

RESPONSE OF CORN TO  
MANGANESE APPLICATION ON  
ATLANTIC COASTAL PLAIN SOILS

by

Eduardo Uribe B.

thesis submitted to the Faculty of the  
Virginia Polytechnic Institute and State University  
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

in

Agronomy

APPROVED:

\_\_\_\_\_  
D. C. Martens, Co-chairman

\_\_\_\_\_  
D. E. Brann, Co-chairman

\_\_\_\_\_  
G. W. Hawkins

\_\_\_\_\_  
T. B. Hutcheson, Jr.

May, 1985  
Blacksburg, Virginia



## TABLE OF CONTENTS

	<u>Page</u>
ACKNOWLEDGEMENTS. . . . .	ii
LIST OF TABLES. . . . .	v
LIST OF FIGURES . . . . .	vi
INTRODUCTION. . . . .	1
LITERATURE CITED. . . . .	8
RESPONSE OF CORN TO BAND APPLIED MANGANESE SULFATE IN ATLANTIC COASTAL PLAIN SOILS. . . . .	10
MATERIALS AND METHODS . . . . .	12
FIELD EXPERIMENTATION. . . . .	12
TISSUE ANALYSES. . . . .	15
SOIL ANALYSES. . . . .	16
YIELD MEASUREMENT. . . . .	17
STATISTICAL ANALYSES . . . . .	17
RESULTS AND DISCUSSION. . . . .	19
GRAIN YIELD VERSUS MANGANESE APPLICATION . . . . .	19
GRAIN YIELD VERSUS EAR LEAF MANGANESE. . . . .	23
GRAIN YIELD VERSUS GRAIN MANGANESE . . . . .	26
MEHLICH I VERSUS MEHLICH III EXTRACTABLE MANGANESE . . . . .	30
SUMMARY . . . . .	31
LITERATURE CITED. . . . .	32
RESPONSE OF CORN TO BROADCAST MANGANESE SULFATE IN ATLANTIC COASTAL PLAIN SOILS. . . . .	34
MATERIALS AND METHODS . . . . .	36
FIELD EXPERIMENTATION. . . . .	36
TISSUE ANALYSES. . . . .	37
SOIL ANALYSES. . . . .	37
STATISTICAL ANALYSES . . . . .	38
RESULTS AND DISCUSSION. . . . .	39
BROADCAST MANGANESE VERSUS EXTRACTABLE MANGANESE . . . . .	39
EXTRACTABLE MANGANESE VERSUS EAR LEAF MANGANESE. . . . .	44
EXTRACTABLE MANGANESE VERSUS GRAIN MANGANESE . . . . .	48
CORN GRAIN YIELD VERSUS EAR LEAF MANGANESE . . . . .	49
CORN GRAIN YIELD VERSUS CORN GRAIN MANGANESE . . . . .	52
EXTRACTABLE MANGANESE VERSUS CORN GRAIN YIELD. . . . .	52
EAR LEAF MANGANESE VERSUS GRAIN MANGANESE. . . . .	53

	<u>Page</u>
SUMMARY . . . . .	56
LITERATURE CITED . . . . .	57
CONCLUSIONS . . . . .	59
VITA . . . . .	62
ABSTRACT	

LIST OF TABLES

	<u>Page</u>
Table 1. Response categories of some important agricultural crops to Mn application under soil conditions favorable to Mn deficiency. . . . .	5
Table 2. Classification and selected properties in the Ap horizon of the three soils under study. . . . .	14
Table 3. Response of corn to Mn application on three soils . . .	20
Table 4. Nutrient concentrations in corn ear leaves at the early silk growth stage as affected by Mn applications on three soils. . . . .	22
Table 5. Classification and selected properties of the two soils under study . . . . .	40
Table 6. Manganese concentrations in soil and plant tissue and corn grain yields as affected by broadcast application of Mn in two soils. . . . .	41
Table 7. Coefficients of simple correlation for relationships between broadcast Mn rates, Mn concentrations in corn tissue and grain yield for two soils . . . . .	42
Table 8. Nutrient concentration in corn ear leaves at the early silk growth stage as affected by broadcast Mn application on two soils . . . . .	51

## LIST OF FIGURES

	<u>Page</u>
Figure 1. Manganese deficiency symptoms in corn plants. . . . .	13
Figure 2. The relationship between percent maximum yield (Y) and Mn concentration in ear leaf (X) at the early silk growth stage . . . . .	24
Figure 3. The relationship between corn grain yield (Y) and Mn concentration in the ear leaf (X) at the early silk growth stage . . . . .	25
Figure 4. The relationship between percent maximum corn grain yield (Y) and Mn concentration in corn grain (X) . . . . .	27
Figure 5. The relationship between corn grain yield (Y) and Mn concentration in corn grain (X). . . . .	28
Figure 6. The relationship between Mehlich I (Y) and Mehlich III (X) extractable Mn. . . . .	29
Figure 7. The relationship between Mehlich I (Y) and Mehlich III (X) extractable Mn. . . . .	43
Figure 8. The relationship between Mehlich I extractable Mn (X) and Mn concentration in the ear leaf (Y) for the Dragston (C) and (°) and the Slagle (Δ) soil. . . . .	46
Figure 9. The relationship between Mehlich III extractable Mn (X) and Mn concentration in the ear leaf (Y) for the Dragston (C) soil and (°) and the Slagle (Δ) soil. . . . .	47
Figure 10. The relationship between Mn concentrations in the ear leaf (X) and corn grain yield (Y) on the Dragston (C) fine sandy loam. . . . .	50
Figure 11. The relationship between Mn concentrations in the corn ear leaf (X) and grain (Y) . . . . .	54

## INTRODUCTION

The essentiality of Mn for plant growth was proven by McHargue in 1922 (Gilbert, 1948). Since then, much research has been conducted to determine the functions of Mn in plants. Manganese in coordination with a protein participates in the electron transfer reactions of photosystem II (McGilvery, 1983). It also activates certain enzymes involved in fatty acid synthesis, nucleotide synthesis, and respiration (Devlin, 1975). Manganese substitutes for Mg in many of the ATP dependent enzymes of sugar metabolism (Follet et al., 1981). Under conditions of inadequate Mn, disruptions of biochemical processes lead to a decrease in plant growth (Devlin, 1975).

Manganese is taken up by plants predominantly as  $Mn^{2+}$ . The activity of  $Mn^{2+}$  in soil solution is mainly dependent upon two soil properties, Eh (reduction potential) and pH (Gotoh and Patrick, 1972). As the soil Eh and pH decrease, the  $Mn^{2+}$  activity increases in soil solution and, consequently, higher Mn uptake occurs by plants (Lutz et al., 1972; Ponnampetuma et al., 1969). When soil pH and Eh increase,  $Mn^{2+}$  in soil solution is oxidized to  $Mn^{3+}$  and  $Mn^{4+}$ , and the trivalent and tetravalent Mn precipitate as very insoluble hydroxides and oxides (Bohn et al., 1979). The pre-

precipitation reactions decrease the amount of Mn in soil solution and, thereby, decrease Mn uptake by plants.

Much of the  $Mn^{2+}$  in soil solution is present as complexes with organic molecules rather than as  $Mn^{2+}$  (Geering et al., 1969). Divalent Mn forms relatively weak bonds with functional groups of organic matter in soil solution (Geering et al., 1969) and competes with  $H_3O^+$  for bond formation with the functional groups. Research by Schnitzer et al. (1967) indicated that  $Mn^{2+}$  bonded to soil fulvic acid became more soluble as pH decreased from 5.0 to 3.5. Undoubtedly, the bond strength between  $Mn^{2+}$  and functional groups of soil solution organic matter is too weak to prevent precipitation of insoluble Mn hydroxides and oxides at higher levels of soil Eh and pH. For this reason, low Mn uptake occurs by plants from soils with high levels of soil Eh and pH.

Mehlich (1957) found that Mn deficiency developed when strongly acidic soils were brought to a pH higher than 6.2. However, less severe Mn deficiency occurred if slightly acidic soils were limed to a pH level above 6.2. This effect was more pronounced in strongly acidic soils with wider Al/Mn and Fe/Mn ratios. It is possible that higher Al and Fe activities could lead to much Mn occlusion in hydroxides and oxides formed during neutralization of the strongly acidic soils and that the occluded Mn would be unavailable to plants.

An inverse relationship between Mn uptake and Fe activity in soil solution was observed long ago (Shive, 1941). It was noticed that Mn toxicity symptoms could be decreased by addition of either Fe or Al. Vlamis et al. (1962) found that Mn uptake by plants was depressed very effectively by Fe addition to nutrient solution. Calcium,  $Mg^{++}$  and  $NH_4^+$  additions also decreased Mn uptake. The authors explained this decrease as competition for absorption sites in plant roots. An increase in Zn level also depressed Mn uptake by corn (Zea mays L.) and barley (Hordeum vulgare L.) from a soil with low levels of available Mn and Zn (Singh and Steenberg, 1974). This decrease in Mn uptake by Zn application was attributed to competition of Zn with Mn for absorption sites at the root surface.

Rattan and Taylor (1970) found that Mn uptake by corn was enhanced by B, Cu, K, N, P, and Zn fertilization. They established that Mn concentrations in corn ear leaves increased with closeness of the water table to the soil surface up to 15 cm. This was probably due to higher  $Mn^{2+}$  activity in soil solution under anaerobic conditions. The ionic strength of soil solution affected Mn uptake by barley. That is, Mn uptake decreased with an increase in total solute concentration in soil solution (Rattan and Taylor, 1970).

Manganese deficiency is widespread in eastern United States (Kubota and Allaway, 1972). Species of plants and even varieties differ in tolerance to low levels of soil Mn (Nair and Prabhat, 1977). Plants that are sensitive to Mn deficiency are equally sensitive to Mn toxicity (Jones, 1972). The response of selected crops to Mn applications under soil conditions conducive to Mn deficiency is shown in Table 1. The low sensitivity rating indicates that, in most situations, corn yields will not be increased by Mn application (Lucas and Knezek, 1972).

