table 2.36. Effect of irrigation on zinc concentration and uptake, and dry matter (DM) yield in various plant parts at growth stages 3, 5 and 10 in 1985.

Growth Stages	Plant Part	Irrigation	Zn Concentration	Zn Uptake	DM Yield
			----mg/kg----	--g/ha--	--Mg/ha--
3	plant shoot	Yes	42.1	44.2	0.96
		No	48.0*	52.5*	1.07
		CV(%)	18.8	26.6	27.5
5	ear-leaf	Yes	25.6	-	-
		No	34.2*	-	-
		CV(%)	19.1		
10	stover	Yes	17.5	198	9.59
		No	23.4*	167	8.39*
		CV(%)	34.8	39.0	8.9
10	leaves	Yes	15.0	58.0	3.83
		No	24.6*	83.0*	3.31*
		CV(%)	29.4	40.2	11.0
10	stalk	Yes	7.14	41.0	5.96
		No	12.6*	65.0*	5.11*
		CV(%)	76.9	84.1	14.7
10	grain	Yes	21.3	246.0	11.5
		No	23.9*	201.0*	8.4*
		CV(%)	15.3	18.3	8.2

*, significantly different at p=0.05

Table 2.37. Effect of hybrid - plant population on zinc concentration in maize shoots at growth stage 3 in 1985.

Hybrid	Plant Population (pph) 65000	90000
	mg/kg	
Pioneer 3925	46.4	39.0
Co-op 2645	46.2	48.6

CV(%)=18.8 $LSD_{0.05}$=6.0 mg/kg

Table 2.38. Effect of hybrid - plant population - irrigation on the zinc concentration in maize leaves at harvest in 1985.

	Irrigation: Yes		No	
	Plant Population		Plant Population	
Hybrid	65000	90000	65000	90000
	mg/kg			
Pioneer 3925	12.5	13.2	22.9	18.8
Co-op 2645	16.8	17.5	23.8	32.8

CV(%)=29.4 $LSD_{0.05}$=5.9 mg/kg

2.3.2.4. Plant tissue manganese

In general, uptake of Mn with time as a function of hybrid, population density, fertilizer and irrigation followed a quadratic curve in 1984 and a sigmodial curve in 1985 (Figures. 13, 14, 15, and 16)

2.3.2.4.1 Growing season 1984

High fertilizer rates in comparison with normal rates, gave higher concentrations of Mn in the whole plant at growth stage 2 and 4, in the ear-leaf at stage 5, and in the grain and stover at growth stage 10 (Table 2.39). High fertilizer rates were also associated with a higher uptake of Mn by the whole plant at stage 4, and by the stover and grain at stage 10 (Table 2.39).

At growth stage 10, irrigation resulted in a lower Mn uptake by the stover, and lower Mn concentration in the grain (Table 2.40).

Figure 13. Mn uptake over growing season

Hybrid effect

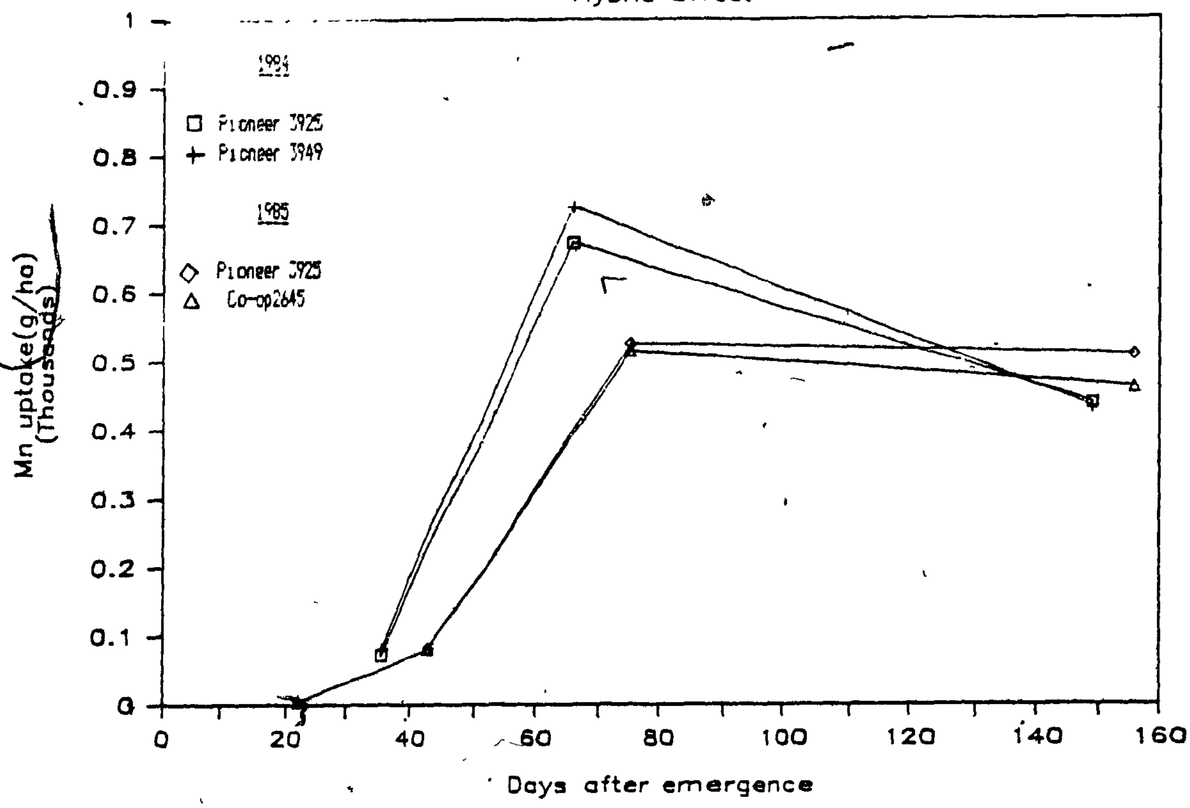


Figure 14. Mn uptake over growing season

Plant population effect

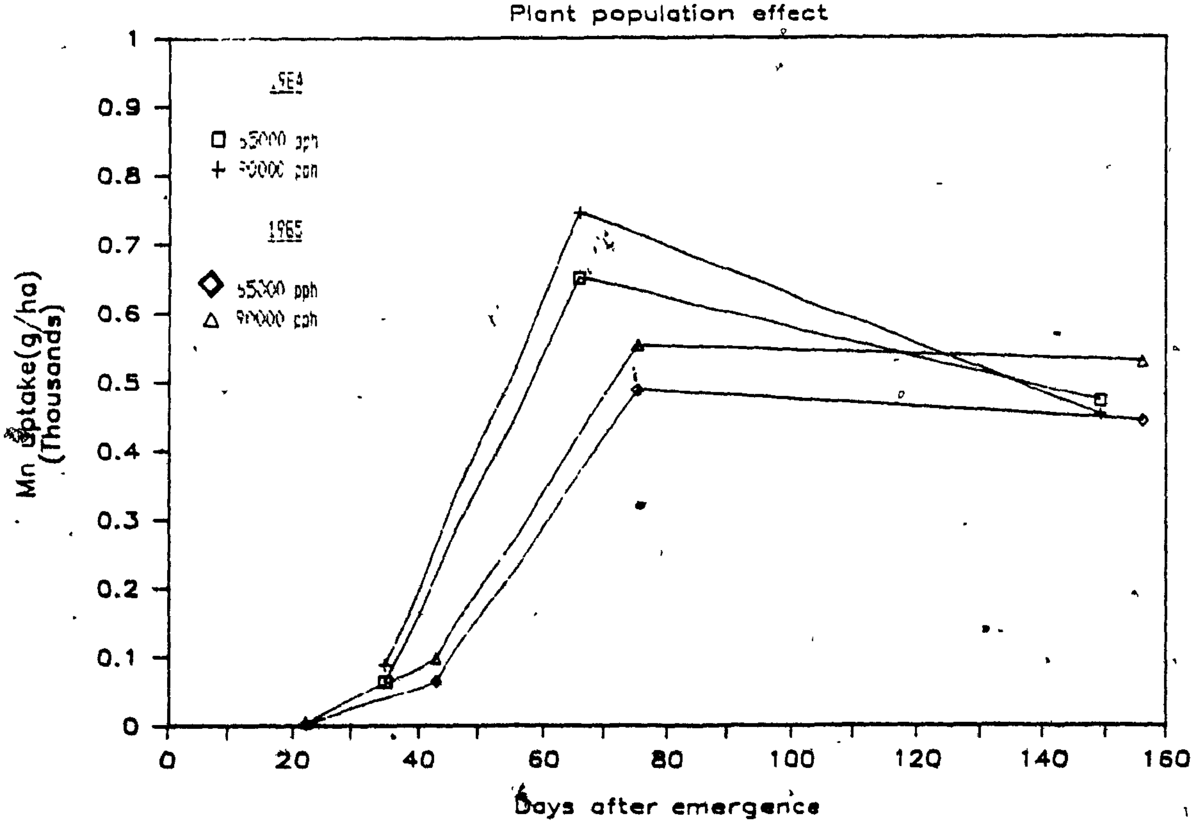


Figure 15. Mn uptake over growing season

Fertilizer effect

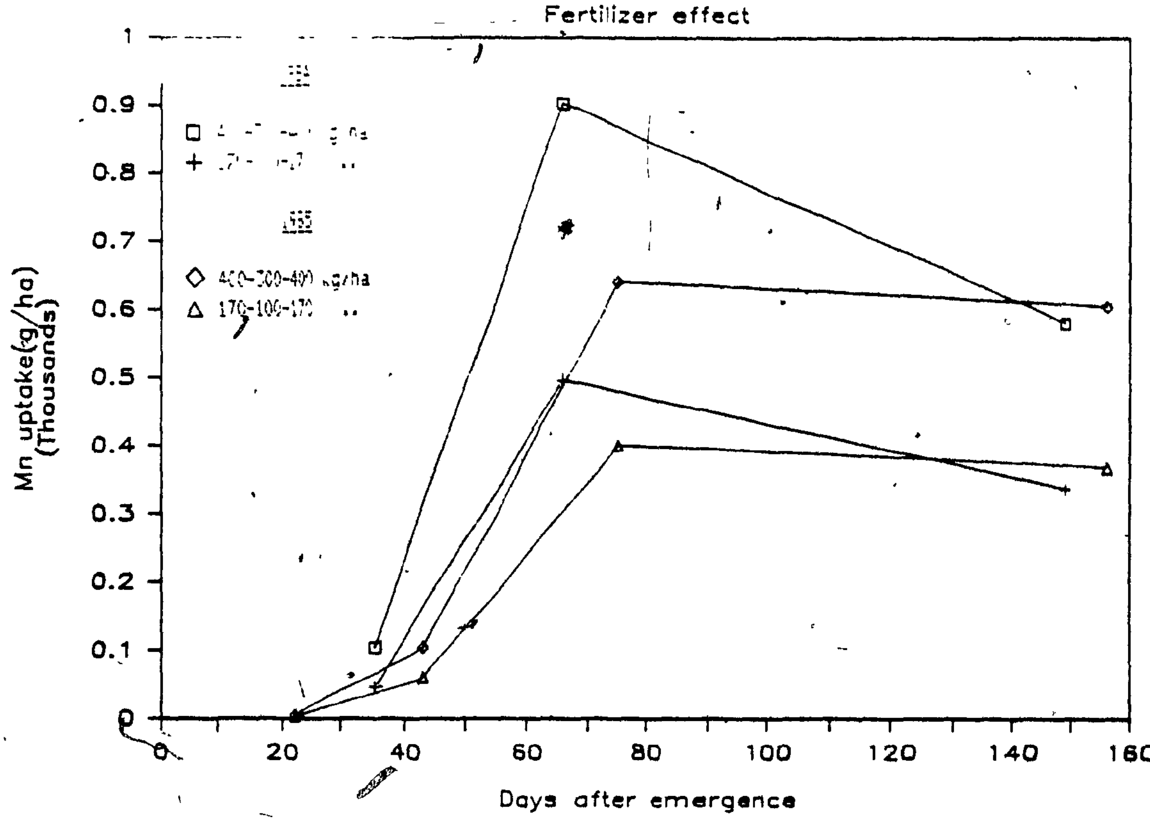


Figure 16. Mn uptake over growing season

Irrigation effect

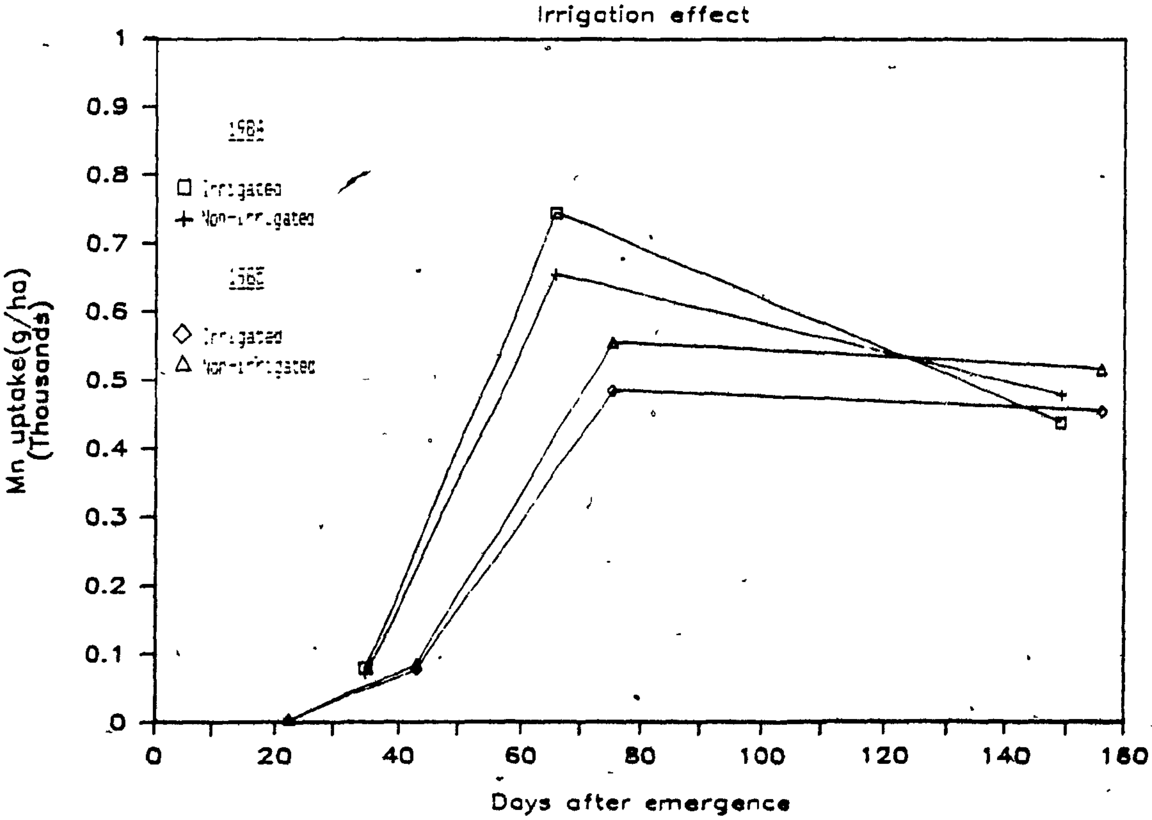


Table 2.39. Effect of fertilizer rate on manganese concentration and uptake, amd dry matter (DM) yield in various plant parts at growth stages 2*, 4, 5 and 10 in 1984.

Growth Stage	Plant Part	$N - P_2O_5 - K_2O$ Rate	Mn Concentration	Mn Uptake	DM Yield
		---kg/ha---	---mg/kg---	--g/ha--	--Mg/ha--
2*	plant shoot	170-100-170	139.0	47.0	0.034
		400-300-400	255.0 *	105.0 *	0.042 *
		CV(%)	20.0	42.1	37.9
4	plant shoot	170-100-170	71.0	497.0	7.03
		400-300-400	125.0 *	903.0 *	7.14
		CV(%)	30.0	38.6	13.9
5	ear-leaf	170-100-170	129.0	-	
		400-300-400	245.0 *	-	
		CV(%)	21.7		
10	stover	170-100-170	43.0	305.0	7.11
		400-300-400	77.3 *	539.0 *	7.07
		CV(%)	22.4	23.6	10.1
10	grain	170-100-170	3.86	32.0	8.34
		400-300-400	4.75 *	41.0 *	8.69
		CV(%)	13.8	14.7	9.6

*, significantly different at p=0.05

Table 2.40. Effect of irrigation on manganese concentration and uptake, and dry matter (DM) yield in various plant parts at growth stage 10 in 1984.

Growth Stage	Plant Part	Irrigation	Mn Concentration	Mn Uptake	DM Yield
			----mg/kg---	--g/ha--	--Mg/ha--
10	stover	Yes	55.6	404	7.31
		No	64.7	441	6.87
			*		*
		CV(%)	22.4	23.6	10.1
10	grain	Yes	3.85	57.7	9.03
		No	4.79	52.0	8.00
			*	*	*
		CV(%)	13.8	18.1	9.6

*, significantly different at p=0.05

2.3.2.4.2. Growing season 1985

In general, high populations and fertilizer rates increased Mn concentration and uptake, and irrigation reduced Mn uptake.

Co-op 2645 tended to have higher Mn concentration than Pioneer 3925 at early growth stages. At growth stage 2, Co-op 2645 was higher than Pioneer 3925 in Mn uptake; but at harvest (stage 10), Co-op 2645 was lower in Mn concentration and uptake by leaves, and also had a lower Mn concentration in the grain (Table 2.41). High plant population was associated with a comparatively higher uptake of Mn by the plant shoots at growth stage 2, and by the leaves and stalks of plants at growth stage 10 (Table 2.42).

High fertilizer rates resulted in higher concentrations and uptake of Mn than normal rates with respect to the whole plant at growth stages 2 and 3, and in leaves and stalks at stage 4 (Table 2.43); the higher fertilizer rate was associated with high Mn concentration in the ear-leaf at stage 5, and the concentrations and uptake of Mn in the stover, leaves, stalk and grain at stage 10 were higher at high than at normal fertilizer rates (Table 2.44).

Irrigation was associated with a lower concentration of Mn in the plant stalks and leaves at stage 4, in the ear-leaf at stage 5, and in the stover, leaves, stalks and grain at stage 10 (Table 2.45). Irrigation also was associated with a lower uptake of Mn by leaves at stage 4, and the stover, leaves and stalk at stage 10 (Table 2.45).

Several interactions among plant population, fertilizer rates and irrigation were noted. At growth stage 3, plants at low populations and receiving low rates of fertilizer, had a lower Mn uptake than those at high plant population and at high fertilizer rates (Table 2.46). At growth stage 4, differences in uptake by the plant stalks at different populations occured only under irrigated conditions, with the high population resulting in a greater uptake of Mn (Table 2.47).

At harvest, stover had a higher concentration of Mn in plants treated with high rates of fertilizer and differences between fertilizer rates were largest when plants were not irrigated (Table 2.48). Grain uptake of Mn was similar for the hybrids when irrigated, but in the absence of irrigation Co-op 2645 had a lower uptake than Pioneer 3925 (Table 2.49).

Table 2.41. Effects of hybrid on manganese concentration and uptake, and dry matter (DM) yield in various plant parts at growth stages 2 and 10 in 1985.

Growth Stages	Plant Part	Hybrid	Mn Concentration	Mn Uptake	DM Yield
			----mg/kg----	--g/ha--	--Mg/ha--
2	plant shoot	Pioneer 3925	67.2	3.99	0.058
		Co-op 2645	70.2	4.89 *	0.068 *
		CV(%)	21.5	31.6	16.4
10	leaves	Pioneer 3925	106.0	376.0	3.55
		Co-op 2645	94.0 *	333.0 *	3.56
		CV(%)	21.8	24.6	11.0
10	grain	Pioneer 3925	5.89	57.4	9.9
		Co.op 2645	5.27 *	52.3 *	10.1
		CV(%)	17.1	18.1	8.2

*, significantly different at p=0.05

Table 2.42. Effect of plant population on manganese uptake and concentration, and dry matter (DM) yield by various plant parts at growth stages 2, 4 and 10 in 1985.

Growth Stages	Plant Part	Plant Population	Mn Uptake	Mn Concentration	DM Yield
		---pph---	--g/ha--	---mg/kg---	--Mg/ha--
2	plant shoot	65000	3.51	66.8	0.052
		90000	5.36 *	70.7	0.074 *
		CV(%)	31.6	21.5	16.4
4	leaves	65000	313	122	2.55
		90000	362 *	116	3.10 *
		CV(%)	23.4	18.9	11.7
10	leaves	65000	315	99.3	3.21
		90000	395 *	100.0	3.91 *
		CV(%)	24.6	21.8	11.0
10	stalks	65000	63	13.4	4.81
		90000	78 *	12.5	6.25 *
		CV(%)	33.7	25.9	14.7

*, significantly different at p=0.05

Table 2.43. Effect of fertilizer rate on the manganese concentration and uptake, and dry matter (DM) yield in various plant parts at growth stages 2, 3, and 4 in 1985.