Due to the few yield responses from Mn application, very little is known about the diagnosis of Mn deficiency in corn. Several soil extraction procedures have been used to predict Mn availability to corn plants (Browman et al., 1969). However, due to the complexity of Mn chemistry in soil, extractable Mn alone has not been sufficient to predict Mn uptake. Other variables besides extractable Mn have been included in equations for prediction of Mn uptake by corn and soybeans [Glycine max (L.) Merr.] under field conditions (Browman et al., 1969; Cox, 1968; Gettier et al., 1984; Mascagni and Cox, 1984). Inclusion of organic C and clay contents and CEC have not improved the prediction of Mn uptake as compared with extractable Mn alone ( $p = 0.05$ ). Soil pH, when used with extractable Mn, has been the only

Table 1. Response categories of some important agricultural crops to Mn application under soil conditions favorable to Mn deficiency.+

Common name	Scientific name	Response Category
Alfalfa	<u>Medicago sativa</u> L.	medium
Barley	<u>Hordeum vulgare</u> L.	medium
Corn	<u>Zea mays</u> L.	low
Oats	<u>Avena sativa</u> L.	high
Peanut	<u>Arachis hypogea</u> L.	high
Rye	<u>Secale cereale</u> L.	low
Sorghum	<u>Sorghum bicolor</u> (L.) Moench.	high
Soybeans	<u>Glycine max</u> (L.) Merr.	high
Wheat	<u>Triticum aestivum</u> (L.) em Thell.	high

+From Lucas and Knezek (1972).

variable to improve the prediction of Mn uptake by plants under field conditions ( $p = 0.05$ ).

Mascagni and Cox (1984) developed a regression equation to predict whether Mn application would increase corn yields. Variables in their equation were soil pH and Mehlich III extractable Mn. This regression equation accounted for 50.5% of the variation in corn grain yield for one Atlantic Coastal Plain soil. They reported that the critical level of Mn in corn was  $11 \text{ mg kg}^{-1}$  based on the ear leaf at early silk growth stage; the critical level was defined as the concentration of Mn in the tissue for attainment of 99% of maximum yield. Mascagni and Cox (1984) also found that Mn banded with diammonium phosphate was three times more effective in increasing the Mn concentration in corn tissue on four Atlantic Coastal Plain soils than Mn broadcast with diammonium phosphate.

Manganese application increased soybean seed yields in field experiments on 17 Atlantic Coastal Plain soils in Virginia (Gettier et al., 1984). However, yield response of corn to applied Mn has not been evaluated on these soils. This investigation was conducted during the 1984 growing season to study corn response to Mn application on five soils where foliar Mn had increased soybean seed yield. The specific objectives of this research were as follows:

1. To evaluate yield response of corn to Mn application under field conditions.
2. To compare rates of broadcast Mn as  $\text{MnSO}_4$  for correction of Mn deficiency.
3. To determine the efficiency of Mehlich I and Mehlich III extractable Mn for prediction of Mn uptake by corn plants.
4. To establish critical Mn levels in corn based on ear leaf and grain samples.

#### LITERATURE CITED

- Bohn, H. L., B. L. McNeal, and G. A. O'Connor. 1979. John Wiley and Sons, New York, NY.
- Browman, G. M., G. Chesters, and H. B. Pionke. 1969. Evaluation of tests for predicting the availability of soil manganese to plants. *J. Agric. Sci., Camb.* 72:335-340.
- Cox, F. R. 1968. Development of a yield response prediction and manganese soil test interpretation for soybeans. *Agron. J.* 60:521-524.
- Devlin, R. M. 1975. Plant physiology. D. Van Nostrand Co., New York, NY.
- Follet, R. H., L. S. Murphy, and R. L. Donahue. 1981. Fertilizers and soil amendments. Prentice-Hall, Inc., Englewood Cliffs, NJ.
- Geering, H. R., J. F. Hodgson, and C. Sdano. 1969. Micronutrients cation complexes in soil solution: IV. The chemical state of manganese in soil solution. *Soil Sci. Soc. Am. Proc.* 33:81-85,
- Gettier, S. W., D. C. Martens, and S. J. Donohue. 1985. Soybean yield response prediction from soil test and tissue manganese levels. *Agron. J.* 77:63-67.
- Gilbert, F. A. 1948. Mineral nutrition of plants and animals. Univ. of Oklahoma Press, Norman, OK.
- 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.
- Jones, J. B. 1972. Plant tissue analysis for micronutrients p. 319-346. In J. J. Mortvedt, P. M. Giordano, and W. L. Lindsay (ed.) *Micronutrients in agriculture.* Soil Science Society of America, Madison, WI.
- Kubota, J., and W. H. Allaway. 1972. Geographic distribution of trace element problems. p. 525-554. In J. J. Mortvedt, P. M. Giordano, and W. L. Lindsay (ed.) *Micronutrients in agriculture.* Soil Science Society of America, Madison, WI.

- Lucas, R. E. and B. D. Knezek. 1972. Climatic and soil conditions promoting micronutrient deficiencies in plants. p. 265-288. In J. J. Mortvedt, P. M. Giordano, and W. L. Lindsay (ed.) *Micronutrients in agriculture*. Soil Science Society of America, Madison, WI.
- Lutz, J. A., C. F. Genter, and G. W. Hawkins. 1972. Effect of soil pH on element concentration and uptake by maize: II. Cu, B, Zn, Mn, Mo, Al, and Fe. *Agron. J.* 64:583-585.
- Mascagni, H. J., and F. R. Cox. 1984. Diagnosis and correction of manganese deficiency in corn. *Commun. Soil Sci. Plant Anal.* 15:1323-1333.
- McGilvery, R. W. 1983. *Biochemistry a functional approach*. W. B. Sanders Company, Philadelphia, PA.
- Mehlich, A. 1957. Aluminum, iron, and pH in relation to lime induced manganese deficiencies. *Soil Sci. Soc. Am. Proc.* 21:625-628.
- Nair, P. K. P. and G. Prabhat. 1977. Differential response of tropical maize genotypes to zinc and manganese nutrition. *Plant Soil* 47:149-159.
- Ponnamperuma, F. N., T. A. Loy, and E. M. Tianco. 1969. Redox equilibria in flooded soils. II. The manganese oxide systems. *Soil Sci.* 108:48-57.
- Rattan, L., and G. S. Taylor. 1970. Drainage and nutrient effects in a field lysimeter study: II. Mineral uptake by corn. *Soil Sci. Soc. Am. Proc.*, 34:245-248.
- Shive, J. W. 1941. Significant roles of trace elements in the nutrition of plants. *Plant Physiol.* 16:435-445.
- Schnitzer, M., and S. I. M. Skinner. 1967. Organo-metallic interactions in soils: 7 stability constants of  $Pb^{++}$ ,  $Ni^{++}$ ,  $Mn^{++}$ ,  $Co^{++}$ ,  $Ca^{++}$ , and  $Mg^{++}$ -fulvic acid complexes. *Soil Sci.* 103:247-251.
- Vlavis, J., and D. E. Williams. 1962. Ion competition in manganese uptake by barley plants. *Plant Physiol.* 37:650-655.

RESPONSE OF CORN TO BAND APPLIED MANGANESE  
SULFATE IN ATLANTIC COASTAL PLAIN SOILS

Plants differ in susceptibility to Mn deficiency (Lucas and Knezek, 1972). The susceptibility of corn (Zea mays L.) to Mn deficiency is low as compared with other crops, such as soybeans [Glycine max (L.) Merr.] and wheat [Triticum aestivum (L.) em Thell.] (Lucas and Knezek, 1972). The low susceptibility to Mn deficiency indicates that Mn application will not increase corn yields in most situations (Lucas and Knezek, 1972). Although corn is rated as low in susceptibility to Mn deficiency, Mascagni and Cox (1984) found that Mn application increased corn grain yield by as much as 6190 kg ha<sup>-1</sup> on two Aquic Paleudults, Exum fine sandy loam and Goldsboro sandy loam.

Manganese deficiency of soybeans is prevalent in the Atlantic Coastal Plain region (Alley et al., 1978; Boswell et al., 1981; Cox, 1968; Gettier et al., 1985; Robertson et al., 1973; Woodruff, 1979). Gettier et al. (1985) found that foliar Mn application increased soybean seed yields in 17 of 30 field experiments on Atlantic Coastal Plain soils in Virginia. The purpose of this research was to evaluate corn response to Mn application on Atlantic Coastal Plain soils on which foliar Mn had previously increased soybean seed yield. Foliar Mn increased soybean seed yields by 1220

to 2620 kg ha<sup>-1</sup> on the three soils selected for this research during either the 1981 or 1983 growing season (Gettiner et al., 1985).

## MATERIALS AND METHODS

Three experiments were conducted in farmer's fields during the 1984 growing season. Experimental areas in each field were selected on the basis of uniform deficiency symptoms in corn as shown in Figure 1. The abnormality was thought to be Mn deficiency of corn. Classification and selected properties of the soils under study are shown in Table 2.

### FIELD EXPERIMENTATION

Two treatments applied to the three soils were 1) a control and 2) Mn applied both in a band and to foliage. These treatments were replicated four times and arranged in a randomized complete block design. The band and foliar Mn were applied when plants were approximately 30 cm tall. Five kg Mn ha<sup>-1</sup> as MnSO<sub>4</sub>•H<sub>2</sub>O were banded 7.5 cm beside the corn row to a depth of 5 cm with 2.0 kg Cu ha<sup>-1</sup> as CuSO<sub>4</sub>•5H<sub>2</sub>O and 4.0 kg Zn ha<sup>-1</sup> as ZnSO<sub>4</sub>•7H<sub>2</sub>O. The band for the control treatment contained the 2.0 kg Cu and 4.0 kg Zn ha<sup>-1</sup> as sulfates and sufficient K<sub>2</sub>SO<sub>4</sub> to compensate for the SO<sub>4</sub><sup>2-</sup> from MnSO<sub>4</sub>•H<sub>2</sub>O in the + Mn treatment. Potassium chloride was banded in the + Mn treatment to compensate for the K in K<sub>2</sub>SO<sub>4</sub>. Foliar Mn as MnSO<sub>4</sub>•H<sub>2</sub>O was applied at a rate of

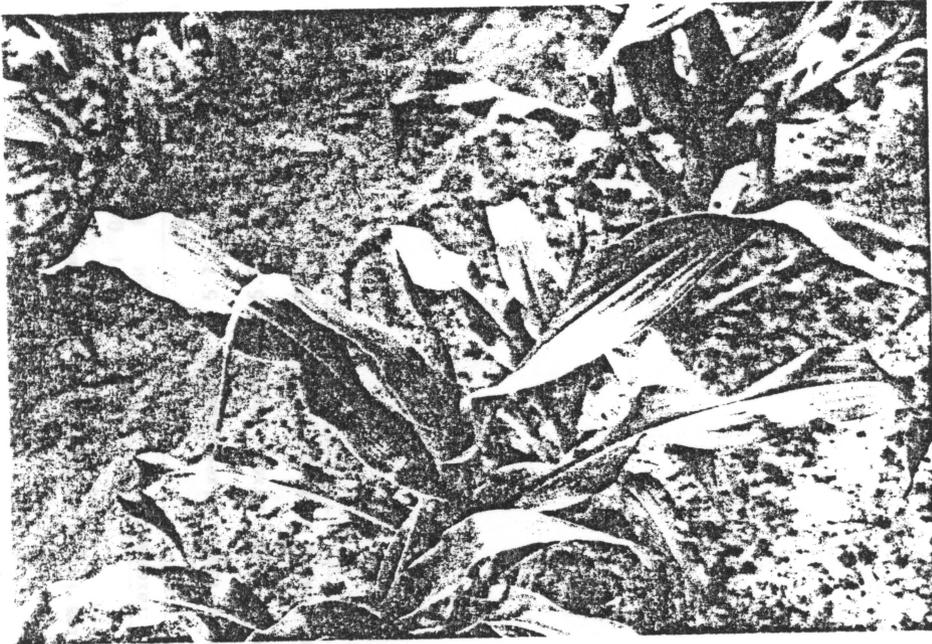


Figure 1. Manganese deficiency symptoms in corn plants.

Table 2. Classification and selected properties in the Ap horizon of the three soils under study.

Series	Soil		Taxonomy	Soil pH	Organic Matter g kg <sup>-1</sup>	Extractable Mn	
	Texture					Mehlich I	Mehlich III
						mg kg <sup>-1</sup>	
Dragston (A)	fsl	Aeric Ochraquults; coarse-loamy, mixed, thermic		5.7	23	1.9	2.6
Dragston (B)	fsl	Aeric Ochraquults; coarse-loamy, mixed, thermic		5.9	20	1.8	3.1
Myatt	fsl	Typic Ochraquults; fine-loam, siliceous, thermic		5.9	16	3.2	5.0

1.0 kg ha<sup>-1</sup>. Corn populations grown on the experiment sites were as follows: 39,800 plants ha<sup>-1</sup> of 'Northrup King PX74' on the Dragston (A), 40,200 plants ha<sup>-1</sup> of 'Beck 89X' on the Dragston (B), and 43,850 plants ha<sup>-1</sup> of 'Pioneer 3192' on the Myatt soil.

#### TISSUE ANALYSES

Twelve whole plants, which were approximately 30-cm tall, were sampled from each experimental location. Ten earleaf samples were taken from guard rows when corn plants were at the early silk growth stage and corn grain samples were obtained at plant maturity. The plant tissue was dried at 70°C for 24 hours and ground to pass a 20-mesh screen. Copper, K, N, P, S and Zn, as well as Mn, were determined in the earleaf samples to evaluate treatment effects from Mn application and to determine if nutrients other than Mn limited corn yield. Only Mn concentrations were determined in whole plant and grain samples.

One-gram subsamples of the ground tissue were dry-ashed at 450°C for two hours in preparation for Cu, K, Mn, P and Zn analyses. Ashed samples were filtered after equilibration in 0.5 M HCl for Cu, Mn and Zn analyses and 0.3 M HNO<sub>3</sub> for P and K analyses. The cations in the filtrates were determined by atomic absorption spectrophotometry and P by a

vanadomolybdophosphoric acid method. Nitrogen in the ground tissue was determined by a microKjeldahl procedure (McKenzie and Wallace, 1954), and S by a combustion technique with a LECO S analyzer (Bremner and Tabatabai, 1971).

#### SOIL ANALYSES

Soil samples, 12 cores plot<sup>-1</sup>, were obtained from the Ap horizon of each plot of the three field experiments when corn plants were approximately 30-cm tall. The samples were dried at 105°C for 24 hours and ground to pass a 10-mesh stainless steel screen. Extractable Mn in the ground samples was determined by the Mehlich I (Nelson et al., 1953) and Mehlich III (Makarim and Cox, 1983) procedures. The soil was measured for extractable Mn analyses by volume with an assumed weight to volume ratio of 1.25. Thus, a 4.0 cm<sup>3</sup> volume of soil, measured with a scoop of radius 0.99 cm and depth 1.30 cm, had an estimated weight of 5.0 g. Soil pH was determined in a 1:1 soil-to-water mixture after a 1-hour equilibration period, and organic matter in the soil samples was determined by a chromic acid oxidation procedure (The Council on Soil Testing and Plant Analysis, 1980).

## YIELD MEASUREMENT

Two 12.2-m rows of corn were harvested from each plot for grain yield measurement. The grain was adjusted to a 15.5% moisture content.

## STATISTICAL ANALYSES

Soil and plant tissue data were analyzed by analyses of variance and by linear and non-linear correlation and regression procedures (Ott, 1977). The relationship between Mn concentration in corn tissue and grain yield was established with the Mitscherlich plant growth model as described by Ware et al. (1982). Their proposed model was:

$$Y = \beta (1 - \gamma e^{-\alpha X}),$$

Where Y is the percent maximum yield and X is the Mn concentration in tissue. For this study, the tissues were the corn ear leaf at the early silk growth stage and the corn seed. The parameter  $\beta$  is the asymptotic maximum as X approaches infinity. This parameter accounts for the fact that yield continues to increase until a point at which it levels off and indicates the point at which this occurs. The parameter  $\alpha$  is a constant of proportionality which determines the rate at which the asymptotic value is reached with respect to the Mn concentration in the plant tissue. The estimate of  $\gamma$  corrects the assumption that  $Y = 0$  where X

= 0, which is too restrictive. An estimate of  $\gamma = 1$  implies that  $Y = 0$  at  $X = 0$  and, therefore, that the prediction line passes through the origin. The parameters  $\beta$ ,  $\alpha$  and  $\gamma$  were estimated from the observed data.

The critical level for Mn deficiency was taken as the Mn concentration in the tissue associated with a 10% reduction from maximum corn grain yield (Ulrich and Hills, 1946). The percent maximum yield was calculated by dividing yield on each plot by the highest yield on all plots in the three field experiments and by multiplying this value by 100%. For example, the highest yield, 9893 kg corn grain ha<sup>-1</sup>, occurred on a + Mn treatment on the Dragston (A) fine sandy loam and the lowest yield of 4940 kg ha<sup>-1</sup> occurred on a control treatment on the Dragston (B) fine sandy loam. Consequently, the percent maximum yield was 49.9 on the control treatment. The unknown parameters and other statistical analyses were computed using the SAS82 statistical analyses system (SAS Institute Inc., 1982).

## RESULTS AND DISCUSSION

This research was conducted to determine yield response of corn to Mn application on three Atlantic Coastal Plain soils with diverse properties. The pH of the soils ranged from 5.7 to 5.9, Mehlich I extractable Mn from 1.8 to 3.2 mg kg<sup>-1</sup>, Mehlich III extractable Mn from 2.6 to 5.0 mg kg<sup>-1</sup>, and organic matter from 16 to 23 g kg<sup>-1</sup> (Table 1). The pH levels in the three soils were below the range of 6.3 to 6.9 for the soils where Mn application increased corn grain yield in the study by Mascagni and Cox (1984). A sufficiency range of 30 to 300 mg Mn kg<sup>-1</sup> was proposed for whole corn plants up to 30-cm tall (Donohue and Hawkins, 1979). The Mn concentrations in whole plants before Mn application were below this range on the three soils and averaged 8.0 mg kg<sup>-1</sup> on the Dragston (A), 10.9 mg kg<sup>-1</sup> on the Dragston (B), and 14.8 on the Myatt soil.

### GRAIN YIELD VERSUS MANGANESE APPLICATION

Application of Mn increased corn grain yields and Mn concentrations in corn grain and ear leaves at the early silk growth stage (Table 3). The mean increase in grain yield on the three soils from correction of Mn deficiency was 960 kg ha<sup>-1</sup>, which is 12.6% higher than yields on the

Table 3. Response of corn to Mn application on three soils.

Treatment†	Mn concentration		Grain Yield kg ha <sup>-1</sup>
	Ear leaf	Grain	
	----- mg kg <sup>-1</sup> -----		
	<u>Dragston (A) fine sandy loam</u>		
Control	5.8 (0.01)‡	3.0 (0.51)	5630 (0.06)
+ Mn	7.2	3.3	7300
	<u>Dragston (B) fine sandy loam</u>		
Control	10.1 (0.06)	3.1 (0.18)	8410 (0.17)
+ Mn	12.2	3.6	9110
	<u>Myatt fine sandy loam</u>		
Control	10.3 (0.17)	4.8 (0.06)	8690 (0.30)
+ Mn	12.7	6.0	9210
	<u>Average of the three soils</u>		
Control	8.7 (0.04)	3.7 (0.03)	7580 (0.02)
+ Mn	10.7	4.3	8540

†5.0 kg Mn ha<sup>-1</sup> as MnSO<sub>4</sub>·H<sub>2</sub>O was banded beside the row and 1.0 kg Mn ha<sup>-1</sup> as MnSO<sub>4</sub>·H<sub>2</sub>O was sprayed on corn plants for the +Mn treatment.

‡The probability levels at which column means within soils are significantly different, as determined by the ANOVA procedure, are shown in parentheses.

control treatments. Application of Mn did not affect Cu, K, N, P, S and Zn concentrations in ear leaves at the early silk growth stage on the three soils (Table 4).

Mehlich III extractable Mn was not closely related ( $r^2 = 0.31$ ,  $p = 0.05$ ) to corn grain yield on a soil to which various levels of Mn were applied (Mascagni and Cox, 1984). The low association between extractable Mn and corn yield reflects the fact that Mn content in soils is not the only parameter that controls Mn uptake (Mehlich, 1957). For example, a two variable equation, Mehlich III extractable Mn and soil pH, was more closely related to corn yields ( $r^2 = 0.50$ ,  $p = 0.001$ ), than extractable Mn alone, on the aforementioned soil (Mascagni and Cox, 1984). Use of Mn concentrations in corn tissue gave a better prediction of corn yield than Mehlich III extractable Mn (Mascagni and Cox, 1984). However, prediction of possible Mn deficiency is needed early and even before planting corn. Thus, it is necessary to use prediction equations based on Mn levels in corn tissue with equations based on extractable Mn and soil parameters to design fertilization programs.