Growth Stage	Plant Part	$N - P_2O_5 - K_2O$ Rate	Mn Concentration	Mn Uptake	DM Yield
		---kg/ha---	----mg/kg----	--g/ha--	-Mg/ha--
2	plant shoot	170-100-170	57.7	3.46	0.060
		400-300-400	79.8 *	5.41 *	0.067 *
		CV(%)	21.5	31.6	21.5
3	plant shoot	170-100-170	63.4	61	0.93
		400-300-400	85.8 *	104 *	1.10 *
		CV(%)	22.5	27.6	25.5
4	stalks	170-100-170	24.6	144	5.86
		400-300-400	35.8 *	222 *	6.20 *
		CV(%)	18.9	21.5	9.8
4	leaves	170-100-170	94	257	2.74
		400-300-400	143 *	418 *	2.91
		CV(%)	18.9	23.4	11.7

*, significantly different at $p=0.05$

Table 2.44. Effect of fertilizer rate on the manganese concentration and uptake, and dry matter (DM) yield in various plant parts at growth stages 5 and 10 in 1985.

Growth Stage	Plant Part	N - P_2O_5 - K_2O Rate	Mn Concentration	Mn Uptake	DM Yield
		---kg/ha---	----mg/kg----	--g/ha--	-Mg/ha-
5	ear-leaf	170-100-170	71	-	-
		400-100-400	113 *	-	-
		CV(%)	21.5		
10	stover	170-100-170	44.8	386	8.61
		400-300-400	69.6 *	646 *	9.37 *
		CV(%)	24.3	27.5	8.9
10	leaves	170-100-170	77	259	3.41
		400-300-400	123 *	450 *	3.71 *
		CV(%)	21.8	24.6	11.0
10	stalks	170-100-170	10.9	56	5.26
		400-300-400	14.9 *	85 *	5.80 *
		CV(%)	25.9	33.7	14.7
10	grain	170-100-170	5.07	47	9.6
		400-300-400	6.09 *	62 *	10.3 *
		CV(%)	17.1	18.1	8.2

*, significantly different at $p=0.05$

Table 2.45. Effect of irrigation on manganese concentration and uptake, and dry matter (DM) yield by various plant parts a growth stages 4, 5 and 10 in 1985.

Growth Stage	Plant Part	Irrigation	Mn Concentration	Mn Uptake	DM Yield
			--mg/kg--	--g/ha--	--Mg/ha--
4	stalks	Yes	28.6	177	6.17
		No	31.8 *	189	5.89
		CV(%)	18.9	21.5	9.8
4	leaves	Yes	109	308	2.81
		No	129 *	367 *	2.84
		CV(%)	18.9	23.4	11.7
5	ear-leaf	Yes	81	-	-
		No	103 *	-	-
		CV(%)	21.5		
10	stover	Yes	47.8	463	9.58
		No	66.7 *	569 *	8.39 *
		CV(%)	24.3	27.5	8.9
10	leaves	Yes	85	328	3.83
		No	114 *	380 *	3.31 *
		CV(%)	21.8	24.6	11.0
10	stalks	Yes	10.7	64	5.96
		No	15.1 *	77 *	5.11 *
		CV(%)	25.9	24.6	14.7
10	grain	Yes	4.98	57.7	11.5
		No	6.18 *	52.0 *	8.4 *
		CV(%)	17.1	18.1	8.2

*, significantly different at $p=0.05$

Table 2.46. Effect of plant population - fertilizer rate on manganese uptake by maize plant shoot at growth stage 3 in 1985.

Plant Population	N - P_2O_5 - K_2O Rates (kg/ha) 170 - 100 - 170	400 - 300 - 400
----pph----	----------g/ha----------	
65000	52.0	79.0
90000	69.0	129.0
	CV(%)=37.6 $LSD_{0.05}$=22.0 g/ha	

Table 2.47. Effects of plant population - irrigation on dry matter yield and manganese uptake by maize plant stalks at growth stage 4 in 1985.

Plant Population	Dry Matter Yield Irrigation		Mn Uptake Irrigation	
	No	Yes	No	Yes
---pph---	----Mg/ha----		----g/ha----	
65000	5.61	5.41	192	157
90000	6.16	6.94	185	197
	CV(%)=9.8	$LSD_{0.05}$=0.42 Mg/ha	CV(%)=21.5	$LSD_{0.05}$=28 g/ha

Table 2.48. Effect of fertilizer rate and irrigation on manganese concentration in stover at harvest in 1985.

N - P_2O_5 - K_2O Rate	Irrigation Yes	Irrigation No
---kg/ha---	----------mg/ha----------	
170 - 100 - 170	39.3	50.2
400 - 300 - 400	56.2	83.1

CV(%)=24.3 $LSD_{0.05}$=9.9 mg/ha

Table 2.49. Effect of hybrid - irrigation on dry matter yields and uptake by maize grain in 1985.

Hybrid	Dry Matter Yields Irrigation Yes	Dry Matter Yields Irrigation No	Mn Uptake Irrigation Yes	Mn Uptake Irrigation No
	--Mg/ha, $LSD_{0.05}$=0.58--		--g/ha, $LSD_{0.05}$=7.02--	
Pioneer 3925	11.2	8.51	58.0	57.0
Co-op 2645	11.9	8.29	58.0	47.0

CV(%)=8.2 $LSD_{0.05}$=0.58 Mg/ha CV(%)=18.1 $LSD_{0.05}$=7.02 g/ha

2.3.3 The Diagnosis and Recommendation Integrated System (DRIS)

2.3.3.1. Growing season 1984

The results of DRIS analysis showed a large nutritional balance index (NBI) at stage 2⁺ with the macronutrients (N, P, and K) being least deficient at that stage (Table 2.50). AT stage 5, the NBI had decreased and the order of requirement indicated that the micronutrients were least deficient at that stage (Table 2.51). The NBI was found to be higher for Pioneer 3925 than for Pioneer 3949 at stage 2^+; at stage 2^+ and 5 the high rate of fertilizer was associated with a higher NBI (Table 2.52). No relationship was found between NBI and dry matter yield or grain yield at any stage of growth.

2.3.3.2. Growing season 1985

The results of DRIS analysis showed a large NBI at stage 2 which decreased at stage 3 (Tables 2.53 and 2.54). However at both stages the least required nutrients were the macronutrients N, P, and K. At stage 5, the NBI had decreased further and the order of requirement showed that K, P and Mn were least required while Mg, Zn and Cu were the most required (Table 2.55).

The NBI at stages 3 and 5 was found to be greater where plants were irrigated as against no irrigation; at stage 5 high fertilizer rates had higher NBI values than normal rates (Table 2.56). Unlike the 1984 season, there was some relationship between NBI and dry matter yields at stage 10. Under non-irrigated conditions the NBI was negatively correlated with the grain yield and the total dry matter at harvest, and with irrigation there was a positive correlation with the total dry matter (Table 2.57). Under the high rate of fertilizer the NBI was positively correlated with grain yield and total dry matter at harvest (Table 2.57).

Table 2.50. DRIS indices for some plant nutrients in maize plant shoot at growth stage 2+ for the 16 treatment combinations in 1984.

Treat. Comb.	N	P	K	Ca	Mg	Mn	Zn	Cu	Sum of indices	NBI	Order of requirement according to DRIS
	----------DRIS indices----------										
A65H+	12	7	8	-25	-10	-4	5	9	2	80	Ca>Mg>Mn>Zn>P>K>Cu>N
A65H-	22	20	22	-22	-22	2	2	-25	-1	137	Cu>Ca=Mg>Mn=Zn>P=N=K
A65N+	17	7	24	-24	-3	-16	12	-16	1	119	Ca>Mn=Cu>Mg>P>Zn>N>K
A65N-	15	12	19	-21	-6	-14	8	-13	0	108	Ca>Mn>Cu>Mg>Zn>P>N>K
A90H+	17	16	21	-15	-11	4	-5	-28	-1	117	Cu>Ca>Mg>Zn>Mn>P>N>K
A90H-	18	16	21	-18	-10	-5	-2	-19	1	109	Cu>Ca>Mg>Mn>Zn>P>N>K
A90N+	17	15	18	-25	-4	-13	-2	-7	-1	101	Ca>Mn>Cu>Mg>Zn>P>N>K
A90N-	19	9	20	-13	-6	-10	-7	-11	1	95	Ca>Cu>Mn>Zn>Mg>P>N>K
B65H+	23	15	20	-18	-20	5	2	-27	0	130	Cu>Mg>Ca>Zn>Mn>P>K>N
B65H-	20	25	24	-22	-17	1	-2	-28	1	139	Cu>Ca>Mg>Zn>Mn>N>P>K
B65N+	15	13	13	-9	-5	-14	2	-15	0	86	Cu>Mn>Ca>Mg>Zn>P=K>N
B65N-	20	10	19	-12	-8	-8	-6	-15	0	98	Cu>Ca>Mg=Mn>Zn>P>K>N
B90H+	12	9	18	-14	-4	-2	-4	-16	-1	79	Cu>Ca>Mg=Zn>Mn>P>N>K
B90H-	22	10	21	-17	-17	-1	1	-19	0	108	Cu>Ca=Mg>Mn>Zn>P>K>N
B90N+	14	12	16	-12	-2	-18	3	-13	0	90	Mn>Cu>Ca>Mg>Zn>P>N>K
B90N-	17	9	23	-12	-8	-19	0	-10	0	98	Mn>Ca>Cu>Mg>Zn>P>N>K

A= Pioneer 3925, B= Pioneer 3949

65= 65000 pph 90= 90000 pph

H= 400-300-400, N= 170-100-170

+= Irrigation -= No irrigation

Table 2.51. DRIS indices for some plant nutrients in maize ear-leaf at growth stage 5 in 1984 for the 16 treatment combinations.

Treat. Comb.	N	P	K	Ca	Mg	Mn	Zn	Cu	Sum of Indices	NBI	Order of requirement according to DRIS
	DRIS indices										
A65H+	-9	-3	-9	-8	-9	40	-2	-1	-1	81	N=K=Mg>Ca>P>Zn>Cu>Mn
A65H-	-16	-7	-7	-8	-10	44	5	-1	0	98	N>Mg>Ca>P=K>Cu>Zn>Mn
A65N+	0	-1	-5	-6	-5	15	0	2	0	34	Ca>K=Mg>P>N=Zn>Cu>Mn
A65N-	-6	-3	-4	-6	-4	14	3	6	0	46	Ca=N>K=Mg>P>Zn>Cu>Mn
A90H+	-9	-2	-6	-9	-12	46	-4	-4	0	92	Mg>N=Ca>K>Zn=Cu>P>Mn
A90H-	-11	-7	-7	-7	-9	37	0	3	-1	81	N>Mg>P=K=Ca>Zn>Cu>Mn
A90N+	-4	-1	-5	-5	-6	16	0	5	0	42	Mg>K=Ca>N>P>Zn>Cu>Mn
A90N-	0	-4	-4	-5	-4	13	1	2	-1	33	Ca>P=K=Mg>N>Zn>Cu>Mn
B65H+	-11	-5	-8	-5	-14	43	0	-1	-1	87	Mg>N>K>P=Ca>Cu>Zn>Mn
B65H-	-13	-8	-10	-2	-7	40	-1	1	0	82	N>K>P>Mg>Ca>Zn>Cu>Mn
B65N+	-9	-2	-7	0	-1	15	0	4	0	38	N>K>P>Mg>Zn=Ca>Cu>Mn
B65N-	-7	-4	-6	-1	-1	17	-2	4	0	42	N>K>P>Zn>Ca>Mg>Cu>Mn
B90H+	-11	-3	-7	-5	-8	37	-1	-3	-1	75	N>Mg>K>Ca>P=Cu>Zn>Mn
B90H-	-13	-5	-7	-2	-8	33	1	1	0	70	N>Mg>K>P>Ca>Zn=Cu>Mn
B90N+	-7	-2	-6	1	0	14	-2	2	0	34	N>K>P=Zn>Mg>Ca>Cu>Mn
B90N-	-7	-4	-6	0	-2	14	-2	6	-1	41	N>K>P>Mg=Zn>Ca>Cu>Mn

A= Pioneer 3925, B= Pioneer 3949

65= 65000 pph, 90= 90000 pph

H= 400-300-400, N= 170-100-170

+= Irrigation -= No irrigation

Table 2.52. Effect of hybrid, and fertilizer rate on NBI in maize plants at growth stage 2+ and 5 in 1984.

Growth Stage	Plant Part	Treatment	NBI
2+	plant shoot	Hybrid	
		Pioneer 3925	136
		Pioneer 3949	119 *
		CV(%)	26.2
2+	plant shoot	N - P_2O_5 - K_2O (kg/ha)	
		170-100-170	116
		400-300-400	138 *
		CV(%)	26.2
5	ear-leaf	N - P_2O_5 - K_2O (kg/ha)	
		170-100-170	43
		400-300-400	89 *
		CV(%)	26.7

*, significantly different at $p=0.05$

Table 2.53. DRIS indices and order of requirement for some plant nutrient in maize plant shoot at growth stage 2 for different treatment combinations in 1985.

Treat. Comb.	N	P	K	Ca	Mg	Mn	Zn	Cu	Sum of indices	NBI	Order of requirement according to DRIS
	DRIS indices										
A65H+	86	29	36	-11	-20	-47	-44	-29	0	302	Mn>Zn>Cu>Mg>Ca>P>K>N
A65H-	80	17	28	-9	-21	-37	-37	-23	0	250	Mn=Zn>Cu>Mg>Ca>P>K>N
A65N+	77	21	26	-1	-9	-61	-35	-18	0	248	Mn>Zn>Cu>Mg>Ca>P>K>N
A65N-	88	24	30	-2	-11	-66	-41	-21	1	283	Mn>Zn>Cu>Mg>Ca>P>K>N
A90H+	86	28	35	-14	-25	-44	-31	-35	0	298	Mn>Cu>Zn>Mg>Ca>P>K>N
A90H-	86	23	27	-16	-20	-39	-39	-23	-1	273	Mn=Zn>Cu>Mg>Ca>P>K>N
A90N+	90	19	27	-9	-16	-55	-30	-26	0	272	Mn>Zn>Cu>Mg>Ca>P>K>N
A90N-	95	18	25	-1	-8	-77	-35	-17	0	276	Mn>Zn>Cu>Mg>Ca>P>K>N
B65H+	97	27	27	-17	-29	-55	-41	-10	-1	303	Mn>Zn>Mg>Ca>Cu>P>K>N
B65H-	94	15	30	1	-38	-37	-34	-32	-1	281	Mg>Mn>Zn>Cu>Ca>P>K>N
B65N+	87	19	16	11	-3	-60	-37	-32	1	265	Mn>Zn>Cu>Mg>Ca>K>P>N
B65N-	96	12	22	12	-9	-79	-33	-21	0	284	Mn>Zn>Cu>Mg>P=Ca>K>N
B90H+	84	22	30	-6	-19	-39	-32	-40	0	274	Cu>Mn>Zn>Mg>Ca>P>K>N
B90H-	86	14	30	-14	-27	-33	-28	-27	1	259	Mn>Zn>Mg=Cu>Ca>P>K>N
B90N+	87	31	18	4	-3	-65	-41	-32	-1	281	Mn>Zn>Cu>Mg>Ca>K>P>N
B90N-	72	14	23	-4	-13	-47	-17	-28	0	218	Mn>Cu>Zn>Mg>Ca>PK>N

A= Pioneer 3925, B= Co-op 2645

65= 65000 pph, 90= 90000 pph

H= 400-300-400, N= 1700-100-170

+= Irrigation . -= No irrigation

Table 2.54. DRIS indices and order of requirement of some plant nutrients in maize plant shoot at growth stage 3 for different treatment combinations in 1985.

Treat. Comb.	N	P	K	Ca	Mg	Mn	Zn	Cu	Sum of indices	NBI	Order of requirement according to DRIS
	DRIS indices										
A65H+	29	15	46	-15	1	-26	-17	-32	1	181	Cu>Mn>Zn>Ca>Mg>P>N>K
A65H-	25	8	48	-15	-16	-21	-8	-21	0	162	Mn=Cu>Mg>C.Zn>P>N>K
A65N+	27	15	46	-17	4	-38	-17	-21	-1	185	Mn>Cu>Ca=Zn>Mg>P>N>K
A65N-	27	6	42	-14	-1	-35	-9	-16	0	150	Mn>Cu>Ca>Zn>Mg>P>N>K
A90H+	27	19	51	-9	-5	-27	-21	-34	1	193	Cu>Mn>Zn>Ca>Mg>P>N>K
A90H-	24	6	47	-12	-6	-21	-16	-21	1	153	Mn=Cu>Zn>Ca>Mg>P>N>K
A90N+	31	18	49	-20	2	-40	-18	-22	0	200	Mn>Cu>Ca>Zn>Mg>P>N>K
A90N-	29	21	44	-10	-3	-42	-20	-19	0	188	Mn>Zn>Cu>Ca>Mg>P>N>K
B65H+	27	10	54	-10	-13	-32	-9	-27	0	182	Mn>Cu>Mg>Ca>Zn>P>N>K
B65H-	29	11	46	-16	-13	-27	-10	-21	-1	173	Mn>Cu>Ca>Mg>Zn>P>N>K
B65N+	30	13	46	1	4	-54	-16	-24	0	188	Mn>Cu>Zn>Ca>Mg>P>N>K
B65N-	38	14	40	-11	-6	-45	-10	-20	0	184	Mn>Cu>Ca>Zn>Mg>P>N>K
B90H+	23	12	44	-11	0	-26	-12	-30	0	160	Cu>Mn>Zn>Ca>Mg>P>N>K
B90H-	26	11	49	-13	-13	-27	-8	-25	0	172	Mn>Cu>Ca=Mg>Zn>P>N>K
B90N+	27	17	42	-4	6	-38	-16	-33	1	183	Mn>Cu>Zn>Ca>Mg>P>N>K
B90N-	25	16	44	-9	-5	-40	-8	-24	-1	171	Mn>Cu>Ca>Zn>Mg>P>N>K

A= Pioneer 3925, B= Co-op 2645

65= 65000 pph, 90= 90000 pph

H= 400-300-400, N= 170-100-170

+= Irrigation, -= No irrigation

Table 2.55. DRIS indices for some plant nutrients in maize ear-leaf at growth stage 5 for the 16 treatment combinations in 1985.

Treat. Comb.	N	P	K	Ca	Mg	Mn	Zn	Cu	Sum of indices	NBI	Order of requirement according to DRIS.
					DRIS indices						
A65H+	-3	20	4	-5	-16	12	-6	-6	0	72	Mg>Zn=Cu>Ca>N>K>Mn>P
A65H-	-9	15	2	-5	-14	17	-1	-6	-1	69	Mg>N>Cu>Ca>Zn>K>P>Mn
A65N+	-2	23	5	-6	-9	3	-9	-6	-1	63	Mg=Zn>Ca=Cu>N>Mn>K>P
A65N-	-7	14	1	-4	-7	7	-1	-3	0	44	N=Mg>Ca>Cu>Zn>K>Mn>P
A90H+	-5	30	7	-3	-16	11	-12	-12	0	96	Mg>Zn=Cu>N>Ca>K>Mn>P
A90H-	-7	9	3	-4	-6	13	-2	-6	0	50	N>Mg=Cu>Ca>Zn>K>P>Mn
A90N+	-4	22	4	-6	-8	0	-5	-3	0	52	Mg>Ca>Zn>N>Cu>Mn>K>P
A90N-	-8	13	5	-3	-3	5	-4	-5	0	46	N>Cu>Zn>Ca=Mg>K=Mn>P
B65H+	-2	22	6	1	-20	11	-9	-10	-1	81	Mg>Cu>Zn>N>Ca>K>Mn>P
B65H-	-9	13	3	0	-8	13	-4	-8	0	58	N>Mg=Cu>Zn>Ca>K=P=Mn
B65N+	-4	21	5	-2	-3	1	-11	-7	0	54	Zn>Cu>N>Mg>Ca>Mn>K>P
B65N-	-6	18	0	-1	-2	3	-7	-5	0	42	Zn>N>Cu>Mg>Ca>K>Mn>P
B90H+	-6	26	6	0	-19	13	-9	-11	0	90	Mg>Cu>Zn>N>Ca>K>Mn>P
B90H-	-9	17	5	1	-11	12	-5	-10	0	70	Mg>Cu>N>Zn>Ca>K>Mn>P
B90N+	-4	22	8	-1	-3	-2	-12	-8	0	60	Zn>Cu>N>Mg>Mn>Ca>K>P
B90N-	-14	20	5	1	0	5	-6	-13	-2	64	N>Cu>Zn>Mg>Ca>K=Mn>P

A= Pioneer 3925, B= Co-op 2645

65= 65000 pph 90= 90000 pph

H= 400-300-400, N= 170-100-100

+= Irrigation -= No irrigation

Table 2.56. Effect of irrigation and fertilizer on NBI in maize plants at growth stages 3 and 5 in 1985.