Table 4. Nutrient concentrations in corn ear leaves at the early silk growth stage as affected by Mn application on three soils.

Treatment†	Nutrient concentrations‡					
	N	P	K	S	Cu	Zn
	----- g kg <sup>-1</sup>			-- mg kg <sup>-1</sup> --		
	Dragston (A) fine sandy loam					
Control	30	3.0	17	2.0	7.9	19.3
+ Mn	29	3.0	17	2.0	7.6	20.4
	Dragston (B) fine sandy loam					
Control	30	3.0	18	2.5	11.2	30.3
+ Mn	29	3.0	18	2.4	10.5	32.1
	Myatt fine sandy loam					
Control	32	3.0	14	2.3	8.1	32.8
+ Mn	32	3.0	15	2.3	7.0	30.3

+5.0 kg Mn ha<sup>-1</sup> as MnSO<sub>4</sub>·H<sub>2</sub>O was banded beside the row and 1.0 kg Mn ha<sup>-1</sup> as MnSO<sub>4</sub>·H<sub>2</sub>O was sprayed on corn plants for the + Mn treatment.  
 ‡Nutrient concentrations within soils were not significantly different (p = 0.10).

## GRAIN YIELD VERSUS EAR LEAF MANGANESE

The relationship between Mn concentrations in the tissue and percent maximum yield was well described ( $r = 0.89$ ,  $p = 0.05$ ) by the Mitscherlich plant growth model (Fig. 2). The estimated values for the parameters  $\alpha$ ,  $\beta$ , and  $\gamma$  were 0.34, 0.95, and 2.8, respectively. The prediction equation for percent maximum yield based on Mn concentration in the ear leaf was as follows:

$$Y = 0.965(1 - 2.8e^{-0.34X}),$$

where  $Y = \% \text{ maximum yield}$  and

$X = \text{mg Mn kg}^{-1}$  in the ear leaf.

The critical level of Mn in the ear leaf at the early silk growth stage, defined as the concentration at which a yield decrease of 10% or greater occurs, was  $10.8 \text{ mg kg}^{-1}$ . This value is very close to critical level of  $11 \text{ mg kg}^{-1}$  reported by Mascagni and Cox (1984).

The relationship between corn grain yield and Mn concentration in the corn ear leaf is shown in Figure 3. The same critical level,  $10.8 \text{ mg kg}^{-1}$ , and the same  $r$  value, ( $0.89$ ,  $p = 0.05$ ) were found for this relationship as compared with ear leaf Mn versus percent maximum yield. This was expected, because the only difference is in the  $\beta$  parameter, which is the asymptotic maximum as  $X$  approaches infinity. The  $\beta$  parameter was higher for actual yield than for

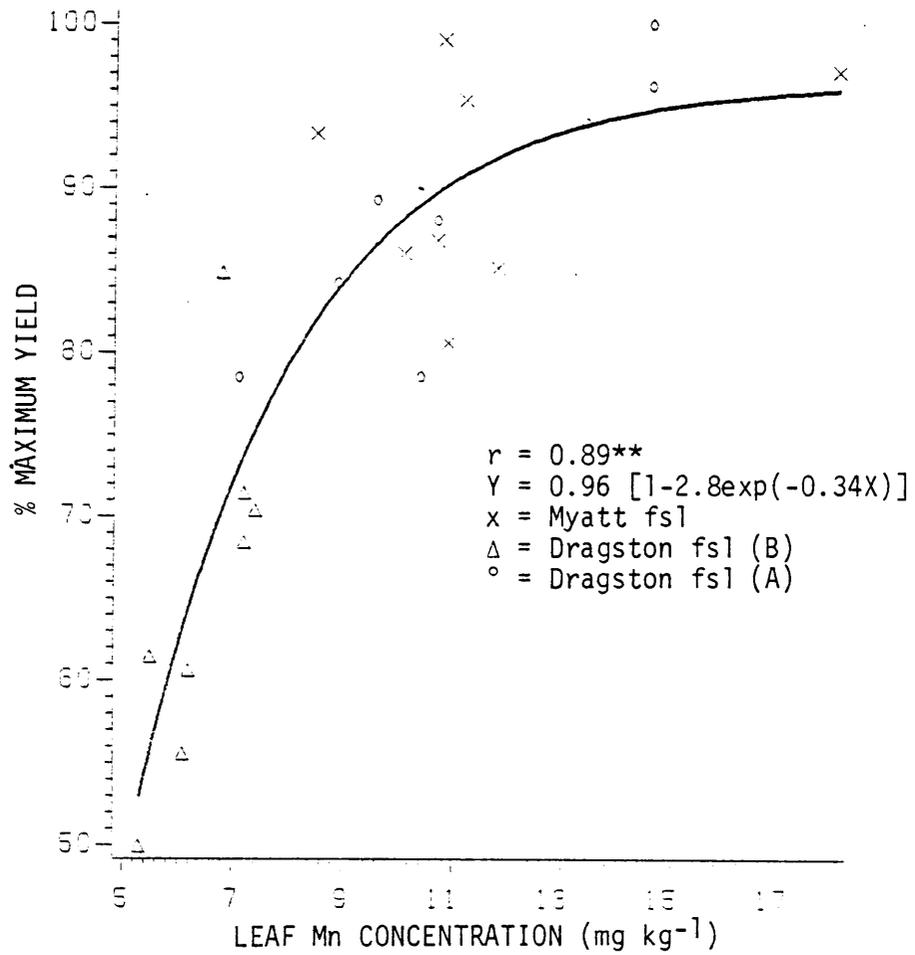


Figure 2. The relationship between percent maximum yield (Y) and Mn concentration in the ear leaf (X) at the early silk growth stage.

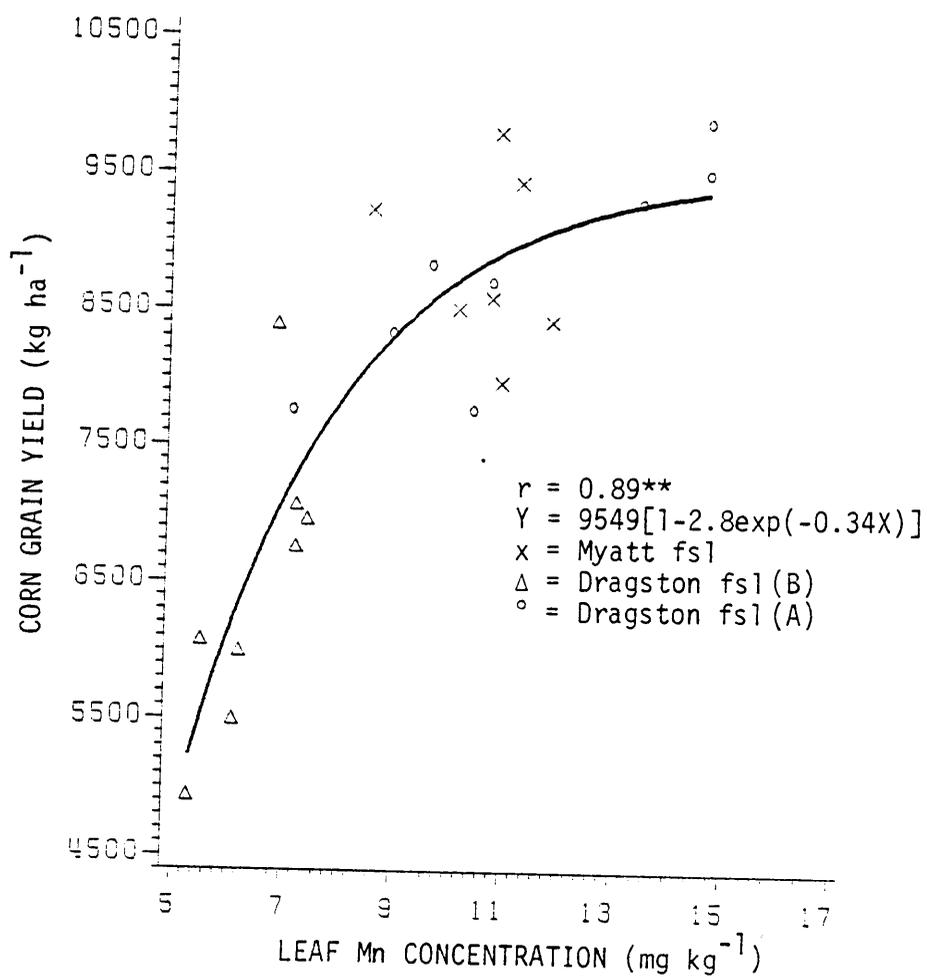


Figure 3. The relationship between corn grain yield (Y) and Mn concentration in the ear leaf (X) at the early silk growth stage.

percent maximum yield because the latter was a larger number.

Based on the relationships for ear leaf Mn and percent maximum grain yield (Fig. 2) and actual grain yield (Fig. 3), it is apparent that Mn deficiency of corn plants was not completely alleviated by Mn application on the Dragston (A) soil. Actual and percent maximum grain yield generally were lower on the Dragston (A) soil than on the Dragston (B) and Myatt soils. The Mn concentration in ear leaves (Table 3) from the + Mn treatment on the Dragston (A) soil was below the critical level of  $10.8 \text{ mg kg}^{-1}$  as determined by this research and of  $11 \text{ mg kg}^{-1}$  as determined by Mascagni and Cox (1984).