Growth Stage	Plant Part	Treatment	NBI
3	plant shoot	Irrigation	
		Yes	214
		No	194 *
		CV(%)	13.8
5	ear-leaf	Irrigation	
		Yes	75
		No	60 *
		CV(%)	28.8
5	ear-leaf	$N - P_2O_5 - K_2O$ (kg/ha)	
		170-100-170	59
		400-300-400	76 *
		CV(%)	28.8

*, significantly different at p=0.05

Table 2.57. Simple correlation showing the relationship between NBI at stage 5 and dry matter yield at stage 4 (TSDM), grain dry matter (GRDM) and total dry matter at harvest (TDM) in 1985

	Irrigation Yes	Irrigation No	$N-P_2O_5-K_2O$ 170-100-170	$N-P_2O_5-K_2O$ 400-300-400
		NBI		
TSDM	0.19	0.31	0.23	0.17
GRDM	0.29	-0.56***	-0.25	0.50***
TDM	0.41*	-0.38*	-0.13	0.46***

*, **, and *** significant at the 5%, 1% and 0.1% levels respectively

2.3.4 Soil Micronutrient Balance Sheet

In general, the Cu, Zn, and Mn requirement of the maize crop, at the two levels of fertilization, in 1984 and 1985 seems to have been satisfied by the supply in the soil and from the applied chelates and manure in 1985 (Table 2.58). The removal of Cu in either year was about 5% of the available supply as determined by the DTPA soil test at the two levels of fertilization, with about 64% of the absorbed Cu returning to the soil via plant residue. In 1984 there were no differences in the values for soil test Cu in the spring and fall. However, in 1985 soil test values for the fall were significantly higher (t-test, $p=0.05$) than the spring values of that year.

The amount of Zn removed from the soil was similar in 1984 and 1985. However, the fraction of soil test Zn removed in 1984 (about 13%) was lower than in 1985 (about 54%). The high fertilization plots were associated with higher Zn removal in 1985. In general, the level of soil test Zn increased in the fall of 1985 over the spring values of that year. Less than 40% of the Zn taken up by the plant was returned with the plant residues to the soil in 1984, and just over 40% in 1985

There was no difference (t-test, $p=0.05$) in the amounts of Mn removed by the crop in 1984 or 1985. On the average, only about 1% of the soil test Mn was removed by the crop. Of the amount taken by the plant, about 90% was returned with the plant residue to the soil.

In comparing the quantity of each micronutrient removed and the quantity returned, it appears that the maize crop depleted soil Zn to a greater extent.

Table 2.58. Micronutrient balance sheet for fertilization rates in 1984 and 1985.

Element	Fert. rate	DTPA-extract. element		Element amount		
		Spring	Fall	Added	Removed	Returned
		kg/ha*				
1984						
Cu	Normal	1.90±0.14	1.75±0.14	0	0.088±0.011	0.050±0.010
	High	2.01±0.65	1.77±0.17	0	0.099±0.011	0.061±0.010
Zn	Normal	2.72±0.52	3.08±0.43	0.41	0.368±0.023	0.124±0.013
	High	2.98±0.89	3.33±0.61	0.41	0.393±0.033	0.131±0.022
Mn	Normal	93.3±7.8	78.7±14.1	0.12	0.334±0.047	0.302±0.047
	High	86.9±6.8	92.9±8.6	0.12	0.584±0.048	0.543±0.046
1985						
Cu	Normal	1.29±0.15	2.02±0.37	0	0.058±0.011	0.044±0.000
	High	1.21±0.30	2.13±0.28	0	0.066±0.011	0.047±0.010
Zn	Normal	0.76±0.12	1.07±0.14	0.41	0.345±0.029	0.148±0.025
	High	0.67±0.04	1.10±0.13	0.41	0.424±0.069	0.182±0.061
Mn	Normal	36.5±3.9	63.4±7.2	0.12	0.365±0.044	0.319±0.043
	High	42.4±4.0	67.2±8.1	0.12	0.603±0.087	0.542±0.087

*, values in body of table represent 'mean±standard deviation'

2.4 DISCUSSION

2.4.1 Treatment Effects on Soil

2.4.1.1. Soil pH

The observed pH decrease with higher rates of fertilizer is consistent with the acidifying effect of urea and monoammonium phosphate (Randall et al. 1975; Blevins et al. 1977; McCoy and Webster 1977). Further, acidification can arise as a result of enhanced uptake of cations, which are believed to produce H^+ as a counter-ion from plant roots (Tisdale et al. 1985).

The lower soil pH at higher rates of fertilizer was more pronounced in 1984, and where the soil was not irrigated. This effect can perhaps be explained in the manner of Adam and Anderson (1983) who found that upon drying there was increased acidity on clay surfaces. The influence of irrigation on pH was absent in 1985, masked perhaps by the application of $Ca(OH)_2$ in the spring of that year.

2.4.1.2 Soil Cu

Of the micronutrients studied, Cu was present in the lowest amounts; which is not unusual for mineral soils. In 1985 the soil Cu level in plots planted at high populations with Pioneer 3925 may have been related to a greater uptake of Cu at high plant populations. In addition, the application of $Ca(OH)_2$ during 1985 may have influenced soil test Cu. Further, the addition of manure may have caused complexation of Cu. However, according to McBride and Blasiak (1979), Cu^{2+} availability is controlled more by organic matter complexation mechanism than soil pH. Thus the effect of $Ca(OH)_2$ may have been minimal on soil test Cu.

It seems that hybrids differed in their ability to extract Cu from the soil, especially when planted at high plant densities. This could be an important factor on soils marginal in available Cu. However the soil levels found in this study were above the 0.2 mg kg^{-1} level considered adequate for sensitive crops (Viets and Lindsay 1973).

2.4.1.3 Soil Zn

The soil test levels of Zn in the soil in the fall of 1984, were found to be above the 1.00 mg kg^{-1} considered adequate for sensitive crops (Viets and Lindsay 1973). The high rate of fertilization was associated with higher soil test levels, due perhaps to the acidifying effect of the higher rate of fertilization. Pioneer 3925 was associated with low soil test Zn when plants were fertilized at high rates. This indicated that this hybrid may be more capable of extracting micronutrients from the soil. However. uptake data did not support such an observation.

Treatment effects on soil Zn were absent in 1985, probably because of the overriding effect of $Ca(OH)_2$ added in that season. However the level of soil test Zn at the end of the 1985 season was reduced over 1984 about 0.75 mg kg^{-1} which is considered marginal for sensitive crops. Thus, continued addition of lime would require monitoring of Zn soil levels to ensure adequate levels were being maintained.

2.4.1.4 Soil Mn

Soil Mn levels were generally high in the 1984 season, but they were lower in 1985 because of increased pH as a result of $Ca(OH)_2$

treatment and precipitation of soluble Mn . In both years, soil test levels were above that which is considered adequate. Pioneer 3925 at high population was associated with lower levels of soil Mn at the end of the season perhaps due to increased uptake. A similar effect on soil Cu and Zn has been noted.

The observed increase in available Mn at high fertilizer rates and under irrigated conditions, was due to soil acidification by fertilizer and an increase in Mn^{2+} resulting from a possible reduction of Mn^{4+}

In general fertilizer appeared to have the largest effect on the soil environment and as a consequence soil test micronutrient levels were increased at high rates of fertilizer, whereas some hybrids tended to reduce soil test levels.

2.4.2 Treatment Effects on Plant Micronutrient Levels

2.4.2.1 Tissue Cu

The results in 1984 show that there were no hybrid effects on Cu concentration and uptake at the various stages of growth of the plants. This may be explained by the fact that soil Cu levels were adequate, and were not greatly influenced by treatment effects.

In 1985 there were hybrid differences, on the concentration and uptake of Cu. Nevertheless, the Cu concentration for both hybrids was within the adequacy range reported by Jones and Eck (1973).

In most cases, third order interaction effects on Cu uptake were found not to be consistent, and were probably due to small variations in soil micro-environments and sampling variability.

In general higher plant populations were associated with a higher Cu uptake, because of the larger amount of dry matter produced. The absence, for the most part, of Cu concentration changes with the increased plant population, would confirm that the soil supply of Cu was adequate for high production levels.

In 1985, high plant populations decreased concentrations of Cu in the leaves of plants at stages 4 and 5, and dry matter accumulation seemed higher than Cu uptake rates, suggesting a possible decrease in supply of soil Cu. However the effect was not critical to plant growth as a positive linear relationship between Cu uptake and dry matter yield was found.

In general, high fertilizer rates were often associated with decreased Cu concentrations, perhaps because of the dilution effect of increased dry matter yield. This effect was not consistent throughout the growing season.

However, in both years, the Cu concentration in the ear-leaf was above the critical values of 5 mg kg^{-1} reported by Melsted at al. (1969). The high fertility treatment gave ear-leaf Cu concentrations values of 12.5 mg kg^{-1} in 1984 and 8.0 mg kg^{-1} in 1985. The decrease at 1985 was due probably to decreased Cu availability as a result of $Ca(OH)_2$ treatment. Flannery (1982) at Rutgers University, and Stevenson and Nuttall (1984), in Ontario, found values of 11 mg kg^{-1} and 8 mg kg^{-1} respectively for their high fertility maize treatments. Thus there appeared to be no antagonistic effect of added fertilizer on Cu uptake.

In both years of the study, irrigation was found to decrease the concentration and uptake of Cu at most growth stages. This would suggest that the supply of available Cu under irrigated soil conditions was less than under non-irrigated conditions. This result is contrary to an expected increase in uptake due to increased Cu diffusion to the roots under irrigation. Perhaps, with irrigation, Cu was leached beyond the root zone. It is also possible that water-logging at the micropore level reduced organic matter mineralization and subsequently the liberation of Cu. These suggestions remain to be tested.

2.4.2.2 Tissue Zn

Zinc concentration values in the ear-leaf were above critical values reported by Melsted et al (1969). Thus Zn deficiences were not observed with any treatments, although some differences in uptake were noted.

The results of 1984 show that hybrid differences occurred mainly with regards to the uptake of Zn in grain. The higher yielding hybrid had a higher Zn uptake, due primarily to higher yields.

In 1985, the higher yielding Co-op 2645 had a consistently higher uptake and concentration of Zn in its tissue. Thus there appeared to be no Zn deficiency even at high yield levels.

The higher demands for Zn under high plant population densities were satisfied, and Zn deficiency could be assumed to be absent in both years. A linear positive relationship was found between Zn uptake and dry matter at all stages in the growth of the plant.

In both years high fertilizer rates increased Zn uptake and dry matter yields and the corresponding concentration of Zn remained unchanged. This indicated that increased uptake was due to a yield increase, and that the plant demands for Zn were satisfied. This was further confirmed with ear-leaf analyses. The high rate of fertilization was associated with a high Zn concentration in the ear-leaf at tasselling. The values for Zn concentration in the ear-leaf at early silk were 46 mg kg^{-1} in 1984 and 31.7 mg kg^{-1} in 1985 for high fertility treatments. Flannery (1982) found Zn concentration of 39 mg kg^{-1}, and Stevenson and Nuttall (1982) found Zn concentration 29 mg kg^{-1} in the ear-leaf of plants at high fertility. Thus it is clear that increased fertilizers rates did not reduce Zn availability.

The apparent decrease in available Zn with irrigation in 1985 may be due in part to a dilution effect through increased dry matter yields. Irrigation tended to enhance grain Zn but reduce stover Zn, either due to increased translocation to grain in response to increased grain yield with irrigation, or due to preferential movement to the grain with irrigation.

2.4.2.3 Tissue Mn

In general soil Mn was not limiting, and uptake in both years was quite high during the periods of rapid dry matter accumulation. Beyond stage 4 there was a decrease in uptake and concentration of Mn. No reason can be found for such a decline.

Manganese concentrations in the ear-leaf at early silking were generally quite high in both years of the study. The values for high fertility treatments were 245.0 mg Mn kg^{-1} in 1984 and 113 mg kg^{-1} in 1985. Flannery (1982) and Stevenson and Nuttall (1982) found values of 43 mg kg^{-1} and 32 mg kg^{-1}, respectively, in high yield environments.

These high Mn values were apparently not toxic to plant growth and yields, as there was a positive linear relationship between Mn uptake and dry matter yields in both years.

In 1984, there was apparent similarity between hybrids with respect to Mn requirement, perhaps due to the acid soil and high Mn availability or due to similarities in the growth habits of the hybrids.

In 1985, at maturity Co-op 2645 had a lower uptake and concentration of Mn in the leaves and grain, perhaps due to a dilution effect with higher dry matter yields. For both hybrids the loss of Mn from the plants as maturity approached was surprising. There was no evidence of Mn loss by maize plants to be found in the literature. A possible mechanism could be loss from leaves as a result of leaching by rainfall, or an active removal of Mn to other parts of the plants like the roots, or excretion into the soil.

There was no population effect on the uptake and concentration of Mn in plants in 1984. In 1985, there was higher uptake at high plant populations, indicating that plants were well supplied with Mn. This was expected because soil Mn was abundant in both years and competition effects were thus eliminated.

Increased Mn uptake and Mn concentration with increased fertilizer rates was probably due to the acidifying effect of the fertilizer. There may have been luxury consumption of Mn, due to greater availability of Mn at the generally low pH.

In 1985, the uptake and concentration of Mn was generally decreased due to the effect of the applied $Ca(OH)_2$.

Irrigation tended to decrease the concentration of Mn in plant tissue probably through a dilution effect of increased dry matter yield.

2.4.3 Diagnosis and Recommendation Integrated System

The results of DRIS analysis indicated that there was an apparent imbalance in nutrients at the early growth stages, indicating a relative excess in N, P and K supplied with the fertilizer. The decrease in the values of the NBI at later stages indicated that calculated imbalances decreased with time.

The fertilizer effect may be due to relative excesses of N, P and K at high fertility, thus increasing the NBI. The effect of irrigation may be due to enhanced growth with irrigation which caused a dilution effect on the less mobile micronutrients and led to a larger value of the NBI.

Sumner (1977a) indicated that yields would decline to about half the maximum value when the degree of overall imbalance reached a NBI value between 250 and 300. Cornforth and Steele (1981) had maximum NBI values of 180. At the comparative stage, the plants in this study had a value of 98. This implies that the nutrient contents of the plants were relatively well balanced.

The positive correlation found between NBI and yield in most instances was interesting in that greater imbalances should not be associated with increased yields. Thus use of NBI to determine nutrient balances seems unwarranted or even misleading.

2.4.4 Micronutrient Balance Sheet

Levels of soil micronutrients from season to season did not vary to any great extent, regardless of the addition of $Ca(OH)_2$. In general soil test values suggested that the levels of available micronutrients were in excess of plant demands. This is consistent with the plant uptake results.

2.5 CONCLUSIONS

The result of this study showed that:

1. Hybrids did not have a large influence on soil properties such as pH and the levels of available micronutrients in the two years of the study. The micronutrient requirements of the three hybrids used throughout the course of the study appear to have been quite similar. However the higher yielding hybrids in all instances had the higher uptake of Cu, Zn and Mn. There were no differences between hybrids with respect to levels of Cu, Zn and Mn in the ear-leaf at the the diagnostic early silk stage. All values of Cu, Zn and Mn concentrations were above documented critical levels. The values also compared favourably to those reported by other workers currently involved in maximum yield studies in maize. Hybrids did not differ with respect to calculated nutrient balances, and the values of nutrient balance indices reflected a generally well balance crop nutrition. Plants of all hybrids utilized micronutrients in the following order:. Zn > Mn > Cu. Uptake of Zn did not decrease with increasing maturity, but the uptake of Mn was reduced as plant reached the tassel stage and beyond. When soil pH was low in 1984, uptake of Cu did not decrease with maturity. However, in 1985, Cu uptake remained relatively constant beyond the tasselling stage.

2. Higher plant populations were associated with higher uptake of micronutrients because of the associated higher dry matter production. However, the generally high levels of Cu, Zn and Mn found in the soil ensured that plants were well supplied.

3. Fertilization was the treatment that had largest impact on soil properties and Mn and Zn contents of the maize plant. High fertilizer rates decreased soil pH and increased the availability of Mn and Zn, but had no marked effect on Cu availability. The combined effect of higher uptake and increased availability with higher fertilization rates resulted in higher concentration of Mn, particularly in the 1984 season. However, the higher levels of micronutrients did not seem detrimental to crop yields.

4. Irrigation decreased uptake of micronutrients though it increased plant dry matter yield. Leaching of micronutrients may have taken place under irrigation. However, a more likely cause of reduced contents is a dilution due to increased dry matter production with irrigation.

5. The application of soil amendments to correct soil pH seemd quite useful in reducing high levels of soil Mn, and yet did not reduce Cu and Zn drastically.

In general the results of the two years of field study showed the maximum yield experiment at the current site does not have a micronutrient disorder problem. Soil supplies of micronutrients are adequate, and levels would be maintained with the return of crop residues. However, some attention should be given to Zn as a large proportion of it is lost with the removal of the grain.

PREFACE TO CHAPTER 3

The preceeding chapter provided information on the effect of fertilizer rate, plant population, hybrids and irrigation on the uptake and concentration of Cu, Zn and Mn in the plant. This information was insufficent to explain.

a) Which fertilizer nutrient, N or P, influenced most significantly the micronutrients in the soil and plants; and

b) The effect of $Ca(OH)_2$ and applied micronutrients on plants and soils.

To get a clearer insight into these factors, a pot experiment was designed to see the effect of levels of urea, monoammonium phosphate, $Ca(OH)_2$ and applied micronutrients on Cu, Zn and Mn in plants and soil. Chapter 3 reports the results of this experiment.

CHAPTER 3

EFFECTS OF N AND P RATES, APPLIED MICRONUTRIENTS AND $Ca(OH)_2$ ON SOIL MICRONUTRIENT, AND ON THE YIELD AND MICRONUTRIENT UPTAKE AND CONCENTRATION IN MAIZE (*Zea mays* L.)

3.1 INTRODUCTION

The fertilizer levels assessed in Chapter 2 utilized a complete fertilizer, and as such it was difficult to separate the effects of specific nutrients. Fertilizer N and P are focused upon in this study, because of their effects on increasing soil acidity, and possible unfavourable interactions of P with micronutrients (Randall et al. 1975; Jolley and Pierre 1977).

The use of lime in improving soil fertility is also associated with decreased availability of micronutrients (MacLean, 1974; Prasad and Sinha, 1982). As described in Chapter 2, $Ca(OH)_2$ was applied to adjust soil pH in the field study. The stimulation of greater growth by high fertilization, and the decrease of available micronutrients as a result of $Ca(OH)_2$ application, could affect the micronutrient nutrition of the crop.

Micronutrients are usually added in small quantities to the soil when needed. Chelates are reported (Halvorson and Lindsay, 1977; Prasad and Sinha, 1981) to be more efficient as a carrier of micronutrients in the soil than the oxide and sulphate forms that are commonly used. Chelates are supposed to maintain micronutrients in a more soluble form in the soil.

Consequently, the work reported here was undertaken to provide information on the effect of soils, N and P fertilization, applied $Ca(OH)_2$, and chelate micronutrients on Cu, Zn and Mn in the soil, and utilization of these micronutrients by young maize plants.

3.2 MATERIALS AND METHODS

3.2.1 Experimental Design

The experiment consisted of factorial combinations of rates of N, P, $Ca(OH)_2$ and micronutrients replicated three times (Table 3.1). Three soils were used in the study.

3.2.2 Soils

Surface samples from a Chicot sandy loam (Gleyed melanic brunisol), an Ormstown silty clay loam (Orthic luvic gleysol) and a Bearbrook heavy clay (Orthic humic gleysol) all from the province of Quebec were collected. Bulk samples were partially air dried and sieved through a 8 mm mesh before potting. For subsequent analyses, subsamples of soil were oven dried at 105°C and ground to pass a 2 mm sieve. Some chemical and physical characteristics of the selected soils are presented in Tables 3.2 and 3.3.

3.2.3 Pots

Pots were constructed from ABS drain pipe with one perforated end cap. All pots were 25 cm. high and 10 cm in diameter.

3.2.4 Potting and Treatment Application.

3.2.4.1 Soil

Pots were filled with soil to a height of about 23 cm., which occupied a volume of about 1854 cubic centimeters. The weight of this quantity of soil was as follows:-

1. Bearbrook - 2050g
2. Chicot - 2474g
3. Ormstown - 2250g

3.2.4.2 Treatments

Urea (fertilizer grade), monoammonium phosphate (MAP) (fertilizer grade), and OLIGOSOL[1] were the source of N, P and micronutrients (Cu, Zn, Mn and Fe) respectively. A blanket application of K (244 mg K_2O/pot) was made using muriate of potash (KCl). $Ca(OH)_2$ was applied in powdered form. All nutrients were applied in solution or suspension.

For N, 53.7, 114.7 and 175.7g of urea; and for P, 50.8, 101.7 and 152.5g of MAP was dissolved separately in distilled water to make a liter of each solution. When the P solutions were applied to the pots, they provided an additional 27.9, 55.9, and 83.9 mg N per pot respectively. For the treatment combinations where the applied urea and MAP did not provide the total amounts of N required, the deficit was made up with a solution of NH_4Cl.

The $Ca(OH)_2$ treatment involved raising the soil pH to 6.5. The quantities of $Ca(OH)_2$ required were determined for each soil using an incubation procedure (Shoemaker et al 1961). Ten-gram portions of oven dried soil were incubated at field capacity and room temperature for one week with $Ca(OH)_2$ equivalent to 0, 9.0, 18.0, 36.0 and 54.0 mg/10g soil. At the end of the incubation period, the pH of the soil was measured and plotted against amounts of applied $Ca(OH)_2$. The amounts of $Ca(OH)_2$ required to raise the pH of the soil to 6.5 were determined from the graph.

The soil from the pots receiving the $Ca(OH)_2$ treatment, was spread over a sheet of plastic and evenly covered with appropriate amounts

---

1 OLIGOSOL, LTD. 1433 DU Cap, Beloeil, Que

of $Ca(OH)_2$ powder. The soil was then divided into quarters, followed by a thorough mixing of each quarter separately, before recombining. The procedure was repeated three times and the soils returned to their respective pots.

The micronutrient products were Oligo-Cu (5% Cu), Oligo-Zn (7% Zn), Oligo-Mn (5% Mn) and Oligo-Fe (5% Fe) with polyphenolic sulphonic acid as the chelating agent. The products each contained 4% S, and for this reason, where micronutrients were not applied a 20 ml solution of 0.2% Na_2SO_4 was used to provide an equivalent amount of S. Micronutrients were applied at a maintenance rate of 2 kg/ha (2 mg/pot, assuming 2.2 x 10^6 kg ha^{-1}) for each element, and based on the manufacture's recommendation a mixture of products was made to provide the required amounts. For ease in application, a mixture consisting of 1.5 ml of Oligo-Zn, and 2.0 ml each of Oligo-Cu, Mn and Fe diluted to 8 liters in distilled water was used.

3.2.4.3. Treatment application

Prior to applying the fertilizer and micronutrients, the top layers of soil to a depth of 7.5-8.0 cm were removed from each pot. Where appropriate, 20 ml of Oligo- mixture or Na_2SO_4 solution was applied to the soil in the pot along two diagonals at right angles using a pipette. A layer of soil about 1 cm thick was then returned to the pot. To this new layer a mixture of 5 ml each of urea, MAP, KCl, and where appropriate, NH_4Cl solutions was applied in a pattern of diminishing concentric circles. An additional soil layer of about 5 cm was again returned to the pots. At this point, using a template, four seeds of maize (Pioneer 3925) were placed on the soil surface such that they were located each in a quadrant formed by the banding of the micronutrients. Seeds were then covered with the remaining soil. All pots were allowed to stand over-night and a calculated volume of water required to attain field capacity was slowly added.

3.2.5 Growth Bench Procedures

Immediately after watering, pots were placed on the growth bench set at 16 hours of light per day. Temperatures were set at 28° C and 22° C, during the light and dark periods respectively. However, a thermometer placed at the upper part of the plant canopy read 30° C during the light periods. The light intensity in the bench was measured to be 60000 Lux above the canopy during the light periods.

Humidity was maintained by placing saucers filled with water on the bench top between pots. Pots were watered twice daily, 8.00 and 18.00 hours with distilled water to maintain soil at 80-100% field capacity.

Germination was usually complete by about the third day, and the plants were thinned to two per pot on the seventh day. After 30 days in the growth bench, plants were harvested by cutting the stem at soil level.

The soil was removed from the pots and as much of the plant roots as possible was separated by hand. The roots were then washed with tap water over a No.35 mesh to remove all soil, dried at 105°C for 24 hours and then weighed. A sample of soil from each pot was placed in a glass jar for subsequent chemical analysis.

3.2.6 Laboratory Procedures

3.2.6.1 Soil analyses

Extractable P was determined by a modification of the method generally known as Bray No.2 (Bray and Kurtz, 1945). The procedure involved shaking 2.0 g of oven-dried-ground soil for 1 minute with 25 ml extracting solution mixture (0.1N HCl and 0.03N NH_4F). The P in the soil extracts was measured on the "Technicon" auto-analyser using a modified chloro-stannous-reduced molybdophosphoric blue colour procedure described by Jackson (1962). A 1% ascorbic acid solution was used instead of stannous chloride (MacKenzie 1975).

The soil pH was measured using a soil:water or KCl ratio of 1:2.5 according to a modified method of McLean (1982). Particle size analysis was performed using the hydrometer method of Juo (1979).

Diethylenetriaminepentaacetic acid (DTPA) extractable Cu, Zn and Mn were measured by the procedure of Baker and Amacher (1982) as described in Chapter 2.

3.2.6.2 Plant analysis

Fresh plant material was weighed, dried in an oven at 70°C for 24 hours and then weighed again. The dried material was ground in a Wiley mill to pass a 20-mesh screen and mixed throughly. A weight of 0.5 g was digested in a block digester using the procedure of Thomas et al. (1967). The digests were diluted to a known weight (50 g) with deionised water, and NH_4-N, P, K, Ca, Mg, Cu, Zn, and Mn were measured in this solution.

The "Technicon" auto-analyser was used to measure NH_4 and P, following the alkaline phenolhypochlorite test described by O'Brien and

Fiore (1962) and a modification of the chloro-stannous-reduced molybdophosphoric blue colour technique of Jackson (1962), respectively. Potassium was measured with a Technicon flame photometer and a Perkin-Elmer Model 2380 atomic absorption spectrophotometer was used to determine Ca, Mg, Cu, Zn and Mn.

3.2.7 Statistical Analysis

Analyses of variance of the data and orthogonal contrasts were performed using the statistical methods available through the Statistical Analysis System (SAS) (Barr et al. 1979). Differences among means were obtained using Duncan's new multiple range test (DMRT) for main effects and the least significant difference test (LSD) for interaction effects (Steel and Torrie 1980).

Table 3.1 A summary of factors, levels, symbols and application rates used in the pot experiment.

Factor	Level	Application Rates: Field Equivalent	Application Rates: Pot Equivalent
		---kg/ha---	---mg/pot---
Nitrogen (N)	1	170	208
	2	285	348
	3	400	488
Phosphorus (P_2O_5)	1	100	122
	2	200	244
	3	300	366
		---Mg/ha---	--g/pot--
Lime ($Ca(OH)_2$	1	0	0
	2	1.22 (Orms.)	1.5 (Orms.)
		1.89 (Bear.)	2.3 (Bear.)
		1.89 (Chicot)	2.3 (Chicot)
		---kg/ha---	---ml/pot---
Micronutrients	1	0	0
	2	2	20

Bear.= Bearbrook soil

Orms.= Ormstown soil

Chicot= Chicot soil

Table 3.2 Some chemical characteristics of the soils used in the pot experiment

Chemical Parameters	Soil		
	Bearbrook	Chicot	Ormstown
	pH		
pH (1:2.5 H_2O)	5.0	4.8	5.5
pH (1:2.5 KCl)	4.1	4.1	4.6
	%		
Organic C (%)	1.53	1.17	1.46
	mg/kg		
Organic N	1943	1406	1850
Bray-2 P	73	135	54
<u>NH_4OAc-Extract</u>			
K	296	54	94
Ca	3523	1034	3268
Mg	1512	137	581
DTPA-Extract			
Cu	2.80	0.83	1.15
Zn	2.85	0.88	1.25
Mn	46.3	28.9	13.9

Table 3.3 Some physical characteristics of the soils used in the pot experiment.

Physical Parameters	Soil		
	Bearbrook	Chicot	Ormstown
	%		
Sand	0.2	58.0	2.6
Silt	24.4	20.1	62.4
Clay	75.4	21.9	35.0
Textural class	Heavy clay	Sandy clay loam	Silty clay loam

3.3 RESULTS

3.3.1 Soil Analyses

Only significant effects will be discussed, and a summary of significant F-values is noted for each soil in Appendix III.

In presenting the results, effects will be grouped according to those common to all soils, those common to two soils, and those unique to a particular soil.

3.3.1.1 Effect of added nitrogen and phosphorus.

Applied N significantly increased soil test Bray-2 P in the Bearbrook soil (Table 3.4). The effect was quadratic with P (Table 3.5). Applied P linearly increased soil test Bray-2 P in Bearbrook and Ormstown soils (Tables 3.6, 3.7).

3.3.1.2 Effect of added $Ca(OH)_2$

Applied $Ca(OH)_2$ decreased the level of DTPA-extractable Zn in all soils (Table 3.8), increased the pH of Bearbrook and Chicot soils (Table 3.9), and decreased the DTPA-extractable Mn in Bearbrook and Chicot soils (Table 3.10).

3.3.1.3 Interaction effects of added nitrogen, phosphorus, $Ca(OH)_2$ and chelated micronutrients

3.3.1.3.1 DTPA-extractable Cu

In general, increasing N or P increased DTPA Cu levels, although the effect of added P was found only with the high rate of N in the Bearbrook soil (Table 3.11) and the low rate of N with the Ormstown soil (Table 3.12). A linear increase in soil Cu with added P occurred at the highest rate of N in Bearbrook soil (Table 3.13), while in the Ormstown soil increasing rates of N had a quadratic effect on increasing extractable soil Cu when the lowest rate of P was applied (Table 3.14)

For Chicot soil, applied $Ca(OH)_2$ decreased the level of DTPA-extractable Cu only when no micronutrients were added to the soil (Table 3.15).

A P x micronutrient x $Ca(OH)_2$ interaction effect on DTPA-extractable Cu was noted in the Bearbrook soil (Table 3.16). The most obvious result was a quadratic effect on soil Cu of increasing rates of P on unlimed soil with applied micro-nutrients (Table 3.17). Other effects were not consistent.

3.3.1.3.2. DTPA-extractable Zn

Extractable Zn seemed to be most influenced by added P although the effects were influenced by interactions with added N and chelated micronutrients.

The level of DTPA-extractable Zn was significantly affected by a N x P interaction (Table 3.18), with no effect of increasing P rates at the highest N rate and a quadratic, though opposite, effect at each of the lower two N rates (Table 3.19). Increasing rates of applied P increased the DTPA-extractable soil Zn in a quadratic manner only where micronutrients had been applied to Bearbrook soil (Tables 3.20, 3.21).

3.3.1.3.3 DTPA-extractable Mn

In general, Mn was decreased by added $Ca(OH)_2$, although the effect was modified with N in Ormstown soil (Table 3.22) and added P and micronutrients in Bearbrook soil (Table 3.23, 3.24).

Where micronutrients were applied in Bearbrook soil the level of

DTPA-extractable soil Mn increased with increasing N, but decreased at the highest N rate (Tables 3.25, 3.26).

3.3.1.3.4 pH

In unlimed Ormstown soil, nitrogen rates had no significant effect on soil pH, but the pH of limed soil linearly decreased with increasing rate of applied N (Tables 3.27, 3.28). There were no significant effects of added N on the other two soils.

3.3.1.3.5 Bray-2 extractable P

A P x micronutrient x $Ca(OH)_2$ interaction effect on Bray-2 P in Chicot soil was found, with the notable effect being that of a general increase in soil P with increasing P rates (Tables 3.29, 3.30).

Table 3.4. Effect of added nitrogen on Bray-2 phosphorus in Bearbrook soil,

N Rates	Bearbrook Soil P
--mg/pot--	---mg/kg---
208	115b
348	111b
488	124a
	*
CV(%)	10.7

*, means for each soil followed by a common letter are not significantly different p=0.05

Table 3.5. Mean squares and level of significance for effect of added nitrogen on Bray-2 Phosphorus in Bearbrook soil,

Source	df	Bearbrook Soil P
		--mean square values--
N	2	
N Lin	1	1321.41**
N Quad	1	1713.45**
Error	70	154.30

*, ** Indicates 0.05 and 0.01 significance levels, respectively

Table 3.6. Effect of added phosphorus on Bray-2 phosphorus in Bearbrook and Ormstown soils.

P_2O_5 Rates	Bray-2 P: Bearbrook	Bray-2 P: Ormstown
-mg/pot-	mg/kg	mg/kg
122	99.2c	69.4c
244	115.8b	80.2b
366	134.9a	93.4a
	*	*
CV(%)	10.7	14.6

*, means in the body of table, for each soil, followed by a common letter are not significantly different (p=0.05) according to Duncan New Multiple range test.

Table 3.7. Mean squares and level of significance for effect of added phosphorus on Bray-2 phosphorus in Bearbrook and Ormstown soils.

Source	df	Bray-2 P: Bearbrook	Bray-2 P: Ormstown
		mean square values	mean square values
P	2		
P Lin	1	22914.60**	1034.43**
P Quad	1	35.99	35.19
Error	70	154.30	139.35

*, ** Indicates 0.05 and 0.01 significance levels,respectively

Table 3.8. Effect of $Ca(OH)_2$ on DTPA-extractable zinc in Bearbrook, Chicot and Ormstown soils.

$Ca(OH)_2$ Rate	Soil Zn		
	Bearbrook	Chicot	Ormstown
-g/pot-	mg/kg		
0	3.0	0.84	1.33
1.5	-	-	1.06
2.3	2.9	0.58	-
	*	*	*
CV(%)	5.8	15.7	26.0

*, significantly different at p=0.05

Table 3.9. Effect of applied $Ca(OH)_2$ on soil pH in Bearbrook and Chicot soils.

$Ca(OH)_2$ Rate	Bearbrook	Chicot
--g/pot--	pH	
0	5.1	4.5
2.3	5.6	5.1
	*	*
CV(%)	5.8	7.0

*, significantly different at p=0.05

Table 3.10. Effect of $Ca(OH)_2$ on DTPA-extractable manganese in Bearbrook and Chicot soils.

$Ca(OH)_2$ rate	Soil Mn	
	Bearbrook	Chicot
g/pot	mg/kg	
0	39.3	30.8
2.3	33.1 *	20.2 *
CV(%)	12.7	26.7

* significantly different at $p=0.05$.

Table 3.11. Effect of added nitrogen and phosphorus on DTPA-extractable copper in Bearbrook soil.

P_2O_5 rates	N Rates (mg/pot)		
	208	348	488
mg/pot	mg Cu/kg soil		
122	1.75	1.28	1.44
244	1.42	1.84	1.69
366	1.57	1.63	2.04
CV(%)=35.64	$LSD_{0.05}$=0.47 mg/kg		

Table 3.12. Effect of added nitrogen and added phosphorus on DTPA-extractable copper in Ormstown soil.

P_2O_5 rates	N Rates (mg/pot)		
	208	348	488
mg/pot	mg Cu/kg soil		
122	0.66	0.83	0.73
244	0.84	0.70	0.70
366	0.73	0.69	0.64
CV(%)=24.3		$LSD_{0.05}$=0.15 mg/kg	

Table 3.13. Mean squares and level of significance for effect of added nitrogen and phosphorus on DTPA-extractable copper in Bearbrook Soil.

Source	df	DTPA- Cu
		---mean square values---
P in N	6	
P Lin in N_1	1	0.1954
P Quad in N_1	1	0.4536
P Lin in N_2	1	0.7536
P Quad in N_2	1	1.1917
P Lin in N_3	1	2.0203*
P Quad in N_3	1	0.0203
Error	70	0.3374

*, ** Indicates 0.05 and 0.01 significance levels, respectively

Table 3.14. Mean squares and level of significance for effect of added nitrogen and phosphorus on DTPA-extractable copper in Ormstown Soil.

Source	df	DTPA- Cu
		--mean square values--
N in P	6	
N Lin in P_1	1	0.0318
N Quad in P_1	1	0.1631*
N Lin in P_2	1	0.1088
N Quad in P_2	1	0.0449
N Lin in P_3	1	0.0423
N Quad in P_3	1	0.0001
Error	70	0.0318

*, ** Indicates 0.05 and 0.01 significance levels, respectively

Table 3.15. Effect of added micronutrients and $Ca(OH)_2$ on DTPA-extractable copper in Chicot Soil.

$Ca(OH)_2$ rate	Applied micronutrients (ml/pot) 0	20
--g/pot--	---------mg Cu/kg soil--------	
0	0.27	0.28
2.3	0.23	0.26
CV(%)=10.8	$LSD_{0.05}$=0.02 mg/kg	

Table 3.16. Effect of added phosphorus, $Ca(OH)_2$ and applied micronutrients on DTPA-extractable copper in Bearbrook soil.

	Applied micronutrients (ml/pot)			
	0		20	
P_2O_5 rates	$Ca(OH)_2$ rate (g/pot) 0	2.3	$Ca(OH)_2$ rate (g/pot) 0	2.3
mg/pot	mg Cu/kg soil			
122	1.26	1.39	1.91	1.41
244	1.83	1.47	1.33	1.97
366	1.67	1.52	1.85	1.95
CV(%)=35.6		$LSD_{0.05}$=0.47 mg/kg		

Table 3.17. Mean square and level of significance for effect of added phosphorus, $Ca(OH)_2$ and applied micronutrients on DTPA-extractable copper in Bearbrook soil.

Source	df	DTPA- Cu
		--mean square values--
P in ML	8	
P Lin in M_1L_1	1	0.7633
P Quad in M_1L_1	1	0.8137
P Lin in M_1L_2	1	0.0731
P Quad in M_1L_2	1	0.0024
P Lin in M_2L_1	1	0.0188
P Quad in M_2L_1	1	1.8320*
P Lin in M_2L_2	1	1.3163
P Quad in M_2L_2	1	0.5202
Error	70	0.3374

*, ** Indicates 0.05 and 0.01 significance levels, respectively.

Table 3.18. Effect of added nitrogen and phosphorus on DTPA-extractable zinc in Bearbrook soil.

P_2O_5 rates	N rates (mg/pot) 208	348	488
mg/pot	----------mg Zn/kg soil----------		
122	3.00	2.78	2.98
244	2.77	3.00	2.87
366	2.94	2.85	3.02
CV(%)=8.8	$LSD_{0.05}$=0.21 mg/kg		

Table 3.19. Mean squares and level of significance for effect of added nitrogen and phosphorus on DTPA-extractable zinc in Bearbrook soil.

Source	df	DTPA- Zn
		--mean square values--
P in N	6	
P Lin in N_1	1	0.0161
P Quad in N_1	1	0.3173*
P Lin in N_2	1	0.0307
P Quad in N_2	1	0.2656*
P Lin in N_3	1	0.01181
P Quad in N_3	1	0.1395
Error	70	0.0652

*, ** Indicates 0.05 and 0.01 significance levels, respectively.

Table 3.20. Effect of added phosphorus and applied micronutrients on DTPA-extractable zinc in Bearbrook soil.

Applied micronutrients	P_2O_5 rates (mg/pot) 122	244	366
ml/pot	mg Zn/kg soil		
0	2.87	2.96	2.82
20	2.97	2.80	3.06
CV(%)=8.77	$LSD_{0.05}$=0.21 mg/kg		

Table 3.21. Effect of added phosphorus and applied micronutrients on DTPA-extractable zinc in Bearbrook soil.

Source	df	DTPA- Zn
		---mean square values---
P in M	4	
P Lin in M_1	1	0.0237
P Quad in M_1	1	0.1595
P Lin in M_2	1	0.0796
P Quad in M_2	1	0.5528*
Error	70	0.0652

*, ** Indicates 0.05 and 0.01 significance levels, respectively.

Table 3.22. Effect of added nitrogen and $Ca(OH)_2$ on DTPA-extractable manganese in Ormstown soil.

$Ca(OH)_2$ rates	N rates (mg/pot) 208	348	488
g/pot	mg Mn/kg soil		
0	12.3	13.2	12.6
1.5	9.5	8.9	8.5
CV(%)=20.3	$LSD_{0.05}$=1.5 mg/kg		

Table 3.23. Effect of added phosphorus, applied micronutrient and $Ca(OH)_2$ on DTPA-extractable manganese in Bearbrook soil.