#### GRAIN YIELD VERSUS GRAIN MANGANESE

The relationship between percent maximum yield and the Mn concentration in corn grain was evaluated by the Mitscherlich plant growth model (Fig. 4). The same model was used to describe the relationship between corn grain yield and Mn concentration in corn grain (Fig. 5). The  $r$  value for the two equations was 0.58 ( $p = 0.05$ ). The parameters  $\alpha$  (constant of proportionality) and  $\gamma$  (accounts for the fact that when  $X = 0$ ,  $Y > 0$ ) had the same numerical values in the equations for percent maximum yield and actual yield. The

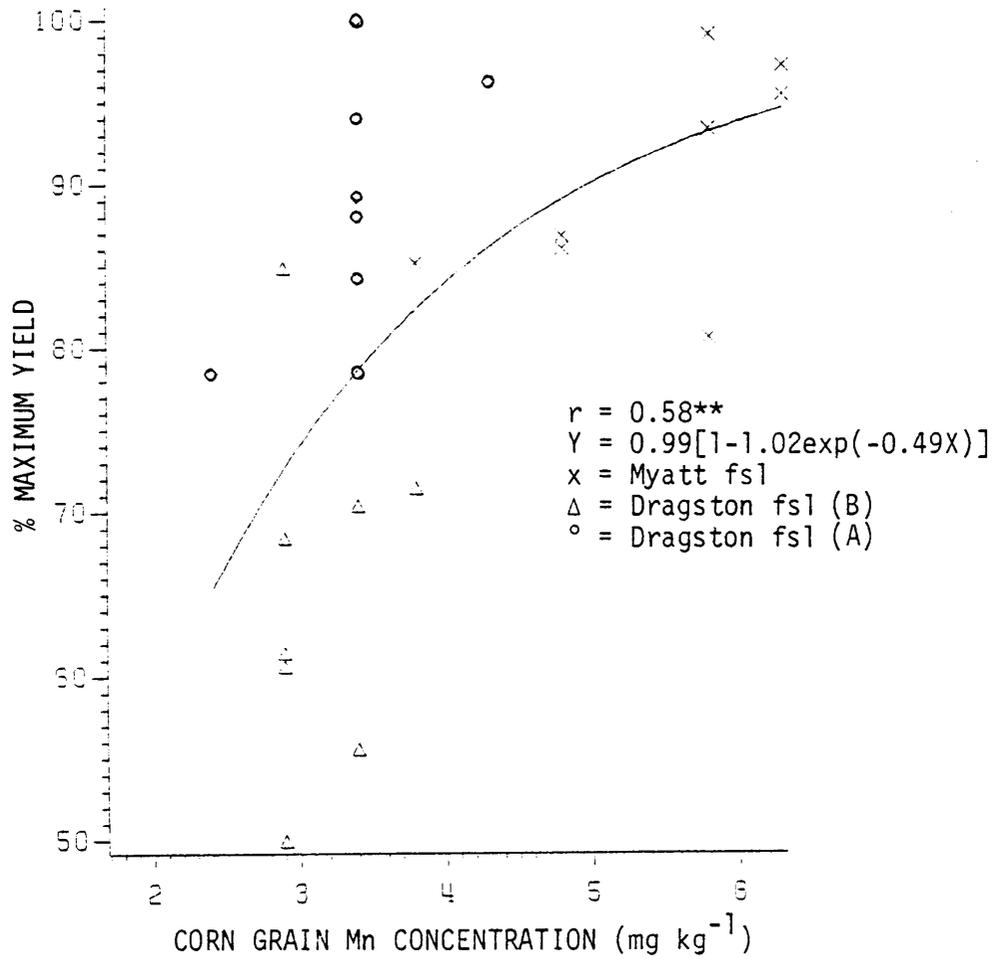


Figure 4. The relationship between percent maximum corn grain yield (Y) and Mn concentration in corn grain (X).

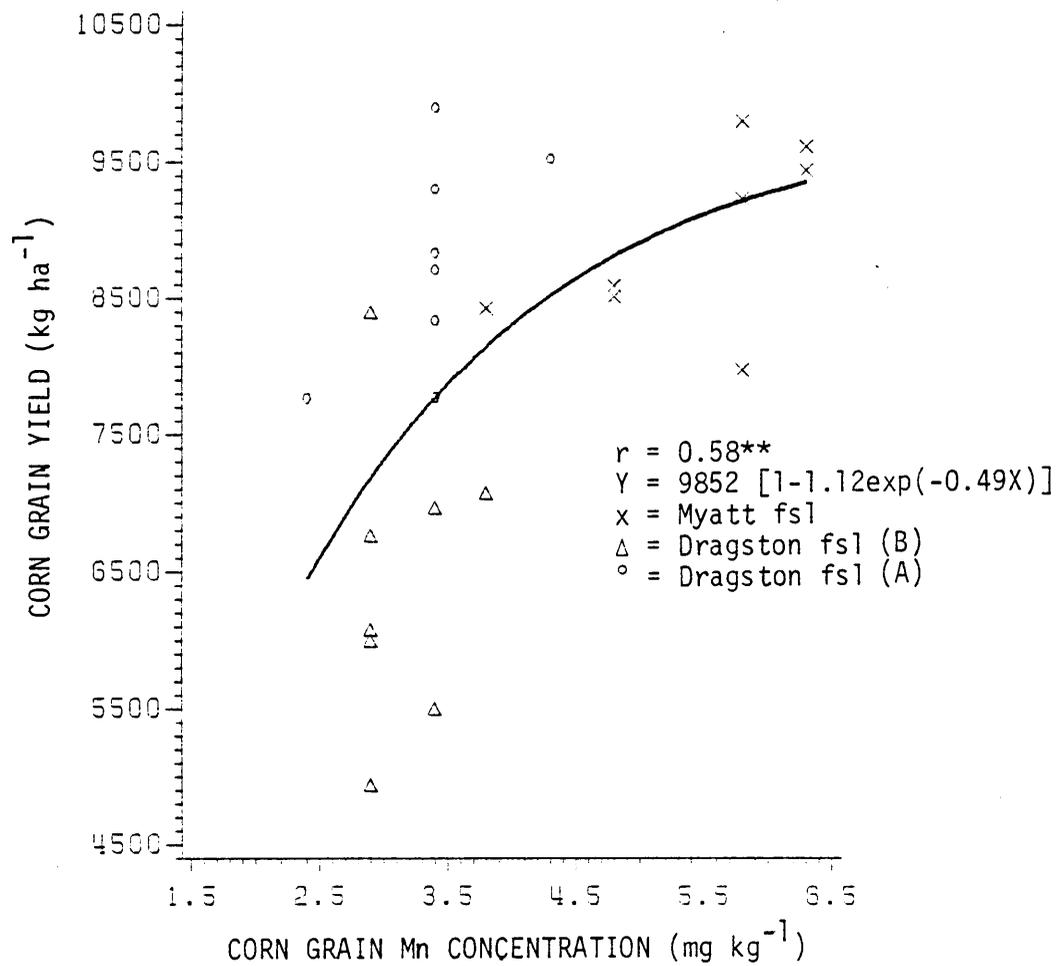


Figure 5. The relationship between corn grain yield (Y) and Mn concentration in corn grain (X).

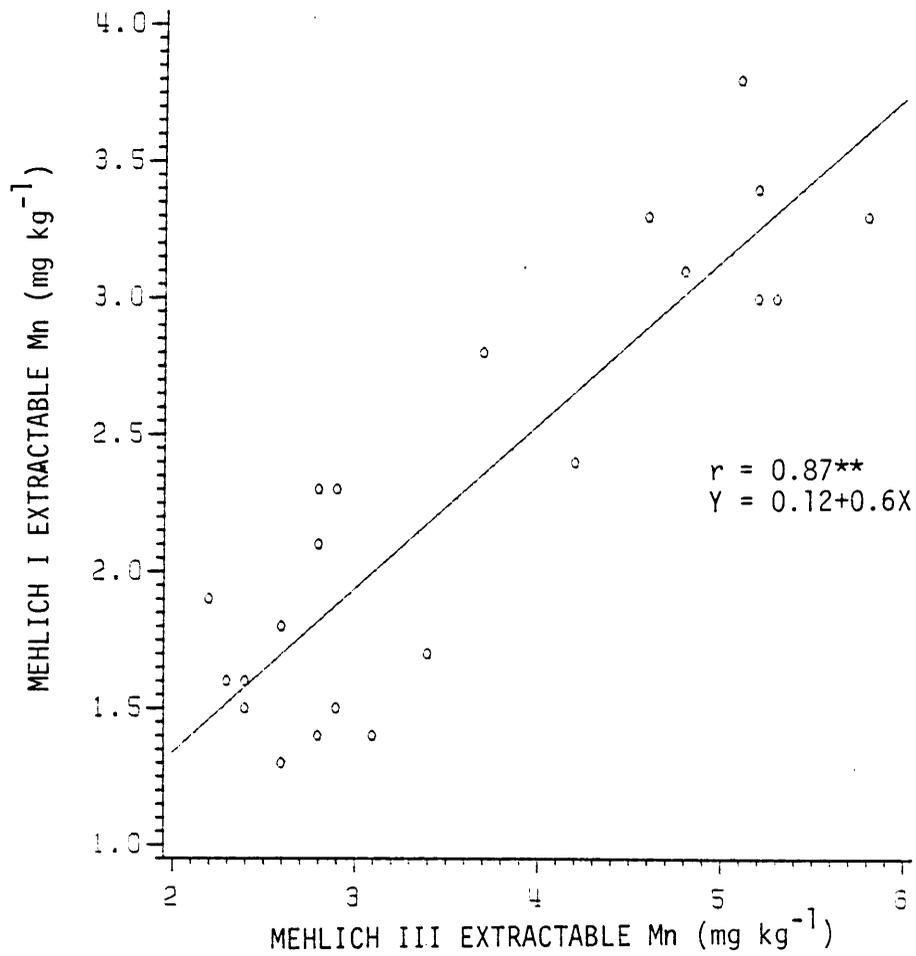


Figure 6. The relationship between Mehlich I (Y) and Mehlich III (X) extractable Mn.

only difference between the two equations was the value of  $\beta$  (asymptotic maximum). The critical Mn level for corn plants based on grain was  $4.9 \text{ mg kg}^{-1}$ . This critical Mn level is  $5.9 \text{ mg kg}^{-1}$  lower than that based on the ear leaf. For soybeans, however, the critical Mn level is higher when based on seeds than when based on blades from uppermost fully expanded trifoliolate leaves (Gettier et al., 1985).