	$Ca(OH)_2$ rate (mg/pot)			
	0		2.3	
P_2O_5 rates	Micronutrients (ml/pot) 0	20	Micronutrients (ml/pot) 0	20
mg/pot	mg Mn/kg soil			
122	39.1	40.1	33.3	31.8
244	41.3	36.7	31.7	36.6
366	38.2	41.0	32.2	33.0
CV(%)=12.8	$LSD_{0.05}$=3.08 mg/kg			

Table 3.24. Mean square and level of significance for effect of added phosphorus, applied micronutrient and $Ca(OH)_2$ on DTPA-extractable manganese in Bearbrook soil.

Source	df	DTPA-Extrac. Mn
		--mean square values--
P in LM	8	
P Lin in L_1M_1	1	3.2236
P Quad in L_1M_1	1	42.3797
P Lin in L_1M_2	1	3.7111
P Quad in L_1M_2	1	90.1060*
P Lin in L_2M_1	1	5.1170
P Quad in L_2M_1	1	6.6032
P Lin in L_2M_2	1	7.5965
P Quad in L_2M_2	1	47.9771*
Error	70	21.4224

*, ** Indicates 0.05 and 0.01 significance levels, respectively.

Table 3.25. Effect of added nitrogen and micronutrients on DTPA-extractable manganese in Bearbrook soil.

N rates	Applied micronutrients (ml/pot) 0.	20
mg/pot	----mg Mn/kg soil----	
208	35.7	35.8
348	34.6	38.3
488	37.6	35.5
CV(%)=12.8	$LSD_{0.05}$=3.1 mg/kg	

Table 3.26. Mean squares and level of significance for effect of added nitrogen and micronutrients on DTPA-extractable manganese in Bearbrook soil.

Source	df	DTPA-Mn
		---mean square values---
N in M	4	
N Lin in M_1	1	31.0574
N Quad in M_1	1	52.0219
N Lin in M_2	1	1.0458
N Quad in M_2	1	87.0101*
Error	70	21.4224

*, ** Indicates 0.05 and 0.01 significance levels, respectively

Table 3.27 Effect of added nitrogen and $Ca(OH)_2$ on the pH of Ormstown soil.

$Ca(OH)_2$ Rate	N Rates (mg/pot) 208	348	488
--g/pot--		---pH---	
0	5.4	5.4	5.4
1.5	5.9	5.8	5.7

CV(%)=2.96 $LSD_{0.05}$=0.1

Table 3.28. Mean squares and level of significance for effect of added nitrogen and $Ca(OH)_2$ on the pH of Ormstown soil.

Source	df	Soil pH
		--mean square values--
N	2	
N Lin in L_1	1	0.0087
N Quad in L_1	1	0.0018
N Lin in L_2	1	0.2601**
N Quad in L_2	1	0.0021
Error	69	0.0288

*, ** Indicates 0.05 and 0.01 significance levels, respectively

Table 3.29. Effects of added phosphorus, micronutrients and $Ca(OH)_2$ on Bray-2 phosphorus in Chicot Soil.

	$Ca(OH)_2$ Rates (g/pot)			
	0		2.3	
	Micronutrients (ml/pot)		Micronutrients (ml/pot)	
P_2O_5 Rates	0	20	0	20
--mg/pot--	--mg/kg--			
122	164	160	169	166
244	166	157	172	181
366	186	189	213	181
CV(%)=9.07	$LSD_{0.05}$=15 mg/kg			

Table 3.30. Mean squares and level of significance for effects of added phosphorus, micronutrients and $Ca(OH)_2$ on Bray-2 phosphorus in Chicot Soil.

Source	df	Bray-2 P
		--mean square values--
P in LM	8	
P Lin in L_1M_1	1	2074.6203**
P Quad in L_1M_1	1	431.9476
P Lin in L_1M_2	1	3623.0845**
P Quad in L_1M_2	1	1954.8836**
P Lin in L_2M_1	1	8536.4403**
P Quad in L_2M_1	1	2073.0317**
P Lin in L_2M_2	1	1023.1524*
P Quad in L_2M_2	1	239.3041
Error	70	252.6658

*, ** Indicates 0.05 and 0.01 significance levels, respectively

3.3.2 Plant Responses to Added N, P, $Ca(OH)_2$ and Micronutrients

Only significant effects will be discussed, and a summary of the probability of the F-statistic for the sources is presented in Appendix IV.

3.3.2.1 Effect of treatments on root and shoot growth

There were no significant effects of added N on roots or shoots except in the Ormstown soil where both root and shoot weights were increased with added N to the rate of 348 mg/pot (Table 3.31), producing a significant quadratic effect (Table 3.32). Also, added N increased shoot yield on the Bearbrook soil but only on soils with added $Ca(OH)_2$ (Tables 3.33, 3.34).

Added P increased shoot dry weights quadratically with the Bearbrook soil and linearly with the Ormstown soil (Tables 3.35, 3.36). Added P increased root weight linearly in the Ormstown soil as well (Table 3.37, 3.38)

Added $Ca(OH)_2$ increased root and shoot weights in the Chicot soil (Table 3.39). Added micronutrients had no effect on dry matter production.

3.3.2.2 Effect of treatments on nutrient concentration and uptake

Added N decreased P in shoots linearly with Bearbrook and Ormstown soils and quadratically with Chicot soil (Tables 3.40, 3.41), whereas added P increased P concentration in shoots linearly in all soils (Tables 3.42, 3.43).

As to effects of added N and P on micronutrient contents, added N increased Cu concentration linearly in two soils, the Bearbrook and

Chicot soils (Tables 3.44, 3.45). Copper uptake was increased linearly with added N in the Chicot soil (Tables 3.46, 3.47). In addition, added N increased linearly Zn concentrations in shoots from the Chicot soil (Tables 3.46, 3.47) and Mn concentration and uptake in the Ormstown soil (Tables 3.31, 3.32). Added P had no significant main effect on micronutrient concentrations or uptake in the plants.

Applied $Ca(OH)_2$ decreased the uptake of Mn by plants from Bearbrook and Ormstown soils (Table 3.48). For Chicot soil, applied $Ca(OH)_2$ decreased concentration and uptake of Zn in plant shoots (Table 3.39).

Applied micronutrients resulted in increased concentration and uptake of Zn by plants grown in Bearbrook and Chicot soil (Table 3.49). For Chicot soil, applied micronutrients increased the concentration and uptake of Cu by the plants (Table 3.50). No other main effects were noted.

There were a number of interactions among added N, P, $Ca(OH)_2$ and micronutrients, however. In general, for the Bearbrook and Chicot soil added N increased Zn and Mn concentration and uptake in the shoots, but the effects were either increased where no $Ca(OH)_2$ was applied or decreased with added $Ca(OH)_2$ (Tables 3.51, 3.52, 3.53, 3.54, 3.55, 3.56, 3.57, 3.58).

Added P was found to enhance Mn uptake only when micronutrients were not added in Chicot soil (Tables 3.59, 3.60). Further, added N increased Cu content but especially at high rates of added P, and with no micronutrients in the Bearbrook soil (Tables 3.61, 3.62)

There was a N x $Ca(OH)_2$ x micronutrient interaction effect on Mn concentration in plants from Bearbrook soil (Table 3.63). Generally, at the low rates of N and where no micronutrients were applied $Ca(OH)_2$ was associated with decreased Mn concentrations; however where micronutrients were applied, $Ca(OH)_2$ was able to decrease Mn concentration only at the highest rate of applied N.

Table 3.31. Effect of nitrogen on the concentrations of nitrogen and manganese, uptake of manganese, and dry weights of roots and shoot of 30-day old maize plants grown in pots of Ormstown soil.

N Rate	Concentration N	Concentration Mn	Uptake Mn	Dry matter yield Shoot	Dry matter yield Root
-mg/pot-	mg/kg		--mg/pot--	g/pot	
208	31.1c	24.2a	0.312c	13.1b	2.82b
348	39.5b	26.7b	0.427b	16.1a	3.87a
488	48.6a	32.8c	0.537a	16.6a	3.78a
	*	*	*	*	*
CV(%)	15.1	23.0	29.8	17.0	30.0

*, means in body of table, for each soil, followed by a common letter are not significantly different (p=0.05) according to Duncan's New Multiple Range test.

Table 3.32. Mean squares and level of significance for effect of nitrogen on the concentrations of nitrogen and manganese, uptake of manganese, and dry weights of roots and shoot of 30-day old maize plants grown in pots of Ormstown soil.

Source	df	Concentration N	Concentration Mn	Uptake Mn	Dry matter yield Shoot	Dry matter yield Root
		mean square values				
N	2					
N Lin	1	5527.5**	1341.08**	0.92	216.67**	16.44**
N Quad	1	3.2	82.67	0.00	38.25*	7.71**
Error	70	37.8	41.08	0.16	6.77	1.10

*, ** Indicates significance at 0.05 and 0.01 levels, respectively.

Table 3.33. Effect of added nitrogen and $Ca(OH)_2$ on shoot dry matter yield of 30-day old maize plants grown in pots of Bearbrook soil.

N Rates	$Ca(OH)_2$ Rates (g/pot)	
	0	2.3
--mg/pot--	--------g/pot--------	
208	12.4	13.5
348	13.7	13.4
488	12.9	11.2
CV(%)=15.9	$LSD_{0.05}$=1.4 mg/kg	

Table 3.34. Mean squares and level of significance for effect of added nitrogen and $Ca(OH)_2$ on shoot dry matter yield in 30-day old maize plants grown in pots of Bearbrook soil

Source	df.	Shoot dry matter
		--mean square values--
N in L	4	
N Lin in L_1	1	2.834
N Quad in L_1	1	12.690
N Lin in L_2	1	49.585**
N Quad in L_2	1	14.090
Error	70	4.158

*, ** Indicates significance at 0.05 and 0.01 levels, respectively.

Table 3.35. Effect of phosphorus on shoot dry weight of 30-day old maize plants grown in pots of Bearbrook and Ormstown soils.

P_2O_5 Rates	Shoot dry weight	
	Bearbrook	Ormstown
-mg/pot-	g/pot	
122	11.4b	13.7b
244	13.7a	15.6a
366	13.5a *	16.6a *
CV(%)	15.9	17.1

*, means in body of table, for each soil, followed by a common letter are not significantly different (p=0.05) according to Duncan's New Multiple Range test.

Table 3.36. Mean square and level of significance for effect of phosphorus on shoot dry weight of 30-day old maize plants grown in pots of Bearbrook and Ormstown soils.

Source	df	Shoot dry weight	
		Bearbrook	Ormstown
		mean square values	
P	2		
P Lin	1	76.01**	155.17**
P Quad	1	36.94**	4.08
Error	70	4.16	6.77

*, ** Indicates significance at 0.05 and 0.01 levels, respectively.

Table 3.37. Effect of phosphorus on nitrogen concentration and root dry weight of 30-day old maize plants grown in pots of Ormstown soil.

P_2O_5 Rates	N concentration	Root dry weight
-mg/pot-	---mg/kg---	----g/pot----
122	42.2a	3.09b
244	39.2b	3.62a
366	37.7b *	3.76a *
CV(%)	15.1	30.0

*, means in body of table, for each soil, followed by a common letter are not significantly different (p=0.05) according to Dumcan's New Multiple Range test.

Table 3.38. Mean square and level of significance for effect of phosphorus on nitrogen concentration and root dry weight of 30-day old maize plants grown in pots of Ormstown soil.

Source	df	N concentration	Root dry weight
		-------------mean square values------------	
P	2		
P Lin	1	353.61**	8.07**
P Quad	1	13.02	0.84
Error	70	35.78	1.95

*, ** Indicates significance at 0.05 and 0.01 levels, respectively.

Table 3.39. Effect of $Ca(OH)_2$ on root and shoot dry weights, and zinc concentration and uptake by 30-day old maize plants grown in pots Chicot soil.

$Ca(OH)_2$ Rates	Dry weight		Zn	
	Root	Shoot	Concentration	Uptake
-g/pot-	g/pot		mg/kg	-mg/pot-
0	3.88	16.3	19.2	0.317
2.3	4.19	17.0	14.0	0.236
	*	*	*	*
CV(%)	15.5	7.8	50.0	53.6

*, significantly different (p=0.05) for each soil

Table 3.40. Effect of nitrogen on phosphorus concentration in 30-day old maize shoots grown in pots of Bearbrook, Chicot and Ormstown soil.

N Rates	P concentration		
	Bearbrook	Chicot	Ormstown
-mg/pot-	mg/kg		
208	5.92a	4.09a	6.26a
348	5.67ab	3.70b	5.22b
488	5.35b	4.18a	4.69c
	*	*	*
CV(%)	13.5	19.0	19.9

*, means for separate soils followed by a common letter are not significantly different (p=0.05) according to Duncan's New Multiple Range test

Table 3.41. Mean squares and level of significance for effect of nitrogen on phosphorus concentration in 30-day old maize shoots grown in pots of Bearbrook, Chicot and Ormstown soil.

Source	df	P concentration		
		Bearbrook	Chicot	Ormstown
		mean square values		
N	2			
N Lin	1	6.1082*	0.1632	44.8879**
N Quad	1	0.0197	4.4301**	1.6269
Error	70	0.9751	0.5764	1.6270

*, ** Indicates significance at 0.05 and 0.01 levels, respectively.

Table 3.42. Effect of phosphorus on the phosphorus concentration in 30-day old maize shoots grown in pots of Bearbrook, Chicot and Ormstown soil.

P_2O_5 Rates	P concentration		
	Bearbrook	Chicot	Ormstown
-mg/pot-	mg/kg		
122	4.69c	3.05c	4.33c
244	5.67b	4.11b	5.32b
366	6.60a *	4.81a *	6.51a *
CV(%)	17.5	19.0	19.9

*, means in body of table, for each soil, followed by a common letter are not significantly different (p=0.05) according to Duncan's New Multiple range test.

Table 3.43. Mean squares and level of significance for effect of phosphorus on the phosphorus concentration in 30-day old maize shoots grown in pots of Bearbrook, Chicot and Ormstown soil.

		P concentration		
Source	df	Bearbrook	Chicot	Ormstown
		mean square values		
P	2			
P Lin	1	64.09**	53.49**	85.60**
P Quad	1	0.01	0.84	0.10
Error	70	0.98	0.58	1.15

*, ** Indicates significance at 0.05 and 0.01 levels, respectively.

Table 3.44. Effect of nitrogen on copper concentration in 30-day old maize shoots grown in pots of Bearbrook and Chicot soil.

	Cu concentration	
N Rates	Bearbrook	Chicot
-mg/pot-	mg/kg	
208	6.05b	1.85c
348	6.56b	2.33b
488	8.00a *	2.98a *
CV(%)	18.0	22.5

*, means in body of table, for each soil, followed by a common letter are not significantly different (p=0.05) according to Duncan New Multiple range test.

Table 3.45. Mean squares and level of significance for effect of nitrogen on copper concentration in 30-day old maize shoots grown in pots of Bearbrook and Chicot soil.

Source	df	Cu concentration Bearbrook	Chicot
		-----mean square values-----	
N	2		
N Lin	1	65.105**	22.912**
N Quad	1	5.460	0.1541
Error	70	1.5359	0.2878

*, ** Indicates significance at 0.05 and 0.01 levels, respectively.

Table 3.46. Effect of nitrogen on zinc concentration and copper uptake by 30-day old maize shoots grown in pots of Chicot soil.

N Rates	Zn Concentration	Cu Uptake
-mg/pot-	--mg/kg--	--mg/pot--
208	13.7b	0.029c
348	15.6b	0.040b
488	20.4a	0.051a
	*	*
CV(%)	50.0	22.1

*, means in the body of table, for each soil, followed by a common letter are not significantly different (p=0.05) according to Duncan's New Multiple Range test.

Table 3.47. Means squares and level of significance for effect of nitrogen on zinc concentration and copper uptake by 30-day old maize shoots grown in pots of Chicot soil.

Source	df	Zn Concentration	Cu Uptake
		------mean square values-------	
N	2		
N Lin	1	816.453**	0.324**
N Quad	1	53.411	0.005
Error	70	68.764	0.022

*, ** Indicates significance at 0.05 and 0.01 levels, respectively.

Table 3.48. Effect of $Ca(OH)_2$ on manganese uptake by 30-day old maize shoots grown in pots of Bearbrook and Ormstown soil.

$Ca(OH)_2$ Rates	Mn uptake: Bearbrook	Mn uptake: Ormstown
-g/pot-	-------------mg/pot-----------	
0	0.620	0.486
1.5		0.365
2.3	0.484	
CV(%)	28.7 *	29.8 *

*, means for each soil are significantly different p=0.05

Table 3.49. Effect of applied micronutrients on zinc concentration and uptake by 30-day old maize shoots grown in pots of Bearbrook and Chicot soils.

Applied micronutrient	Zn concentration		Zn uptake	
	Bearbrook	Chicot	Bearbrook	Chicot
--ml/pot--	------------mg/kg---------		---------mg/pot--------	
0	28.9	14.9	0.364	0.244
20	34.0	18.3	0.434	0.309
	*	*	*	*
CV(%)	40.0	50.0	44.3	53.6

*, significantly different (p=0.05) for each soil.

Table 3.50. Effect of applied micronutrient on copper concentration and uptake by 30-day old maize shoots grown in pot of Chicot soil.

Applied micronutrients	Cu	
	Concentration	Uptake
--ml/pot--	--mg/kg--	-mg/pot-
0	2.27	0.037
20	2.49	0.042
	*	*
CV(%)	22.5	22.1

*, significantly different (p=0.05)

Table 3.51. Effect of added nitrogen and $Ca(OH)_2$ on zinc concentration in 30-day old maize shoots grown in pots of Bearbrook soil

N Rates	$Ca(OH)_2$ Rates (g/pot)	
	0	2.3
--mg/pot--	--mg/kg--	
208	27.6	26.5
348	24.8	40.4
488	32.6	36.9
CV(%)=40.1	$LSD_{0.05}$=8.4 mg/kg	

Table 3.52. Mean squares and level of significance for effect of added nitrogen and $Ca(OH)_2$ on zinc concentration in 30-day old maize shoots grown in pots of Bearbrook soil

Source	df	Zn concentration
		---mean square values---
N in L	4	
N Lin in L_1	1	217.16
N Quad in L_1	1	338.37
N Lin in L_2	1	974.61*
N Quad in L_2	1	901.94*
Error	70	158.79

*, ** Indicates significance at 0.05 and 0.01 levels, respectively.

Table 3.53. Effect of added nitrogen and $Ca(OH)_2$ on zinc uptake by 30-day old maize shoots grown in pots of Bearbrook soil.

N Rates	$Ca(OH)_2$ Rates (g/pot) 0	2.3
--mg/pot--	--------------mg/pot--------------	
208	0.337	0.354
348	0.338	0.545
488	0.420	0.339
CV(%)=44.3	$LSD_{0.05}$=0.118 mg/pot	

Table 3.54. Mean squares and level of significance for effect of added nitrogen and $Ca(OH)_2$ on zinc uptake in 30-day old maize shoots grown in pots of Bearbrook soil

Source	df	Zn uptake
		--mean square values--
N in L	4	
N Lin in L_1	1	0.062
N Quad in L_1	1	0.020
N Lin in L_2	1	0.018
N Quad in L_2	1	0.340**
Error	70	0.031

*, ** Indicates significance at 0.05 and 0.01 levels, respectively.

Table 3.55. Effect of added nitrogen and $Ca(OH)_2$ on manganese concentration in 30-day old maize shoots grown in pots of Chicot Soil.

Nitrogen Rates.	$Ca(OH)_2$ Rates (g/pot) 0	2.3
---mg/pot---	-------------mg/kg------------	
208	65.1	32.7
348	86.7	43.0
488	126.5	66.1
CV(%)=19.5	$LSD_{0.05}$=9.1 mg/kg	

Table 3.56. Mean squares and level of significance for effect of added nitrogen and $Ca(OH)_2$ on manganese concentration in 30-day old maize shoots grown in pots of Chicot soil

Source	df	Mn concentration
		--mean square values--
N in L	4	
N Lin in L_1	1	34053.07**
N Quad in L_1	1	1003.24*
N Lin in L_2	1	10064.27**
N Quad in L_2	1	1493.32
Error	70	186.44

*, ** Indicates significance at 0.05 and 0.01 levels, respectively.

Table 3.57. Effect of added nitrogen and $Ca(OH)_2$ on the manganese uptake by 30-day old maize shoots grown in pots of Chicot Soil.

Nitrogen Rates.	$Ca(OH)_2$ Rates (g/pot) 0	2.3
--mg/pot--	--mg/pot--	
208	0.98	0.53
348	1.47	0.74
488	2.16	1.15
CV(%)=20.5	$LSD_{0.05}$=0.16 mg/kg	

Table 3.58. Mean squares and level of significance for effect of added nitrogen and $Ca(OH)_2$ on manganese uptake by 30-day old maize shoots grown in pots of Chicot soil

Source	df	Mn uptake
		--mean square values--
N in L	4	
N Lin in L_1	1	12.55**
N Quad in L_1	1	0.13
N Lin in L_2	1	3.39**
N Quad in L_2	1	0.11
Error	70	0.06

*, ** Indicates significance at 0.05 and 0.01 levels, respectively.

Table 3.59. Effect of added phosphorus and micronutrients on the manganese uptake by 30-day old maize shoots grown in pots of Chicot Soil.

P_2O_5 Rates.	Applied Micronutrients (ml/pot) 0	20
--mg/pot--	---------------mg/pot---------------	
122	0.96	1.15
244	1.22	1.27
366	1.27	1.16
CV(%)=20.5	$LSD_{0.05}$=0.016 mg/pot	

Table 3.60. Mean square and level of significance for effect of added phosphorus and micronutrients on the manganese uptake by 30-day old maize shoots grown in pots of Chicot Soil.

Source	df	Mn uptake
		--mean square values--
P in M	4	
P Lin in M_1	1	0.889**
P Quad in M_1	1	0.130
P Lin in M_2	1	0.002
P Quad in M_2	1	0.152
Error	70	0.057

*, ** Indicates significance at 0.05 and 0.01 levels, respectively.

Table 3.61. Effect of added nitrogen, phosphorus and micronutrients on the copper uptake by 30-day old maize shoots grown in pots of Bearbrook soil.

	Applied micronutrients (ml/pot)					
	0			20		
	P_2O_5 Rates (mg/pot)			P_2O_5 Rates (mg/pot)		
N Rates	122	244	366	122	244	366
--mg/pot--	mg/pot					
208	0.083	0.077	0.082	0.057	0.085	0.087
348	0.088	0.087	0.085	0.082	0.095	0.091
488	0.081	0.099	0.107	0.088	0.094	0.095

CV(%)=17.9 $LSD_{0.05}$=0.018 mg/pot

Table 3.62. Mean squares and level of significance for effect of added nitrogen, phosphorus and micronutrients on the copper uptake by 30-day old maize shoots grown in pots of Bearbrook soil.

Source	df	Cu uptake
		--mean square values--
N in MP	12	
N Lin in M_1P_1	1	0.00001
N Quad in M_1P_1	1	0.00015
N Lin in M_1P_2	1	0.00031
N Quad in M_1P_2	1	0.00000
N Lin in M_1P_3	1	0.00197**
N Quad in M_1P_3	1	0.00037
N Lin in M_2P_1	1	0.00297**
N Quad in M_2P_1	1	0.00035
N Lin in M_2P_2	1	0.00023
N Quad in M_2P_2	1	0.00012
N Lin in M_2P_3	1	0.00001
N Quad in M_2P_3	1	0.00000
Error	70	0.00024

*, ** Indicates significance at 0.05 and 0.01 levels, respectively.

Table 3.63. Effect of added nitrogen, $Ca(OH)_2$ and micronutrients on manganese concentration in 30-day old maize shoots grown in pots of Bearbrook soil.

	Applied micronutrients (ml/pot)			
	0		20	
	$Ca(OH)_2$ Rates (g/pot)		$Ca(OH)_2$ Rates (g/pot)	
N Rates	0	2.3	0	2.3
--mg/pot--	mg/kg			
208	53.1	37.8	45.7	43.0
348	44.3	32.0	46.0	40.6
488	41.9	42.9	56.8	39.1

CV(%)=28.6 $LSD_{0.05}$=11.7 mg/kg

3.4 DISCUSSION

3.4.1 Effect of N, P, $Ca(OH)_2$ and Chelated Micronutrients on Soil

The results show that some differences existed among soils studied, with respect to the changes in soil P, N, pH, Cu, Zn and Mn to the applied treatments of N, P, $Ca(OH)_2$ and chelated micronutrients.

In general there were not many main effects of applied N or P on the measured soil parameters; N effects were through a number of interactions involving the other treatments. Nitrogen was found to increase the level of soil-test P in Bearbrook soil. Similar effects were observed by Bouldin and Sample (1959) and it is believed that nitrification of ammonia causes acidification and increased solubility of P compounds and is responsible for the increased availability of P when NH_4 fertilizers are used. The absences of similar effects in the other soils remained unexplained.

The expected effect of added N in decreasing soil pH was not found. A possible reason, could be the relatively short duration of the experiment, and incomplete nitrification of NH_4. In fact, hydrolysis of the applied urea could cause an initial increase in soil pH. However, a N x $Ca(OH)_2$ interaction effect on Ormstown soil was found, where applied N lowered the pH of soil treated with $Ca(OH)_2$. This result may be due to more favourable soil pH conditions that enhanced nitrification of the added N.

Increasing rates of N and P increased soil test Cu, but primarily in soils high in clay and organic matter, which had higher soil test Cu levels initially. Since there was no P * N interaction effect on soil pH, it can be assumed that the availability of soil Cu was not controlled by the solubility of inorganic soil Cu, as a function of pH, but perhaps by factors such as organic matter decomposition which was enhanced by N and P or by displacement of adsorbed Cu with added N and P compounds. Geering and Hodgson (1969) have shown that micronutrients were largely associated with organic constituents in the soil.

Nitrogen x phosphorus interaction effects on soil Zn were noted for the Bearbrook soil only. High rates of P and N seem to increase the levels of soil test Zn. Thus high rates of P were not antagonistic to the level of soil test Zn in the soil. This effect on Zn was not found with the other soils, which were both lower in organic-N, Zn, and clay. This P x N effect on Zn was similar to that found with Cu, and suggests that P x N effects are specific to certain soils, but common across micronutrients with differing affinities for soil organic matter.

The application of $Ca(OH)_2$ was found to increase the pH of all soils and decrease the level of soil test Zn and Mn. However $Ca(OH)_2$ was found to have no effect on Cu in the soils studied. The decrease in Mn and Zn was consistent with effects of pH described by Lindsay (1972). The behavior of Cu can be explained by the mechanism of strong complexing of Cu by soil organic matter, described by Hodgson et al. (1966), whereby Cu remains labile and available even though there is decreased solubility with increases in pH.

Applied micronutrient effects were noted through interactions with the other treatments. However, the effects on the different soils were not consistent. On the Bearbrook soils, increasing N rates increased the level of soil Mn where chelated micronutrients were applied. This was probably because N nitrification decreased soil pH in soil microsites, and Mn in the chelate was not precipitated. Phosphorus x micronutrient interactions on soil test Zn were found to be similar to that of N x chelated micronutrients on Mn. The effect on soil Cu was not consistant, again probably because Cu availability was controlled to a greater extent by soil organic matter.

Added Cu effects were found only for the Chicot soil, where applied $Ca(OH)_2$ and micronutrient chelate increased the soil test Cu in the soil. Again, reduced organic matter in this soil compared to the other soils may have resulted in Cu-pH solubility factors overiding the effects of organic matter chelation of Cu

In general, added chelates appeared to maintain soil levels of soluble Zn and Mn. Cu was influenced to a lesser extent because of the important interaction of Cu with organic matter.

3.4.2 Plant Responses to Added N, P, $Ca(OH)_2$ and Micronutrient.

In general, shoot and root yields were increased with added N in the soils with the highest organic N, indicating that organic N was not related to plant available N in this experiment. However, added P increased shoot and root yields in soils with the lowest soil test P values of 135 mg kg^{-1}. Thus, soil test P reflected the relative P fertility status of the soils.

Root yields were found to increase with increasing rates of applied P only on the Ormstown soil. Root weight is known to be influenced by P nutrition, and Friesen et al. (1980) found increased root weights with applied P. However, they used Ultisols which are known to fix P. The absence of an effect of P on root yields from the other soils is probably because these soils were not as deficient in P, having higher values than Ormstown in Bray-2 extractable P.

On the Ormstown soil sample, plant N concentration decreased with increasing rate of added P. This is as a result of increased growth brought about by added P. This suggests that P levels in the soil were not adequate.

Nitrogen in general increased the uptake and concentration of micronutrients in the shoots on most soils. Shoots from Bearbrook and Chicot soils had increased concentration of Cu due to increased uptake of soil Cu. Similar effects of N on the concentration and uptake of Zn in the plants from Chicot soil were noted. An adequate supply of soil Mn together with enhanced growth with applied N, were the reasons for the noted increases in uptake and concentration of Mn found in plants from Ormstown and Chicot soils. In general, it appears that where soil micronutrients were not limiting, their uptake was determined by the growth of the plants. Thus, any fertilizer nutrient increasing yield also increased micronutrient uptake.

It was noted that added P did not have a negative effect on the Zn content of the plants. The absence of any P induced Zn deficiency, may be because all soils had adequate amounts of Zn.

The application of $Ca(OH)_2$ to all soils caused a decrease in uptake of Mn by shoots mainly because of decreased soil availability. The effects of $Ca(OH)_2$ on Cu and Zn were not marked, and this could be related to the adequate amounts found in the soils studied, even when $Ca(OH)_2$ was applied, as well as the short term duration of the study.

In general, applied chelated micronutrients increased the concentration and uptake of most micronutrients in Bearbrook and Chicot soils, but not in the Ormstown soil.

Where there were interactions between chelates and the other treatments, the general pattern was that chelates were always associated with increased uptake of micronutrients. This would suggest that the chelate used in this study was effective in maintaining Cu, Zn and Mn in a form available for plant utilization. This is in agreement with the observation of Prasad and Sinha (1981) and Halvorson and Lindsay (1977), that chelates aid in the transportation and movement of metal ions to plant roots. The absence of chelate micronutrient effects on plant uptake for the Ormstown soil remains unexplained.

3.5. CONCLUSIONS

1. The application of N and P to two soils studied increased plant growth indicating a relative deficiency in N and P. There was little response to added N and P in the Chicot soil, indicating a relative sufficiency of N and P.

2. Nitrogen decreased soil pH in only the Ormstown soil while P had no effect on soil pH. The general absence of effect of N and P sources on soil pH could be due to the short duration of the study which resulted in incomplete nitrification of the applied NH_4 fertilizer.

3. Added N and P were found to increase the level of soil test Cu and Zn in the Bearbrook soil. Plants on most soils had increased uptake of micronutrients where N and P were applied. This suggested that soil supply was adequate and that increased growth as a result of added N and P increased micronutrient uptake by the plant.

4. The application of $Ca(OH)_2$ decreased soil test Zn and Mn in most soils, but levels remained adequate for plant growth. The absence of a $Ca(OH)_2$ effect on soil Cu suggests that Cu complexation with soil organic matter overrode the effect of pH on Cu solubility.

5. Chelate micronutrients were able to maintain the level of soil available micronutrients, even in the presence of added $Ca(OH)_2$.

In general, the pot experiment was able to demonstrate the effectiveness of chelates in supplying micronutrients. Also, the increase of soil pH did not decrease soil Mn, or soil Zn, to deficient levels. Differences in organic matter, pH and clay content of soils may have had an effect on the release of native micronutrients to plants in that the available micronutrient contents of high clay - high organic matter soils were increased more by the fertilizer treatments whereas in the low organic matter-low clay soil (Chicot) micronutrient levels were decreased more by added $Ca(OH)_2$ than in the high clay soils.

CHAPTER 4

OVERALL SUMMARY AND CONCLUSIONS

The status of micronutrients in the soil and the effects of hybrid, plant population, fertilization and irrigation on the uptake of Cu, Zn and Mn by maize plants were studied in a field experiment on a Chicot soil. In addition, a growth chamber experiment was conducted to investigate the effect of N, P, $Ca(OH)_2$ and chelate micronutrients, applied to surface samples of three Quebec soils (Chicot, Bearbrook and Ormstown series), on the nutrition of young maize plants.

In the field, there were no micronutrient deficiencies because of increased fertilization with N, P and K. The available levels of Zn and Mn increased with increased fertilization, and there was increased uptake of Zn and Mn, probably the result of decreased pH. Results in the growth chamber showed that added N and P could also increase micronutrient uptake on the Chicot soil. The tendency for Cu availability to decrease with fertilization in the field indicated that Cu in the soil was controlled by different mechanisms than Zn and Mn.

Irrigation tended to decrease available Cu, Zn, and Mn in the soil, and reduced contents of these nutrients in the plant tissue. Leaching of these nutrients may have occurred with irrigation, and increased growth probably resulted in nutrient dilution effects in the plants

Hybrid and plant population effects were analogous to high fertilization rate effects, where increased dry matter was associated with increased uptake of Zn and Mn, and decreased Cu uptake.

The calculated nutritional balance index was not related to plant growth or nutrient deficiences. Depletion of soil Cu, Zn and Mn did not seem likely under the system studied.

The results of the pot experiment were inconclusive on the effect of N and P on soil acidification. Effects of fertilizers on micronutrient uptake seem primarily due to N, although added P tended to increase Zn and Mn uptake. Chelates were found to be effective in making micronutrients available for plant utilization. It is interesting to note that the Chicot soil used for the field experiment was the soil least responsive to added N and P in the pot experiment. Thus a lack of fertilizer effect in the field is consistent with results in the pot experiment.

In considering the results of the two experiments, it appears that added $Ca(OH)_2$ had no adverse influence on Cu, Zn, and Mn nutrition of plants. Increased micronutrient uptake due to higher fertilization of N, P and K in the field was probably due to N effects on increased soil acidity and plant growth. There were no adverse effects of P on Cu, Zn and Mn uptake. Also, early effects of added N and P were probably due to enhanced micronutrient uptake due to physiological or soil exchange reactions. Subsequent effects of added N and P on increased uptake of Zn and Mn in the field may be due more to acidification caused by added N.

LITERATURE CITED

Adam, A.I. and W.B. Anderson. 1983. Soil moisture influence on micronutrient cation availability under aerobic conditions. Plant Soil 72: 77-83.

Armbruster, J.A., L.S. Murphy, L.J. Meyer, P.J. Gallagher, and D.A. Whitney. 1975. Field and growth-chamber evaluations of potassium polyphosphate. Soil Sci. Soc. Am. Proc. 39: 144-150.

Baker, D.E. and M.C. Amacher. 1982. Nickel, copper, zinc, and cadmium. In A.L. Page, R.H. Miller, and D.R. Keeney (eds.) Methods of Soil Analysis, Part 2 (2nd ed.) Agronomy 9 :323-336. Am. Soc. Agron., Madison, WI.

Barber, S.A. and R.A. Olson. 1968. Fertilizer use on corn. In L.B. Nelson, M.H. McVickar, R.D. Munson, L.F. Seatz, S.L. Tisdale, and W.C. White (eds.) Changing Patterns in Fertilizer Use. Soil Sci. Soc. Am., Madison, WI. p. 163-188.

Barr, A.J., J.H. Goodnight, and J.P. Sall. 1979. Statistical Analysis System. SAS Institute Inc., Raleigh, NC.

Bingham, F.T. 1963. Relation between phosphorus and micronutrients in plants. Soil Sci. Soc. Am. Proc. 27: 389-391.

Bingham, F.T. and M.J. Garber. 1960. Solubility and availability of micronutrients in relation to phosphorus fertilization. Soil Sci. Soc. Am. Proc. 24: 209-213.

Bishop, N.I. 1971. Photosynthesis: The electron transport system of green plants. Ann. Rev. Biochem. 40: 197-226.

Blevins, R.L., G.W. Thomas, and P.L. Cornelius. 1977. Influence of no-tillage and nitrogen fertilization on certain soil properties after 5 years of continuous corn. Agron. J. 69: 383-386.

Boardman, N.K. 1975. Trace elements in photosynthesis. In D.J.D. Nicholas and A.R. Egan (eds.) Trace Elements in Soil-Plant-Animal Systems. Academic Press, New York. p. 199-212.

Boawn, L.C., F.G. Viets, Jr., C.L. Crawford, and J.L. Nelson. 1960. Effect of nitrogen carrier, nitrogen rate, zinc rate, and soil pH on zinc uptake by sorghum, potatoes, and sugar beets. Soil Sci. 90: 329-337.

Bouldin, D.R. and E.C. Sample. 1959. Laboratory and greenhouse studies with monocalcium, monoammonium, and diammonium phosphates. Soil Sci. Soc. Am. Proc. 23: 338-342.

Bowen, J.E. 1969. Absorption of copper, zinc and manganese by sugarcane leaf tissue. Plant Physiol. 44: 255-261.

Bray, R.H and L.T. Kurtz. 1945. Determination of total, organic, and available forms of phosphorus in soils. Soil Sci. 59: 39-45.

Bremner, J.M. 1965. Inorganic forms of nitrogen. In C.A. Black (ed.) Methods of Soil Analysis, Part 2. Agronomy 9: 1179-1237. Am. Soc. Agron., Madison, WI.

Brown, A.L., B.A. Krantz, and J.L. Eddings. 1970. Zinc-phosphorus interactions as measured by plant response and soil analysis. Soil Sci. 110: 415-420.

Burleson, C.A., A.D. Dacus, and C.J. Gerard. 1961. The effect of phosphorus fertilization on the zinc nutrition of several irrigated crops. Soil Sci. Soc. Am. Proc. 25: 365-368.

Gheniae, G.M. 1970. Photosystem II and O_2 evolution. Ann. Rev. Plant Physiol. 21: 467-498.

Chester, R. 1965. Adsorption of zinc and cobalt on illite in sea water. Nature 206: 884-886.

Christensen, N.W. and T.L. Jackson. 1981. Potential for phosphorus toxicity in zinc-stressed corn and potato. Soil Sci. Soc. Am. J. 45: 904-909.

Cornforth, I.S. and K.W. Steele. 1981. Interpretation of maize leaf analyses in New Zealand. N.Z. J. Exp. Agric. 9: 91-96.

Crookston, R.K. and J.J. Afuakwa. 1983. Corn maturity indicators: Kernel milk line more useful than black layer. Crops Soils 35(8): 12-14.

Elwali, A.M.O. and G.J. Gascho. 1984. Soil testing, foliar analysis, and DRIS as guides for sugarcane fertilization. Agron. J. 76: 466-470.

Elwali, A.M.O., G.J. Gascho, and M.E. Sumner. 1985. DRIS norms for 11 nutrients in corn leaves. Agron. J. 77: 506-508.

Escano, C.R., C.A. Jones, and G. Uehara. 1981. Nutrient diagnosis in corn grown on Hydric Dystrandepts: II. Comparison of two systems of tissue diagnosis. Soil Sci. Soc. Am. J. 45: 1140-1144.

Flannery, R. 1982. High-yield corn: Nutrient uptake. In B. Agreton, D. Armstrong, and S. Martin (eds.) Better Crops With Plant Food. Phosphate and Potash Institute, Atlanta, GA.

Friesen, D.K., M.H. Miller, and A.S.R. Juo. 1980. Liming and lime-phosphorus-zinc interactions in two Nigerian Ultisols: II. Effects on maize root and shoot growth. Soil Sci. Soc. Am. J. 44: 1227-1232.

Gamron, R.B., D.C. Adriano, G.M. Paulsen, and L. S. Murphy. 1969. Effect of phosphorus carriers and zinc sources on phosphorus-zinc interaction in corn. Soil Sci. Soc. Am. Proc. 33: 306-309.

Geering, H.R. and J.F. Hodgson. 1969. Micronutrient cation complexes in soil solution: III. Characterization of soil solution ligands and their complexes with Zn^{2+} and Cu^{2+}. Soil Sci. Soc. Am. Proc. 33: 54-59.

Geraldson, C.M., G.R. Klacan, and O.A. Lorenz. 1973. Plant analysis as an aid in fertilizing vegetable crops. In L.M. Walsh and J.D. Beaton (eds.) Soil Testing and Plant Analysis. Soil Sci. Soc. Am., Madison, WI. p. 365-379.

Ghanem, I., M.M. El-Gabaly, M.N. Hassan, and V. Tadros. 1971. Effect of organic materials addition on transformation of added manganese dioxide to alkali calcareous soils. Plant Soil 34: 653-661.

Giordano, P.M. and J.J. Mortvedt. 1969. Response of several corn hybrids to level of water-soluble zinc in fertilizers. Soil Sci. Soc. Am. Proc. 33: 145-148.

Godo, G.H. and H.M. Reisenauer. 1980. Plant effects on soil manganese availability. Soil Sci. Soc. Am. J. 44: 993-995.

Gotoh, S. and W.H. Patrick, Jr. 1972. Transformation of manganese in a waterlogged soil as affected by redox potential and pH. Soil Sci. Soc. Am. Proc. 36: 738-742.

Halvorson, A.D. and W.L. Lindsay. 1977. The critical Zn^{2+} concentration for corn and the nonabsorption of chelated zinc. Soil Sci. Soc. Am. J. 41: 531-534.

Hanway, J.J. 1963. Growth stages of corn (Zea mays, L.) Agron. J. 55: 487-491.

Hatlitligil, M.B., R.A. Olson, and W.A. Compton. 1984. Yield, water use, and nutrient uptake of corn hybrids under varied irrigation and nitrogen regimes. Fert. Res. 5: 321-333.