#### MEHLICH I VERSUS MEHLICH III EXTRACTABLE MANGANESE

Mehlich I and Mehlich III extractable Mn were determined in soil from the Ap horizon of each plot of the three field experiments. Although almost twice as much Mn was extracted by the Mehlich III procedure, there was a close relationship ( $r = 0.87$ ,  $p = 0.001$ ) between the amounts of Mn extracted by the two procedures. The relationship between the amounts of Mn extracted by the two procedures (Fig. 6) is described by the following linear regression equation:

$$Y = 0.12 + 0.6X,$$

where Y = Mehlich I extractable Mn and

X = Mehlich III extractable Mn.

It was inappropriate to correlate extractable soil Mn with corn yield from this research because of the narrow range for either Mehlich I or Mehlich III extractable Mn in the experimental areas on the three soils (Table 2).

## SUMMARY

Very little is known about correction of Mn deficiency in corn. Even though corn is considered tolerant to low levels of Mn, it was suspected that a response to Mn application could be obtained on soils where Mn applications had increased soybean seed yields. Three field studies were conducted to evaluate the response of corn to band applied  $\text{MnSO}_4 \cdot \text{H}_2\text{O}$  and to determine critical Mn levels in corn based on ear leaf and grain samples. The Mitscherlich model was used to develop grain yield prediction equations based on the Mn concentrations in the corn tissues. A critical level  $10.8 \text{ mg Mn kg}^{-1}$  was obtained based on the concentration in the ear leaf versus percent maximum yield ( $r = 0.89$ ,  $p = 0.05$ ). The critical level based on Mn concentration in the corn grain versus percent maximum yield ( $r = 0.58$ ,  $p = 0.05$ ) was  $4.9 \text{ mg kg}^{-1}$ . These critical levels were based on 90% of maximum corn grain yield. Mehlich I extractable Mn correlated closely with Mehlich III extractable Mn ( $r = 0.87$ ,  $p = 0.05$ ) for the three soils under study. It should be pointed out, however, that the Mehlich III solution is a stronger Mn extractant than the Mehlich I solution and, therefore, that higher amounts of Mn were extracted by the former.

## LITERATURE CITED

- Alley, M. M., C. I. Rich, G. W. Hawkins, and D. C. Martens. 1978. Correction of manganese deficiency in soybeans. *Agron. J.* 70:35-38.
- Boswell, F. C., K. Ohki, M. B. Parker, L. M. Shuman, and D. O. Wilson. 1981. Methods and rates of applied manganese for soybeans. *Agron. J.* 73:904-912.
- Bremner, J. M., and M. A. Tabatabai. 1971. Use of automated combustion techniques for total carbon, total nitrogen, and total sulfur analysis of soils. p. 1-14. In L. M. Walsh (ed.) *Instrumental methods for analysis of soil and plant tissue.* Soil Science Society of America, Madison, WI.
- Cox, F. R. 1968. Development of a yield response prediction and manganese soil test interpretation for soybeans. *Agron. J.* 60:521-524.
- Donohue, S. J., and G. W. Hawkins. 1974. Sampling instructions and nutrient sufficiency ranges for plant tissue analysis. Extension Division, Virginia Polytechnic Institute and State University MA 211.
- Gettier, S. W., D. C. Martens, and S. J. Donohue. 1985. Soybean yield response prediction from soil test and tissue manganese levels. *Agron. J.* 77:63-67.
- Lucas, R. E., and B. D. Knezek. 1972. Climatic and soil conditions promoting micronutrient deficiencies in plants. p. 265-288. In J. J. Mortvedt, P. M. Giordano, and W. L. Lindsay (ed.) *Micronutrients in agriculture.* Soil Science Society of America, Madison, WI.
- Makarim, A. K., and F. R. Cox. 1983. Evaluation of the need for copper with several soil extractants. *Agron. J.* 75:493-496.
- Mascagni, H. J., and F. R. Cox. 1984. Diagnosis and correction of manganese deficiency in corn. *Commun. Soil Sci. Plant Anal.* 15:1323-1333.
- McKenzie, H. A., and H. S. Wallace. 1954. The Kjeldahl determination of N: a critical study of digestion conditions - temperature, catalyst and oxidizing agent. *Aust. J. Chem.* 7:55-70.

- Mehlich, A. 1957. Aluminum, iron, and pH in relation to lime induced manganese deficiencies. Soil Sci. Soc. Am. Proc. 21:625-628.
- Nelson, W. L., A. Mehlich, and E. Winters. 1953. The development, evaluation and use of soil tests for phosphorus availability. In W. H. Pierre and A. G. Norman (ed.) Soil and fertilizer phosphorus in crop nutrition. Agronomy 4:153-188. Academic Press, New York, NY.
- Ott, L. 1977. An introduction to statistical analysis. Duxburg Press, Boston, MA.
- Robertson, W. K., L. G. Thompson, and F. G. Martin. 1973. Manganese and copper requirements for soybeans. Agron. J. 65:641-644.
- SAS Institute Inc. 1982. SAS user's guide: statistics, 1982 edition, SAS Institute, Inc., Cary, NC.
- The Council on Soil Testing and Plant Analysis. 1980. Handbook on reference methods for soil testing. p. 1-130. 1111 Plant Sci. Bldg., Univ. of Georgia, Athens, GA.
- Ulrich, A., and F. J. Hills. 1976. Plant analyses as an aid in fertilizing sugar crops: Part 1. Sugar beets. p. 271-288. In Soil testing and plant analysis. L. M. Walsh and J. D. Beaton (ed.) American Society of Agronomy, Madison, WI.
- Ware, G. O., K. Ohki, and L. C. Moon. 1982. The Mitscherlich plant growth model for determining critical nutrient deficiency levels. Agron. J. 74:88-91.
- Woodruff, J. R. 1979. Soil test Mn, soybean leaf Mn and grain yields as influenced by rate and method of Mn fertilization. Agron. Abstr., American Society of Agronomy, Madison, WI. p. 186.

RESPONSE OF CORN TO BROADCAST MANGANESE SULFATE  
IN ATLANTIC COASTAL PLAIN SOILS

Manganese deficiencies of plants occur in soils of the Atlantic Coastal Plain region. In addition to the properties of these soils conducive to Mn deficiency, such as coarse texture and low water soluble Mn, limestone is sometimes overapplied and, hence, Mn deficiencies are induced on these soils. As pointed by Mehlich (1957), Mn deficiency is likely to develop where acidic soils are brought to a pH of 6.2 or above. Even though Mn deficiency in soybeans is very prevalent on Atlantic Coastal Plain soils in Virginia (Alley et al., 1978; Gettier et al., 1985), this deficiency has not been confirmed in corn on these soils.

Manganese deficiency of soybeans has been corrected on Atlantic Coastal Plain soils by broadcast applications of  $\text{MnSO}_4$  (Alley et al., 1978; Boswell et al., 1981; Cox, 1968, Gettier et al., 1985; Robertson et al., 1973; Woodruff, 1979). Higher rates of broadcast  $\text{MnSO}_4$  are needed to increase Mn concentration in corn tissues as compared with band applied  $\text{MnSO}_4$  (Mascagni and Cox, 1984). The lower efficiency of the broadcast applications as compared to band applications is due to the fact that the strongly acidic environment in the band increases the  $\text{Mn}^{2+}$  activity in solution. In addition, location of the banded Mn near the root

allows for a higher Mn uptake by plants during early growth stages. A residual effect often is obtained from broadcast  $\text{MnSO}_4$  but not from banded  $\text{MnSO}_4$  (Gettier et al., 1984). Yield responses of corn to broadcast  $\text{MnSO}_4$  were obtained by Mascagni and Cox (1984) on Atlantic Coastal Plain soils in North Carolina. The purpose of this study was to evaluate corn response to different rates of broadcast  $\text{MnSO}_4$  in two soils where soybean seed yields had been increased by correction of Mn deficiency.

## MATERIALS AND METHODS

Two experiments were conducted in farmer's fields during the 1984 growing season. The soils were selected based on previously reported Mn deficiency in soybeans. Classification and selected properties of the soils under study are shown in Table 5.

### FIELD EXPERIMENTATION

Five treatments applied to two soils were: 0, 6, 12, 18, and 24 kg Mn ha<sup>-1</sup> as MnSO<sub>4</sub>. The treatments were arranged in randomized complete block designs and replicated four times. One kg B ha<sup>-1</sup> as Borate 68, 10 kg Cu ha<sup>-1</sup> as CuSO<sub>4</sub>, and 25 kg Zn ha<sup>-1</sup> as ZnSO<sub>4</sub> were broadcast on the experimental areas of both sites. Gypsum was applied to the plots in different rates to compensate for the S applied for treatments as MnSO<sub>4</sub>. The amendments were disked into the two soils to a depth of approximately 10 cm. Corn populations at the two experimental sites were as follows: 51600 plants ha<sup>-1</sup> on the Slagle site and 39800 plants ha<sup>-1</sup> on the Dragston (C) site. The variety of corn grown on the Slagle soil was 'Pioneer 3707' and on the Dragston (C) soil was 'Northrup King PX74'.

## TISSUE ANALYSES

Twelve whole plants, about 30 cm tall, were sampled from guard rows of control plots at both sites. Ten ear leaf samples were obtained from each plot of the two field experiments at the early silk growth stage, and corn grain samples were collected at plant maturity. The plant tissues were oven dried at 70°C for 24 hours and ground to pass a 20-mesh stainless steel screen. Concentration of Cu, K, Mn, N, P, and Zn were determined in the tissue samples. For this purpose, one-g subsamples were ashed at 450°C for 2 hours. The ashes were dissolved in 0.5 M HCl for the Cu, Mn, and Zn analyses, whereas, the ashes were dissolved in 0.3 M HNO<sub>3</sub> for the P and K determinations. The cations were determined by atomic adsorption spectrophotometry and P by a vanadomolybdophosphoric acid method. Nitrogen in the tissue samples was determined by a microKjeldahl procedure (McKenzie and Wallace, 1954).

## SOIL ANALYSES

Soil samples, 12 cores/plot, were taken from the Ap horizon of each plot just before application of Mn treatments. The samples were dried at 105°C for 24 hours and ground to pass a 10-mesh stainless steel screen. Extractable Mn was determined by the Mehlich I (Nelson et al., 1953)

and Mehlich III procedures (Makarim and Cox, 1983). The soil for this test was measured on the volume basis, and a bulk density of  $1.25 \text{ g/cm}^3$  was used to convert values to the weight basis. The soil pH was determined in a 1:1 soil-to-water suspension after a 1-hour equilibration period. Organic matter was determined by a chromic acid oxidation procedure (The Council on Soil Testing and Plant Analysis, 1980).