Heintze, S.G. and P.J.G. Mann. 1947. Soluble complexes of manganic manganese. J. Agric. Sci. 37: 23-26.

Heintze, S.G. and P.J.G. Mann. 1949. Studies on soil manganese. J. Agric. Sci. 39: 80-95.

Hodgson, J.F. 1963. Chemistry of the micronutrient elements in soils. Adv. Agron. 15: 119-159.

Hodgson, J.F., W.L. Lindsay, and J.F. Trierweiler. 1966. Micronutrient cation complexing in soil solution: II. Complexing of zinc and copper in displaced solutions from calcareous soils. Soil Sci. Soc. Am. Proc. 30: 723-726.

Hoyt, P.B. and A.M.F. Henning. 1982. Soil acidification by fertilizers and longevity of lime applications in the Peace River region. Can. J. Soil Sci. 62: 155-163.

Jackson, M.L. 1962. Soil Chemical Analysis. Prentice-Hall, Inc., Englewood Cliffs, NJ.

Jahiruddin, M., N.T. Livesey, and M.S. Cresser. 1985. Observations on the effect of soil pH upon zinc absorption by soils. Commun. Soil Sci. Plant Anal. 16: 909-922.

Jolley, V.D. and W.H. Pierre. 1977. Soil acidity from long-term use of nitrogen fertilizer and its relationship to recovery of the nitrogen. Soil Sci. Soc. Am. J. 41: 368-373.

Jones, J.B, Jr. and H.V. Eck. 1973. Plant analysis as an aid in fertilizing corn and grain sorghum. In L.M. Walsh and J.D.Beaton (eds.) Soil Testing and Plant Analysis. Soil Sci. Soc. Am., Madison, WI. p. 349-364.

Juo, A.S.R. 1979. Selected Methods for Soil and Plant Analysis. Mimeo Report, Manuel Series No. 1. International Institute of Tropical Agriculture, Ibadan, Nigeria.

Jurinak, J.J. and T.S. Inouye. 1962. Some aspects of zinc and copper phosphate formation in aqueous systems. Soil Sci. Soc. Am. Proc. 26: 144-147.

Kluthcouski, J. and L.E. Nelson. 1979. Variations in the manganese concentrations in soybean trifoliolates. Commun. Soil Sci. Plant Anal. 10: 1299-1310.

Krauskopf, K.B. 1972. Geochemistry of micronutrients. In J.J. Mortvedt, P.M. Giordano, W.L. Lindsay (eds.) Micronutrients in Agriculture. Soil Sci. Soc. Am., Madison, WI. p. 7-40.

Langin, E.J., R.C. Ward, R.A. Olson, and H.F. Rhoades. 1962. Factors responsible for poor response of corn and grain sorghum to phosphorus fertilization: II. Lime and P placement effects on P-Zn relations. Soil Sci. Soc. Am. Proc. 26: 574-578.

Lehninger, A.L. 1975. Biochemistry: The Molecular Basis of Cell Structure and Function. Worth Publishers, Inc., New York.

Letzsch, W.S. and M.E. Sumner. 1983. Computer program for calculating DRIS indices. Commun. Soil Sci. Plant Anal. 14: 811-815.

Lindsay, W.L. 1972. Inorganic phase equilibra of micronutrients in soil. In J.J. Mortvedt, P.M. Giordano, and W.L. Lindsay (eds.)

Micronutrients in Agriculture. Soil Sci. Soc. Am., Madison, WI. p. 41-57.

Lockman, R.B. 1972. Mineral composition of grain sorghum plant samples III. Suggested nutrient sufficiency limits at various stages of growth. Commun. Soil Sci. Plant Anal. 3: 295-306.

Lohnis, M.P. 1960. Effect of magnesium and calcium supply on the uptake of manganese by various crop plants. Plant Soil 12: 339-376.

Loneragan, J.F. 1975. The availability and absorption of trace elements in soil-plant systems and their relation to movement and concentrations of trace elements in plants. In D.J.D. Nicholas and A.R. Egan (eds.) Trace Elements in Soil-Plant-Animal Systems. Academic Press, New York. p. 109-134.

Loneragan, J.F., D.L. Grunes, R.M. Welch, E.A. Aduayi, A. Tengah, V.A. Lazar, and E.E. Cary. 1982. Phosphorus accumulation and toxicity in leaves in relation to zinc supply. Soil Sci. Soc. Am. J. 46: 345-352.

Maas, E.V., D.P. Moore, and B.J. Mason. 1969. Influence of calcium and magnesium on manganese absorption. Plant Physiol. 44: 796-800.

MacKenzie, A.F. 1975. Methods of analysis used by the Macdonald College Soil Test Lab. Mimeo. McGill University, Montreal.

MacLean, A.J. 1974. Effects of soil properties and amendments on the availability of zinc in soils. Can. J. Soil Sci. 54: 369-378.

Mandal, L.N. 1961. Transformation of iron and manganese in waterlogged rice soils. Soil Sci. 91: 121-126.

McBride, M.B. and J.J. Blasiak. 1979. Zinc and copper solubility as a function of pH in an acid soil. Soil Sci. Soc. Am. J. 43: 866-870.

McCoy, D.A. and G.R. Webster. 1977. Acidification of a Luvisolic soil caused by low-rate, long-term applications of fertilizers and its effects on growth of alfalfa. Can. J. Soil Sci. 57: 119-127.

McLean, E.O. 1982. Soil pH and lime requirement. In A.L. Page, R.H. Miller, and D.R. Keeney (eds.) Methods of Soil Analysis, Part 2 (2nd ed.) Agronomy 9: 199-224. Am. Soc. Agron., Madison, WI.

Melsted, S.W., H.L. Motto, and T.R. Peck. 1969. Critical plant nutrient composition values useful in interpreting plant analysis data. Agron. J. 61: 17-20.

Mengel, K. and E.A. Kirkby. 1982. Principles of Plant Nutrition (3rd ed.) International Potash Institute, Bern.

Mitchell, R.L. 1964. Trace elements in soils. In F.E. Bear (ed.) Chemistry of the Soil (2nd ed.) Van Nostrand Reinhold Company, New York. p. 320-368.

Moore, D.P. 1972. Mechanisms of micronutrient uptake by plants. In J.J. Mortvedt, P.M. Giordano, W.L. Lindsay (eds.) Micronutrients in Agriculture. Soil Sci. Soc. Am., Madison, WI. p. 171-198.

Murphy L.S., R. Ellis, Jr., and D.C. Adriano. 1981. Phosphorus-micronutrient interaction effects on crop production. J. Plant Nutr. 3: 593-613.

Nelson, L.E. 1977. Changes in water-soluble Mn due to soil sample preparation and storage. Commun. Soil Sci. Plant Anal. 8: 479-487.

Nielsen, N.E. 1976. The effect of plants on the copper concentration in the soil solution. Plant Soil 45: 679-687.

Norvell, W.A. and W.L. Lindsay. 1970. Lack of evidence of $ZnSiO_3$ in soils. Soil Sci. Soc. Am. Proc. 34: 360-361.

O'Brien, J.E. and J. Fiore. 1962. Ammonium determination by automated analysis. Wastes Eng. 33: 352.

Olsen, S.R. 1972. Micronutrient interactions. In J.J. Mortvedt, P.M. Giordano, W.L. Lindsay (eds.) Micronutrients in Agriculture. Soil Sci. Soc. Am., Madison, WI. p. 243-264.

Orabi, A.A. and I.M. Abdel-Aziz. 1982. Zinc-phosphorus relationship and effect on some biocomponents of corn (Zea mays L.) grown on a calcareous soil. Plant Soil 69: 437-444.

Page, E.R. 1962. Studies in soil and plant manganese: II. The relationship of soil pH to manganese availability. Plant Soil 16: 247-257.

Petrie, S.E. and T.L. Jackson. 1984a. Effects of fertilization on soil solution pH and manganese concentration. Soil Sci. Soc. Am. J. 48: 315-318.

Petrie, S.E. and T.L. Jackson. 1984b. Effects of nitrogen fertilization on manganese concentration and yield of barley and oats. Soil Sci. Soc. Am. J. 48: 319-322.

Pierre, W.H., J.R. Webb, and W.D. Shrader. 1971. Quantitative effects of nitrogen fertilizer on the development and downward movement of soil acidity in relation to level of fertilization and crop removal in a continuous corn cropping system. Agron. J. 63: 291-297.

Prasad, B. and M.K. Sinha. 1981. The relative efficiency of zinc carriers on growth and zinc nutrition of corn. Plant Soil 62: 45-52.

Prasad, B. and N.P. Sinha. 1982. Changes in the status of micronutrients in soil with long term applications of chemical fertilizers, lime and manure. Plant Soil 64: 437-441.

Price, C.A., H.E. Clark, and E.A. Funkhouser. 1972. Function of micronutrients in plants. In J.J. Mortvedt, P.M. Giordano, W.L. Lindsay (eds.) Micronutrients in Agriculture. Soil Sci. Soc. Am., Madison, WI. p. 231-242.

Prince, A.L. 1957. Trace element delivering capacity of 10 New Jersey soil types as measured by spectrographic analyses of soils and mature corn leaves. Soil Sci. 84: 413-418.

Przemeck, E. and B. Schrader. 1981. The effect of manganese nutrition on nitrogen assimilation in roots. Plant Soil 63: 5-9.

Racz, G.J. and P.W. Haluschak. 1974. Effects of phosphorus concentration on Cu, Zn, Fe and Mn utilization by wheat. Can. J. Soil Sci. 54: 357-367.

Randall, G.W., E.E. Schulte, and R.B. Corey. 1975. Soil Mn availability to soybeans as affected by mono and diammonium phosphate. Agron. J. 67: 705-709.

Rinne, R.W. and R. Langston. 1960. Effect of growth on redistribution of some mineral elements in peppermint. Plant Physiol. 35: 210-215.

Safaya, N.M. 1976. Phosphorus-zinc interactions in relation to absorption rates of phosphorus, zinc, copper, manganese, and iron in corn. Soil Sci. Soc. Am. J. 40: 719-722.

Salami, A.U. and D.G. Kenefick. 1970. Stimulation of growth in zinc-deficient corn seedlings by the addition of tryptophan. Crop Sci. 10: 291-294.

Schnitzer, M. 1969. Reactions between fulvic acid, a soil humic compound and inorganic soil constituents. Soil Sci. Soc. Am. Proc. 33: 75-81.

Shoemaker, H.E., E.O. McLean, and P.F. Pratt. 1961. Buffer methods for determining lime requirement of soil with appreciable amounts of extractable aluminum. Soil Sci. Soc. Am. Proc. 25: 274-277.

Smilde, K.W. 1973. Phosphorus micronutrient metal uptake by some tree species as affected by phosphate and lime applied to an acid sandy soil. Plant Soil 39: 131-148.

Spencer, W.F. 1966. Effect of copper on yield and uptake of phosphorus and iron by citrus seedlings grown at various phosphorus levels. Soil Sci. 102: 296-299.

Steel R.G.D., J.H. Torrie. 1980. Principles and Procedures of Statistics (2nd ed.) McGraw-Hill Book Company, New York.

Stevenson, C.K. 1984. Harvesting technique procedure for maximum yield. Mimeo report. Ridgetown College of Agricultural Technology, Ridgetown, Ont.

Stevenson, C.K. and M.A. Nuttall. 1982. Maximum yield research with corn and soybeans. A Progress Report. Ridgetown College of Agricultural Technology, Ridgetown, Ont.

Stukenholtz, D.D., R.J. Olsen, G. Gogan, and R.A. Olson. 1966. On the mechanism of phosphorus-zinc interaction in corn nutrition. Soil Sci. Soc. Am. Proc. 30: 759-763.

Sumner, M.E. 1977a. Use of the DRIS system in foliar diagnosis of crops at high yield levels. Commun. Soil Sci. Plant Anal. 8: 251-268.

Sumner, M.E. 1977b. Effect of corn leaf sampled on N, P, K, Ca and Mg content and calculated DRIS indices. Commun. Soil Sci. Plant Anal. 8: 269-280.

Sumner, M.E. 1979. Interpretation of foliar analyses for diagnostic purposes. Agron. J. 71: 343-348.

Sumner, M.E. 1982. The Diagnosis and Recommendation Integrated System (DRIS). Paper presented at Soil/Plant Analysts Seminar. Council on Soil Testing and Plant Analysis, Anaheim, CA.

Terman, G.L., P.M. Giordano, and N.W. Christensen. 1975. Corn hybrid yield effects on phosphorus, manganese, and zinc absorption. Agron. J. 67: 182-184.

Thomas, R.L., R.W. Sheard, and J.R. Moyer. 1967. Comparison of conventional and automated procedures for nitrogen, phosphorus and potassium analysis of plant material using a single digestion. Agron. J. 59: 240-243.

Tisdale, S.L., W.L. Nelson, and J.D. Beaton. 1982. Soil Fertility and Fertilizers (4th ed.) Macmillan Publishing Company, New York.

Tsui, C. 1948. The role of zinc in auxin synthesis in the tomato plant. Am. J. Bot. 35: 172-179.

Ulrich, A. and F.J. Hills. 1973. Plant analysis as an aid in fertilizing sugar crops: Part I. Sugar beets. In L.M. Walsh and J.D. Beaton (eds.) Soil Testing and Plant Analysis. Soil Sci. Soc. Am., Madison, WI. p. 271-288.

Viets, F.G., Jr. and W.L. Lindsay. 1973. Testing soils for zinc, copper, manganese and iron. In L.M. Walsh and J.D. Beaton (eds.)

Soil Testing and Plant Analysis. Soil Sci. Soc. Am., Madison, WI. p. 153-172.

Viets, F.G., Jr., L.C. Boawn, and C.L. Crawford. 1957. The effect of nitrogen and types of nitrogen carrier on plant uptake of indigenous and applied zinc. Soil Sci. Soc. Am. Proc. 21: 197-201.

Ward, R.C., D.A. Whitney, and D.G. Westfall. 1973. Plant analysis as an aid in fertilizing small grains. In L.M. Walsh and J.D. Beaton (eds.) Soil Testing and Plant Analysis. Am. Soc. Agron., Madison, WI. p. 329-348.

Warnock, R.E. 1970. Micronutrient uptake and mobility within corn plants (*Zea mays* L.) in relation to phosphorus-induced zinc deficiency. Soil Sci. Soc. Am. Proc. 34: 765-769.

APPENDIX I

Table 1. Probabilities associated with the F-statistic of some sources for soil pH, DTPA-extractable copper, zinc and manganese at fall of 1984 and 1985.

	Soil Parameter							
	1984				1985			
Source	pH	Cu	Zn	Mn	pH	Cu	Zn	Mn
	probability							
H	ns	ns	ns	ns	ns	ns	ns	ns
P	ns	ns	ns	ns	ns	ns	ns	ns
H*P	ns	ns	ns	ns	ns	*	ns	**
F	ns	ns	ns	*	**	ns	ns	ns
H*F	ns	ns	**	ns	ns	ns	ns	ns
P*F	ns	ns	ns	ns	ns	ns	ns	ns
H*P*F	ns	ns	ns	ns	ns	ns	ns	ns
I	*	ns	ns	ns	ns	ns	ns	ns
H*I	ns	ns	ns	ns	ns	ns	ns	ns
P*I	ns	ns	ns	ns	ns	ns	ns	ns
H*P*I	ns	ns	ns	ns	ns	ns	ns	ns
F*I	*	ns	ns	ns	ns	ns	ns	ns
H*F*I	ns	ns	ns	ns	ns	ns	ns	ns
P*F*I	ns	ns	ns	ns	ns	ns	ns	*
H*P*F*I	ns	ns	ns	ns	ns	ns	ns	ns

*, **: significant at the 0.05 and 0.01 levels respectively.
ns: not significant at p=0.05

H=hybrids; P=plant population; F=fertilizer rate; I=irrigation

APPENDIX II

Table 1. Probabilities associated with the F-statistic of some sources for concentration and uptake of copper, zinc and manganese and dry matter (DM) yield in plant shoot at growth stage 2+ in 1984.

Source	Concentration			DM yield	Uptake		
	Cu	Zn	Mn		Cu	Zn	Mn
	probability						
H	ns	ns	ns	ns	ns	ns	ns
P	ns	*	ns	**	*	*	**
H*P	ns	**	ns	ns	ns	ns	ns
F	ns	ns	**	*	ns	ns	**
H*F	ns	ns	ns	ns	ns	ns	ns
P*F	ns	ns	ns	*	ns	*	*
H*P*F	ns	ns	ns	ns	ns	ns	ns
I	ns	ns	ns	ns	ns	ns	ns
H*I	ns	ns	ns	ns	ns	ns	ns
P*I	ns	ns	ns	ns	ns	ns	ns
H*P*I	ns	ns	ns	ns	ns	ns	ns
F*I	ns	ns	*	ns	ns	ns	ns
H*F*I	ns	ns	ns	ns	ns	ns	ns
P*F*I	ns	ns	ns	*	ns	ns	**
H*P*F*I	ns	ns	*	ns	*	ns	ns

*, **: significant at the 0.05 and 0.01 levels respectively.
ns: not significant at p=0.05

H=hybrids; P=plant population; F=fertilizer rate; I=irrigation

Table 2. Probabilities associated with the F-statistic of some sources for concentration and uptake of copper, zinc and manganese and dry matter (DM) yield in plant shoot at growth stage 4 in 1984.

Source	Concentration Cu	Concentration Zn	Concentration Mn	DM yield	Uptake Cu	Uptake Zn	Uptake Mn
	probability						
H	ns	ns	ns	ns	ns	ns	ns
P	ns	ns	ns	**	*	*	ns
H*P	ns	ns	ns	ns	ns	ns	ns
F	ns	ns	**	ns	ns	ns	**
H*F	ns	ns	ns	ns	ns	ns	ns
P*F	ns	ns	ns	ns	ns	ns	ns
H*P*F	ns	ns	ns	ns	ns	ns	ns
I	*	ns	ns	ns	ns	ns	ns
H*I	*	ns	ns	ns	*	ns	ns
P*I	ns	ns	ns	ns	ns	ns	ns
H*P*I	ns	ns	ns	ns	ns	ns	ns
F*I	ns	ns	ns	ns	ns	ns	ns
H*F*I	ns	ns	ns	ns	ns	ns	ns
P*F*I	ns	ns	ns	ns	ns	ns	ns
H*P*F*I	ns	ns	ns	ns	ns	ns	ns

*, **: significant at the 0.05 and 0.01 levels respectively,
ns: not significant at p=0.05

H=hybrids; P=plant population; F=fertilizer rate; I=irrigation

Table 3. Probabilities associated with the F-statistic of some sources for concentration of copper, zinc and manganese in the ear-leaf at early silk in 1984.

Source	Concentration		
	Cu	Zn	Mn
	-----probability-----		
H	ns	ns	ns
P	ns	ns	ns
H*P	ns	ns	ns
F	*	**	**
H*F	ns	ns	ns
P*F	ns	ns	ns
H*P*F	ns	ns	ns
I	*	ns	ns
H*I	ns	ns	ns
P*I	ns	ns	ns
H*P*I	ns	ns	ns
F*I	ns	ns	ns
H*F*I	ns	ns	ns
P*F*I	ns	ns	ns
H*P*F*I	ns	ns	ns

*, **: significant at the 0.05 and 0.01 levels respectively.
ns: not significant at p=0.05

H=hybrids; P=plant population; F=fertilizer rate: I=irrigation

Table 4. Probabilities associated with the F-statistic of some sources for concentration and uptake of copper, zinc and manganese and dry matter (DM) yield in stover at harvest in 1984.

Source	Concentration			DM yield	Uptake		
	Cu	Zn	Mn		Cu	Zn	Mn
	probability						
H	ns	ns	ns	ns	ns	ns	ns
P	ns	ns	ns	ns	ns	ns	ns
H*P	ns	ns	ns	ns	ns	ns	ns
F	ns	ns	**	ns	ns	ns	**
H*F	ns	ns	ns	ns	ns	ns	ns
P*F	ns	ns	ns	ns	ns	ns	ns
H*P*F	ns	ns	ns	ns	ns	ns	ns
I	ns	**	**	ns	ns	*	ns
H*I	ns	ns	ns	ns	ns	ns	ns
P*I	ns	ns	ns	ns	ns	ns	ns
H*P*I	ns	ns	ns	ns	ns	ns	ns
F*I	ns	ns	ns	ns	ns	ns	ns
H*F*I	ns	ns	ns	ns	ns	ns	ns
P*F*I	ns	ns	ns	ns	ns	ns	ns
H*P*F*I	ns	ns	ns	ns	ns	ns	ns

*, **: significant at the 0.05 and 0.01 levels respectively.
ns: not significant at p=0.05

H=hybrids; P=plant population; F=fertilizer rate; I=irrigation

Table 5. Probabilities associated with the F-statistic of some sources for concentration and uptake of copper, zinc and manganese and dry matter (DM) yield in the grain in 1984.