#### STATISTICAL ANALYSES

Soil and plant tissue data were analyzed by analyses of variance and by linear and nonlinear regression procedures (Ott, 1977). Nonlinear regression analyses was used to explain the relationship between Mn content in the ear leaf and Mn content in the corn grain. For this purpose the Mitscherlich model was used as described by Ware et al. (1982). The SAS82 Statistical Analysis System was used to estimate the parameters for the Mitscherlich model and to compute the analyses of variance and regression statistics (SAS Institute Inc., 1982).

## RESULTS AND DISCUSSION

This research was conducted on two Atlantic Coastal Plain soils to determine the response of corn to broadcast  $\text{MnSO}_4$  applications. The pH levels in the Ap horizon of the two soils were 5.3 and 5.5, amounts of Mehlich I extractable Mn were 1.5 and 2.0  $\text{mg kg}^{-1}$  and of Mehlich III extractable Mn were 2.5 and 3.5  $\text{mg kg}^{-1}$ , and contents of organic matter were 16.7 and 23.8  $\text{g kg}^{-1}$  (Table 5).

Manganese concentrations in whole plants, approximately 30-cm tall, from control plots on the Dragston (C) and Slagle fine sandy loams were 25.4 and 26.8  $\text{mg kg}^{-1}$ , respectively. These levels were below the Mn sufficiency range of 30-300  $\text{mg kg}^{-1}$  proposed by Donohue and Hawkins (1974). However, the Mn concentrations in whole plants were two to three times higher for these broadcast studies than for plants where banded Mn increased corn grain yield (Table 3).

### BROADCAST MANGANESE VERSUS EXTRACTABLE MANGANESE

The amount of Mn extracted by the Mehlich I and III procedures from the Dragston (C) and Slagle soils increased with rate of broadcast Mn application (Tables 6 and 7). A linear correlation analysis was performed between Mehlich I and Mehlich III extractable Mn (Fig. 7). Data from each

Table 5. Classification and selected properties of the two soils under study.

Series	Texture	Soil Taxonomy	Soil pH	Organic Matter g kg <sup>-1</sup>	Extractable Mn	
					Mehlich I	Mehlich III
Dragston (C)	fsl	Aeric Ochraqults; coarse-loamy, mixed, thermic	5.5	16.7	2.0	3.5
Slagle	fsl	Aquic Hapludults; fine-loamy, siliceous, thermic	5.3	23.8	1.5	2.5

Table 6. Manganese concentrations in soil and plant tissue and corn grain yields as affected by broadcast application of Mn in two soils.†

Broadcast Mn kg ha <sup>-1</sup>	Soil pH	Extractable Mn		Mn Concentrations		Corn Grain Yield kg ha <sup>-1</sup>
		Mehlich I	Mehlich III	Ear leaf	Grain	
----- mg kg <sup>-1</sup> -----						
<u>Dragston (C) fine sandy loam</u>						
0	5.5	2.0	3.5	10.9	2.6	9130
6	5.5	2.8	5.0	11.3	3.4	9400
12	5.5	4.0	6.8	12.0	3.1	9260
18	5.6	3.8	7.3	14.0	3.5	8980
24	5.5	4.1	7.8	15.0	2.9	8920
<u>Slagle fine sandy loam</u>						
0	5.3	1.5	2.4	20.0	6.3	8490
6	5.3	2.6	4.4	38.4	6.6	8790
12	5.3	2.4	5.2	52.3	6.2	8800
18	5.4	3.8	6.7	56.5	6.7	9120
24	5.4	4.3	7.7	48.9	6.6	9700

†Each value represents the average of four replications.

Table 7. Coefficients of simple correlation for relationships between broadcast Mn rates, Mn concentrations in corn tissue and grain yield for two soils.

Variables†	Coefficient of Simple Correlation	
	Dragston (C) fs1	Slagle fs1
Mehlich I ext. Mn, Broadcast Mn rate	0.37*	0.90**
Mehlich III ext. Mn, Broadcast Mn rate	0.42*	0.93**
Ear leaf Mn, Mehlich I ext. Mn	0.70*	0.58*
Ear leaf Mn, Mehlich III ext. Mn	0.70**	0.51+
Grain Mn, Mehlich I ext. Mn	0.20	0.22
Grain Mn, Mehlich III ext. Mn	0.15	0.18
Grain Yield, Mehlich I ext. Mn	0.13	0.24
Grain Yield, Mehlich III ext. Mn	0.13	0.24

†Units are  $\text{mg kg}^{-1}$  for extractable Mn, ear leaf Mn, and grain Mn and  $\text{kg ha}^{-1}$  for grain yield.

+, \*, \*\*The coefficients of simple correlation are significant at the 0.1, 0.05 and 0.01 probability levels, respectively.

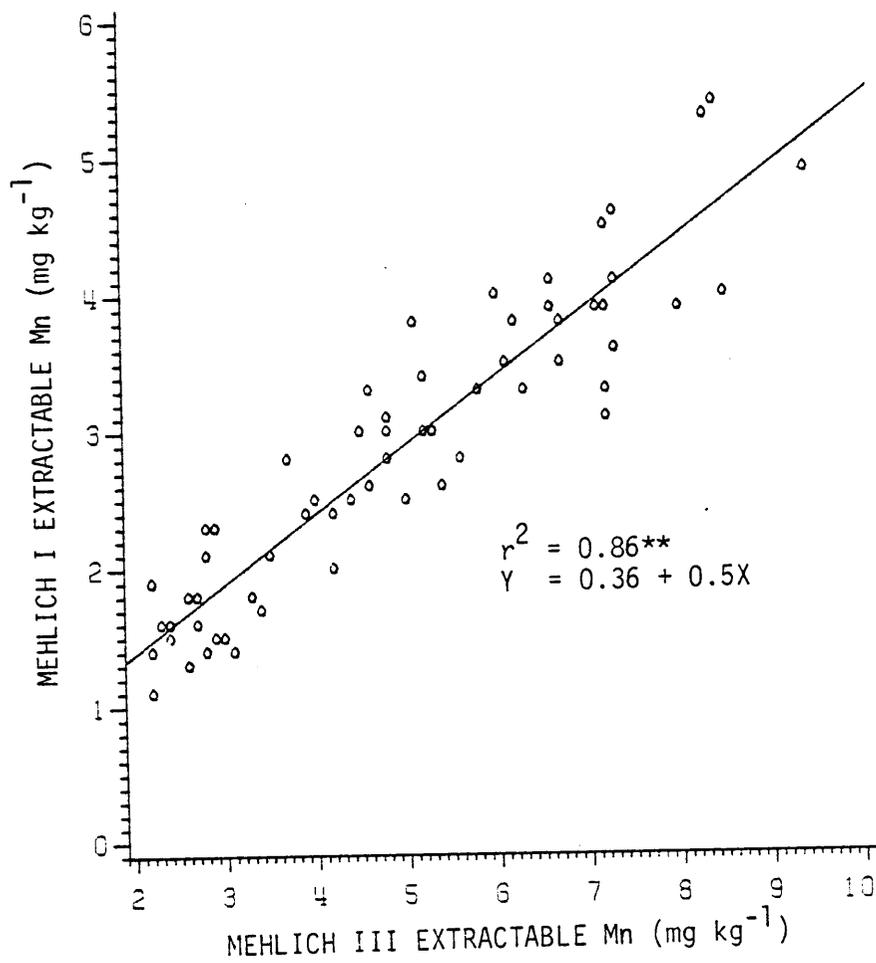


Figure 7. The relationship between Mehlich I (Y) and Mehlich III (X) extractable Mn.

plot of the three band studies (Table 2) and from each plot of the broadcast studies on the Dragston (C) and Slagle soils were included in the linear correlation analyses. A high linear association was obtained ( $r^2 = 0.86$ ,  $p = 0.01$ ) between Mehlich I and Mehlich III extractable Mn for the five soils. The amount of Mehlich III extractable Mn was consistently higher than the amount of Mehlich I extractable Mn in the soils.

#### EXTRACTABLE MANGANESE VERSUS EAR LEAF MANGANESE

Manganese concentrations in ear leaves increased with an increase in either Mehlich I and Mehlich III extractable Mn (Table 6). The  $r^2$  values for the relationships between Mehlich I extractable Mn and Mn concentration in the corn ear leaf were  $r = 0.70$  ( $p = 0.05$ ) and  $0.58$  ( $p = 0.05$ ) for the Dragston (C) and Slagle soils, respectively (Table 7). The relationship between Mehlich III extractable Mn and Mn concentration in the ear leaf were  $r = 0.70$  ( $p = 0.01$ ) and  $0.51$  ( $p = 0.10$ ) for the Dragston (C) and Slagle soils, respectively (Table 7).

Soil acidity has a large effect on Mn availability (Ponnamperuma et al., 1969). The variable soil pH has been included in prediction equations for Mn uptake, and the inclusion of this variable has improved the prediction capa-

bilities of the equations (Mascagni and Cox 1984). Multiple regression analyses were conducted with soil pH and extractable Mn as independent variables to predict Mn concentration in the corn ear leaves. The multiple regression equations for the Dragston soil were as follows:

$$Y = 33.3 + 1.6 M_1 - 4.7 \text{ pH} \quad (r^2 = 0.61, p = 0.01) \text{ and}$$

$$Y = 37.0 + 1 M_3 - 5.7 \text{ pH} \quad (r^2 = 0.68, p = 0.01).$$

For the Slagle soil, the multiple regression equations for prediction of Mn concentration in corn ear leaf were as follows:

$$Y = 64.7 + 10.2 M_1 - 9.7 \text{ pH} \quad (r^2 = 0.31, p = 0.05) \text{ and}$$

$$Y = 95.7 + 4.9 M_3 - 14.7 \text{ pH} \quad (r^2 = 0.29, p = 0.05).$$

For these equations,  $Y$  = Mn concentration in the ear leaf at the early silk growth stage in  $\text{mg kg}^{-1}$ ,  $M_1$  = Mehlich I extractable Mn in  $\text{mg kg}^{-1}$ , and  $M_3$  = Mehlich III extractable Mn in  $\text{mg kg}^{-1}$ . The coefficients for the regression equations indicate that Mn uptake from the two soils increased with an increase in either Mehlich I or III extractable Mn and with a decrease in soil pH.