Source	Concentration Cu	Concentration Zn	Concentration Mn	DM yield	Uptake Cu	Uptake Zn	Uptake Mn
	probability						
H	ns	ns	ns	ns	ns	ns	ns
P	ns	ns	ns	**	ns	*	ns
H*P	ns	ns	ns	ns	ns	ns	ns
F	ns	ns	**	ns	ns	*	**
H*F	ns	ns	ns	ns	ns	ns	ns
P*F	ns	ns	ns	ns	ns	ns	ns
H*P*F	ns	ns	ns	ns	ns	ns	ns
I	ns	**	**	*	ns	ns	ns
H*I	ns	ns	ns	ns	ns	*	ns
P*I	ns	ns	ns	ns	ns	ns	ns
H*P*I	ns	ns	ns	ns	ns	ns	ns
F*I	ns	ns	ns	ns	ns	ns	ns
H*F*I	ns	ns	ns	ns	ns	ns	ns
P*F*I	*	ns	ns	ns	ns	ns	ns
H*P*F*I	ns	ns	ns	ns	ns	ns	ns

*, **: significant at the 0.05 and 0.01 levels respectively.
ns: not significant at p=0.05

H=hybrids; P=plant population; F=fertilizer rate; I=irrigation

Table 6. Probabilities associated with the F-statistic of some sources for concentration and uptake of copper, zinc and manganese and dry matter (DM) yield in plant shoot at growth stage 2 in 1985.

	Concentration			DM	Uptake		
Source	Cu	Zn	Mn	yield	Cu	Zn	Mn
	probability						
H	ns	ns	ns	**	ns	**	*
P	ns	ns	ns	**	ns	**	*
H*P	ns	ns	ns	ns	ns	ns	ns
F	ns	ns	**	**	ns	ns	**
H*F	ns	ns	ns	ns	ns	ns	ns
P*F	ns	ns	ns	ns	ns	ns	ns
H*P*F	ns	ns	ns	ns	ns	ns	ns
I	ns	ns	ns	ns	ns	ns	ns
H*I	ns	*	ns	ns	ns	ns	ns
P*I	ns	ns	ns	ns	ns	ns	ns
H*P*I	ns	ns	ns	ns	ns	*	ns
F*I	ns	ns	ns	ns	ns	ns	ns
H*F*I	ns	ns	ns	ns	ns	ns	ns
P*F*I	ns	ns	ns	ns	ns	ns	ns
H*P*F*I	ns	ns	ns	ns	ns	ns	ns

*, **: significant at the 0.05 and 0.01 levels respectively.
ns: not significant at p=0.05

H=hybrids; P=plant population; F=fertilizer rate; I=irrigation

Table 7. Probabilities associated with the F-statistic of some sources for concentration and uptake of copper, zinc and manganese and dry matter (DM) yield in plant shoot at growth stage 3 in 1985.

Source	Concentration			DM yield	Uptake		
	Cu	Zn	Mn		Cu	Zn	Mn
	probability						
H	ns	*	ns	ns	ns	**	ns
P	ns	ns	ns	**	**	**	**
H*P	ns	*	ns	ns	ns	ns	ns
F	**	ns	**	*	*	**	**
H*F	ns	ns	ns	ns	ns	ns	ns
P*F	ns	ns	ns	*	**	ns	*
H*P*F	ns	ns	ns	ns	ns	ns	ns
I	**	**	ns	ns	**	*	ns
H*I	ns	ns	ns	ns	ns	ns	ns
P*I	ns	ns	ns	ns	ns	ns	ns
H*P*I	ns	ns	ns	ns	ns	ns	ns
F*I	ns	ns	ns	*	ns	ns	ns
H*F*I	ns	ns	ns	ns	ns	ns	ns
P*F*I	ns	ns	ns	ns	ns	ns	ns
H*P*F*I	ns	ns	ns	ns	ns	ns	ns

*, **: significant at the 0.05 and 0.01 levels respectively.
ns: not significant at p=0.05

H=hybrids; P=plant population; F=fertilizer rate; I=irrigation

Table 8. Probabilities associated with the F-statistic of some sources for concentration and uptake of copper, zinc and manganese and dry matter (DM) yield in plant stalks at growth stage 4 in 1985.

Source	Concentration Cu	Concentration Zn	Concentration Mn	DM yield	Uptake Cu	Uptake Zn	Uptake Mn
	probability						
H	ns	**	ns	ns	ns	*	ns
P	ns	ns	ns	**	ns	ns	ns
H*P	ns	ns	ns	ns	ns	ns	ns
F	ns	ns	**	*	ns	*	**
H*F	ns	ns	ns	*	ns	ns	ns
P*F	ns	ns	ns	ns	ns	ns	ns
H*P*F	ns	ns	ns	ns	ns	ns	ns
I	**	ns	*	ns	*	ns	ns
H*I	ns	ns	ns	ns	ns	ns	ns
P*I	ns	ns	ns	**	ns	ns	*
H*P*I	ns	ns	ns	ns	ns	ns	ns
F*I	ns	ns	ns	*	*	ns	ns
H*F*I	*	ns	ns	*	**	ns	ns
P*F*I	ns	ns	ns	ns	ns	ns	ns
H*P*F*I	ns	ns	ns	ns	ns	ns	ns

*, **: significant at the 0.05 and 0.01 levels respectively.
ns: not significant at p=0.05

H=hybrids; P=plant population; F=fertilizer rate; I=irrigation

Table 9. Probabilities associated with the F-statistic of some sources for concentration and uptake of copper, zinc and manganese and dry matter (DM) yield in plant leaves at growth stage 4 in 1985.

Source	Concentration Cu	Concentration Zn	Concentration Mn	DM yield	Uptake Cu	Uptake Zn	Uptake Mn
				probability			
H	*	ns	ns	*	ns	ns	ns
P	**	ns	ns	**	**	ns	*
H*P	ns	ns	ns	ns	ns	ns	ns
F	ns	ns	**	ns	ns	*	**
H*F	ns	ns	ns	ns	ns	ns	ns
P*F	ns	ns	ns	ns	ns	ns	ns
H*P*F	ns	ns	ns	ns	*	ns	ns
I	**	ns	**	ns	*	ns	**
H*I	ns	ns	ns	ns	ns	ns	ns
P*I	ns	ns	ns	ns	ns	ns	ns
H*P*I	ns	ns	ns	ns	ns	ns	ns
F*I	ns	ns	ns	ns	ns	ns	ns
H*F*I	ns	ns	ns	ns	ns	ns	ns
P*F*I	ns	ns	ns	ns	ns	ns	ns
H*P*F*I	ns	ns	ns	ns	ns	ns	ns

*, **: significant at the 0.05 and 0.01 levels respectively.
ns: not significant at p=0.05

H=hybrids; P=plant population; F=fertilizer rate; I=irrigation

Table 10. Probabilities associated with the F-statistic of some sources for concentration of copper, zinc and manganese in the ear-leaf at early silk in 1985.

	Concentration		
Source	Cu	Zn	Mn
	-----probability-----		
H	**	ns	ns
P	**	ns	ns
H*P	ns	ns	ns
F	ns	*	**
H*F	ns	ns	ns
P*F	ns	ns	ns
H*P*F	**	ns	ns
I	**	**	**
H*I	ns	ns	ns
P*I	*	ns	ns
H*P*I	ns	ns	ns
F*I	ns	ns	ns
H*F*I	ns	ns	ns
P*F*I	*	ns	ns
H*P*F*I	ns	ns	ns

*, **: significant at the 0.05 and 0.01 levels respectively.
ns: not significant at p=0.05

H=hybrids; P=plant population; F=fertilizer rate; I=irrigation

Table 11. Probabilities associated with the F-statistic of some sources for concentration and uptake of copper, zinc and manganese and dry matter (DM) yield in stover harvest stage 4 in 1985.

Source	Concentration			DM yield	Uptake		
	Cu	Zn	Mn		Cu	Zn	Mn
	probability						
H	ns	ns	ns	ns	ns	ns	ns
P	ns	ns	ns	**	ns	ns	ns
H*P	ns	ns	ns	ns	ns	ns	ns
F	ns	ns	**	**	ns	ns	**
H*F	ns	ns	ns	ns	ns	ns	ns
P*F	ns	ns	ns	ns	ns	ns	ns
H*P*F	ns	ns	ns	ns	ns	ns	ns
I	**	**	**	**	ns	ns	**
H*I	ns	ns	ns	ns	ns	ns	ns
P*I	ns	ns	ns	ns	ns	ns	ns
H*P*I	*	ns	ns	ns	*	ns	ns
F*I	ns	ns	*	ns	ns	ns	ns
H*F*I	ns	ns	ns	ns	ns	ns	ns
P*F*I	ns	ns	ns	ns	ns	ns	ns
H*P*F*I	ns	ns	ns	ns	ns	ns	ns

*, **: significant at the 0.05 and 0.01 levels respectively.
ns: not significant at p=0.05

H=hybrids; P=plant population; F=fertilizer rate; I=irrigation

Table 12. Probabilities associated with the F-statistic of some sources for concentration and uptake of copper, zinc and manganese and dry matter (DM) yield in plant leaves at harvest stage 4 in 1985.

Source	Concentration Cu	Concentration Zn	Concentration Mn	DM yield	Uptake Cu	Uptake Zn	Uptake Mn
			probability				
H	**	**	*	ns	ns	**	*
P	ns	ns	ns	**	**	*	**
H*P	ns	*	ns	ns	ns	ns	ns
F	ns	ns	**	*	ns	ns	**
H*F	ns	ns	ns	ns	ns	ns	ns
P*F	ns	ns	ns	*	*	ns	ns
H*P*F	ns	ns	ns	ns	ns	ns	ns
I	ns	**	**	**	ns	**	*
H*I	*	ns	ns	ns	ns	ns	ns
P*I	ns	ns	ns	ns	ns	ns	ns
H*P*I	ns	*	ns	ns	ns	ns	ns
F*I	ns	ns	ns	ns	ns	ns	ns
H*F*I	ns	ns	ns	ns	ns	ns	ns
P*F*I	ns	ns	ns	ns	ns	ns	ns
H*P*F*I	ns	ns	ns	*	ns	ns	*

*, **: significant at the 0.05 and 0.01 levels respectively.
ns: not significant at p=0.05

H=hybrids; P=plant population; F=fertilizer rate; I=irrigation

Table 13. Probabilities associated with the F-statistic of some sources for concentration and uptake of copper, zinc and manganese and dry matter (DM) yield in plant stalks at harvest stage 4 in 1985.

Source	Concentration Cu	Concentration Zn	Concentration Mn	DM yield	Uptake Cu	Uptake Zn	Uptake Mn
	probability						
H	ns	ns	ns	ns	ns	ns	ns
P	ns	ns	ns	**	ns	ns	*
H*P	ns	ns	ns	ns	ns	ns	ns
F	ns	ns	**	**	ns	*	**
H*F	ns	ns	ns	ns	ns	ns	ns
P*F	ns	ns	ns	ns	ns	ns	ns
H*P*F	ns	ns	ns	ns	ns	ns	ns
I	ns	**	**	**	ns	*	*
H*I	ns	ns	ns	ns	ns	ns	ns
P*I	*	ns	ns	ns	ns	ns	ns
H*P*I	ns	ns	ns	ns	ns	ns	ns
F*I	ns	ns	ns	ns	ns	ns	ns
H*F*I	ns	ns	ns	ns	ns	ns	ns
P*F*I	ns	ns	ns	ns	ns	ns	ns
H*P*F*I	ns	*	ns	*	ns	ns	ns

*, **: significant at the 0.05 and 0.01 levels respectively.
ns: not significant at p=0.05

H=hybrids; P=plant population; F=fertilizer rate; I=irrigation

Table 14. Probabilities associated with the F-statistic of some sources for concentration and uptake of copper, zinc and manganese and dry matter (DM) yield in plant shoot at growth stage 4 in 1985.

Source	Concentration Cu	Concentration Zn	Concentration Mn	DM yield	Uptake Cu	Uptake Zn	Uptake Mn
	probability						
H	ns	ns	*	ns	ns	ns	*
P	ns	ns	ns	ns	ns	ns	ns
H*P	ns	ns	ns	ns	ns	ns	ns
F	ns	*	**	**	ns	**	**
H*F	ns	ns	ns	ns	ns	ns	ns
P*F	ns	ns	ns	**	ns	ns	ns
H*P*F	ns	ns	ns	**	ns	ns	ns
I	ns	**	**	**	*	**	*
H*I	ns	ns	ns	*	ns	ns	*
P*I	ns	ns	ns	**	ns	ns	ns
H*P*I	ns	ns	ns	ns	ns	ns	ns
F*I	ns	ns	ns	ns	ns	ns	ns
H*F*I	ns	ns	ns	ns	ns	ns	ns
P*F*I	ns	ns	ns	ns	ns	ns	ns
H*P*F*I	ns	ns	ns	ns	ns	ns	ns

*, **: significant at the 0.05 and 0.01 levels respectively.
ns: not significant at $p=0.05$

H=hybrids; P=plant population; F=fertilizer rate; I=irrigation

APPENDIX III

Table 1. Probabilities associated with the F-statistic of some sources for soil pH, DTPA-extractable copper, zinc and manganese, and Bray-2 extractable phosphorus from Bearbrook soil pot experiment.

Source	pH	Cu	Zn	Mn	Bray-2 P
	Soil Parameters				
		DTPA-extractable			
	probability				
N	ns	ns	ns	ns	**
P	ns	ns	ns	ns	**
N*P	ns	*	*	ns	ns
L	**	ns	*	**	**
N*L	ns	ns	ns	ns	ns
P*L	ns	ns	ns	ns	ns
N*P*L	ns	ns	ns	ns	ns
M	ns	ns	ns	ns	ns
N*M	ns	ns	ns	*	ns
P*M	ns	ns	**	ns	ns
N*P*M	ns	ns	ns	ns	ns
L*M	ns	ns	ns	ns	*
N*L*M	ns	ns	ns	ns	ns
P*L*M	ns	*	ns	*	ns
N*P*L*M	ns	ns	ns	ns	ns

*, **: significant at the 0.05 and 0.01 levels respectively.
ns: not significant at the 0.05 level.

N=nitrogen; P=phosphorus; L=$Ca(OH)_2$; M=chelate micronutrients

Table 2. Probabilities associated with the F-statistic of some sources for soil pH, DTPA-extractable copper, zinc and manganese, and Bray-2 extractable phosphorus from Chicot soil pot experiment.

		Soil Parameters			
		DTPA-extractable			Bray-2
Source	pH	Cu	Zn	Mn	P
	probability				
N	ns	ns	ns	ns	ns
P	ns	ns	ns	ns	**
N*P	ns	ns	ns	ns	ns
L	**	**	**	**	**
N*L	ns	ns	ns	ns	ns
P*L	ns	ns	ns	ns	ns
N*P*L	ns	ns	ns	ns	ns
M	ns	**	ns	ns	ns
N*M	ns	ns	ns	ns	ns
P*M	ns	ns	ns	ns	ns
N*P*M	ns	ns	ns	ns	ns
L*M	ns	*	ns	ns	ns
N*L*M	ns	ns	ns	ns	ns
P*L*M	ns	ns	ns	ns	**
N*P*L*M	ns	ns	ns	ns	ns

*, **: significant at the 0.05 and 0.01 levels respectively.
ns: not significant at the 0.05 level.

N=nitrogen; P=phosphorus; L=$Ca(OH)_2$; M=chelate micronutrients

Table 3. Probabilities associated with the F-statistic of some sources for soil pH, DTPA-extractable copper, zinc and manganese, and Bray-2 extractable phosphorus from Ormstown soil pot experiment.

	Soil Parameters				
		DTPA-extractable			Bray-2
Source	pH	Cu	Zn	Mn	P
	probability				
N	ns	ns	ns	ns	ns
P	ns	ns	ns	ns	**
N*P	ns	*	ns	ns	ns
L	**	**	ns	ns	ns
N*L	*	ns	ns	**	ns
P*L	ns	ns	ns	ns	ns
N*P*L	ns	ns	ns	ns	ns
M	ns	ns	ns	ns	ns
N*M	ns	ns	ns	ns	ns
P*M	ns	ns	ns	ns	ns
N*P*M	ns	ns	ns	ns	ns
L*M	ns	ns	ns	ns	ns
N*L*M	ns	ns	ns	ns	ns
P*L*M	ns	ns	ns	ns	ns
N*P*L*M	ns	ns	ns	ns	ns

*, **: significant at the 0.05 and 0.01 levels respectively.
ns: not significant at the 0.05 level.

N=nitrogen; P=phosphorus; L=$Ca(OH)_2$; M=chelate micronutrients

APPENDIX IV

Table 1. Probabilities associated with the F-statistic of some sources for tissue concentration of nitrogen, phosphorus, copper, zinc, and manganese, shoot dry weight (SDW), root dry weight (RDW), and uptake of copper, zinc, and manganese in 30-day old maize plants grown in pots of Bearbrook soil.

	Plant Parameters									
	Concentration					Uptake			Yield	
Source	N	P	Cu	Zn	Mn	Cu	Zn	Mn	SDW	RDW
	probability									
N	**	*	**	**	ns	**	ns	ns	**	ns
P	ns	**	ns	ns	ns	**	ns	**	**	ns
N*P	ns	ns	*	ns	ns	ns	ns	ns	ns	ns
L	**	ns	*	*	**	ns	ns	**	ns	ns
N*L	ns	ns	ns	*	ns	ns	*	ns	*	ns
P*L	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
N*P*L	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
M	ns	ns	ns	*	ns	ns	*	ns	ns	ns
N*M	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
P*M	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
N*P*M	ns	ns	ns	ns	ns	*	ns	ns	ns	ns
L*M	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
N*L*M	*	ns	ns	ns	*	ns	ns	ns	ns	ns
P*L*M	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
N*P*L*M	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns

*, ** : significant at the 0.05 and 0.01 levels respectively
ns: not significant at p=0.05

N=nitrogen; P=phosphorus; L=$Ca(OH)_2$; M=Chelated micronutrients

Table 2. Probabilities associated with the F-statistic of some sources for tissue concentration of nitrogen, phosphorus, copper, zinc, and manganese, shoot dry weight (SDW), root dry weight (RDW), and uptake of copper, zinc, and manganese in 30-day old maize plants grown in pots of Chicot soil.

	Plant Parameter									
	Concentration					Uptake			Yield	
Source	N	P	Cu	Zn	Mn	Cu	Zn	Mn	SDW	RDW
	probability									
N	**	*	**	**	**	**	**	**	**	ns
P	ns	**	ns	ns	ns	ns	ns	**	**	ns
N*P	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
L	*	**	ns	**	**	ns	**	**	**	**
N*L	ns	ns	ns	ns	**	ns	ns	**	ns	ns
P*L	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
N*P*L	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
M	ns	ns	*	*	ns	**	*	ns	ns	ns
N*M	**	ns	ns	ns	ns	ns	ns	ns	ns	ns
P*M	ns	ns	ns	ns	ns	ns	ns	*	ns	ns
N*P*M	ns	ns	ns	ns	ns	ns	ns	ns	*	ns
L*M	ns	*	ns	ns	ns	ns	ns	ns	ns	ns
N*L*M	*	ns	ns	ns	ns	ns	ns	ns	ns	ns
P*L*M	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
N*P*L*M	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns

*, **: significant at the 0.05 and 0.01 levels respectively.
ns: not significant at $p=0.05$.

N=nitrogen; P=phosphorus; L=$Ca(OH)_2$; M=Chelated micronutrients

Table 3. Probabilities associated with the F-statistic of some sources for tissue concentration of nitrogen, phosphorus, copper, zinc, and manganese, shoot dry weight (SDW), root dry weight (RDW), and uptake of copper, zinc, and manganese in 30-day old maize plants grown in pots of Ormstown soil.

	Plant Parameters									
	Concentration					Uptake			Yield	
Source	N	P	Cu	Zn	Mn	Cu	Zn	Mn	SDW	RDW
	probability									
N	**	**	**	ns	ns	ns	*	**	**	**
P	**	**	ns	ns	ns	ns	ns	ns	**	*
N*P	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
L	ns	ns	**	ns	ns	ns	ns	**	ns	**
N*L	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
P*L	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
N*P*L	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
M	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
N*M	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
P*M	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
N*P*M	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
L*M	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
N*L*M	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
P*L*M	ns	ns	ns	ns	ns	ns	ns	ns	ns	nr
N*P*L*M	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns

*, **: significant at the 0.05 and 0.01 levels respectively.
ns: not significant at p=0.05

N=nitrogen; P=phosphorus; L=$Ca(OH)_2$; M=Chelated micronutrients