The relationships between ear leaf Mn and Mehlich I and III extractable Mn in the Dragston (C) and Slagle soils are shown in Fig. 8 and 9. Manganese uptake increased at a greater rate at a constant level of Mehlich I or III extractable Mn for the Slagle soil (pH 5.3) than for the Dragston

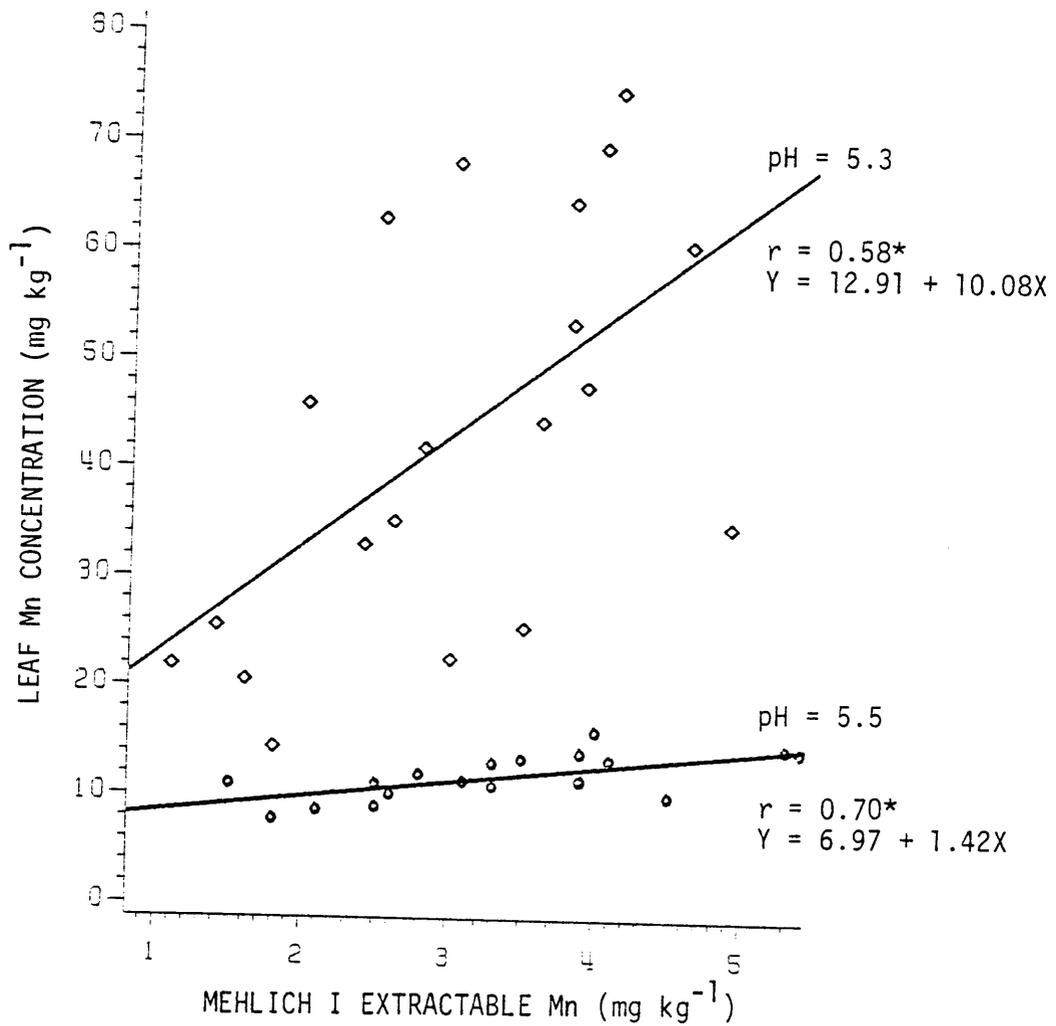


Figure 8. The relationship between Mehlich I extractable Mn (X) and Mn concentration in the ear leaf (Y) for the Dragston (°) and the Slagle (Δ) soil.

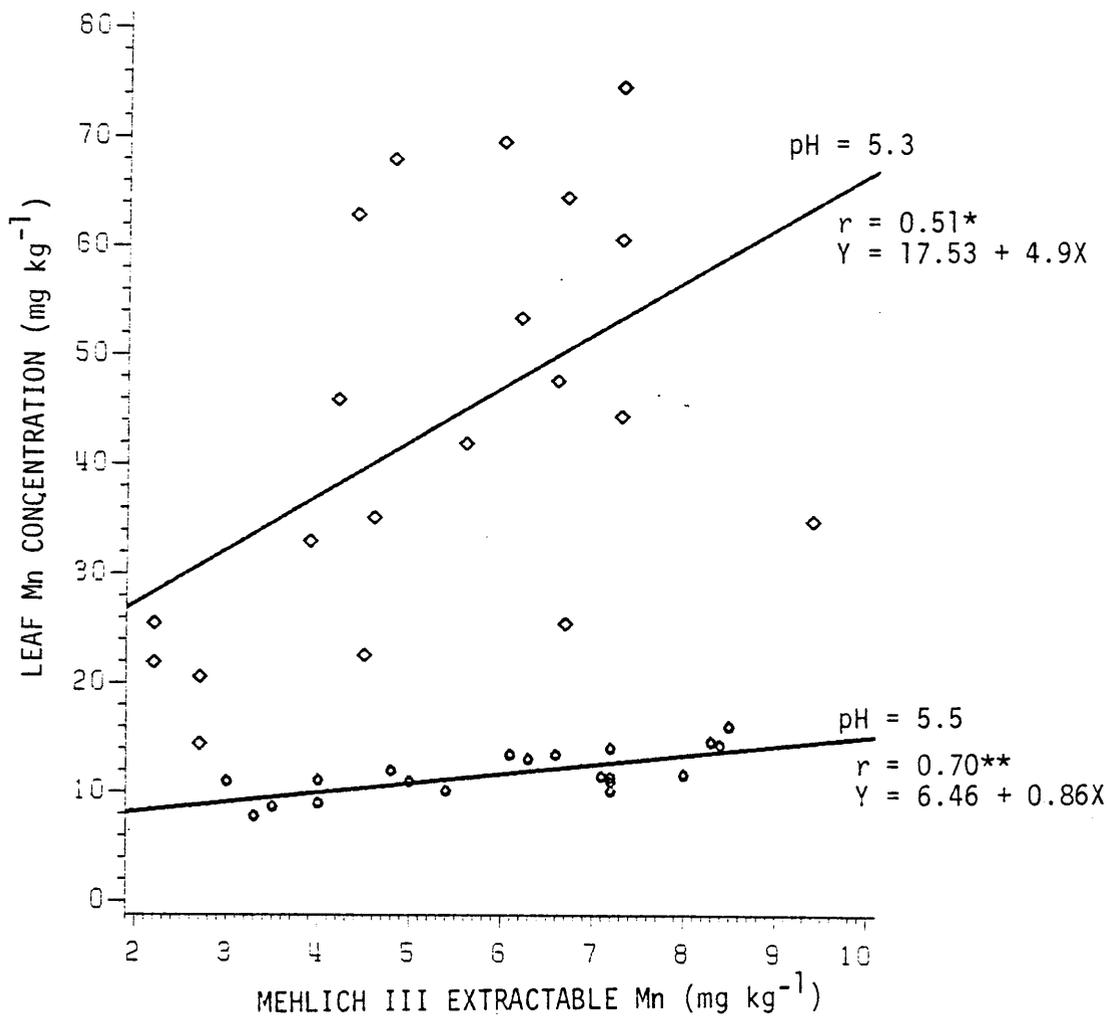


Figure 9: The relationship between Mehlich III extractable Mn (X) and Mn concentration in the ear leaf (Y) for the Dragston (C) soil and (○) and the Slagle (Δ) soil.

(C) soil (pH = 5.5). It is evident that, for the Slagle soil, Mn levels in the ear leaves were above the critical level,  $10.8 \text{ mg kg}^{-1}$ , as determined in the band studies, even at the lower levels of soil extractable Mn (Fig. 8 and 9). For the Dragston soil (pH = 5.5), the Mn levels in ear leaves were very close to the critical level and the rate of increase in Mn uptake with level of extractable Mn was lower than for the Slagle soil (pH = 5.3). This indicates that higher rates of Mn should be applied in less acidic soils to bring Mn tissue levels above the threshold of Mn deficiency. The fact that a difference of two decimal units in soil pH is sufficient to affect Mn uptake by plants (Fig. 8 and 9) suggests that this parameter must be determined as precisely as possible for diagnosis of Mn deficiency.

#### EXTRACTABLE MANGANESE VERSUS GRAIN MANGANESE

Levels of Mn in corn grain were not affected by increases in extractable Mn in the Dragston (C) and Slagle soils due to broadcast Mn application (Tables 6 and 7). The Mn concentrations in corn grain from all treatments on Dragston (C) soil were lower than the critical level of  $4.9 \text{ mg kg}^{-1}$ . This is evidence that the broadcast Mn did not correct Mn deficiency of corn plants on this soil.

## CORN GRAIN YIELD VERSUS EAR LEAF MANGANESE

Even though the analysis of variance indicated a non-significant difference in corn grain yield on the Dragston (C) soil, the simple correlation coefficient for the relationship between corn grain yield and ear leaf Mn was  $r = 0.59$  ( $p = 0.12$ ). This correlation coefficient suggests that there is a trend in this experiment toward a yield increase with an increase in Mn concentration in the ear leaf (Fig. 10). This trend indicates the possibility that the broadcast Mn did not completely correct Mn deficiency of corn on the Dragston (C) soil. For the Slagle soil, however, the association between grain yield and ear leaf Mn concentration was very low ( $r^2 = 0.2$ ) and is non-significant at any meaningful statistical level (Table 7). The lack of association between corn grain yield and ear leaf Mn concentration on the Slagle fine sandy loam indicates that the broadcast Mn application did not increase corn grain yield on the soil. This would be expected because the ear leaf Mn concentrations were above the threshold level for Mn deficiency. The Cu, K, N, P and Zn concentrations (Table 8) were within the respective critical ranges (Jones, 1972) and, consequently, it can be concluded that these nutrients were adequate for high corn grain yields on the two soils.

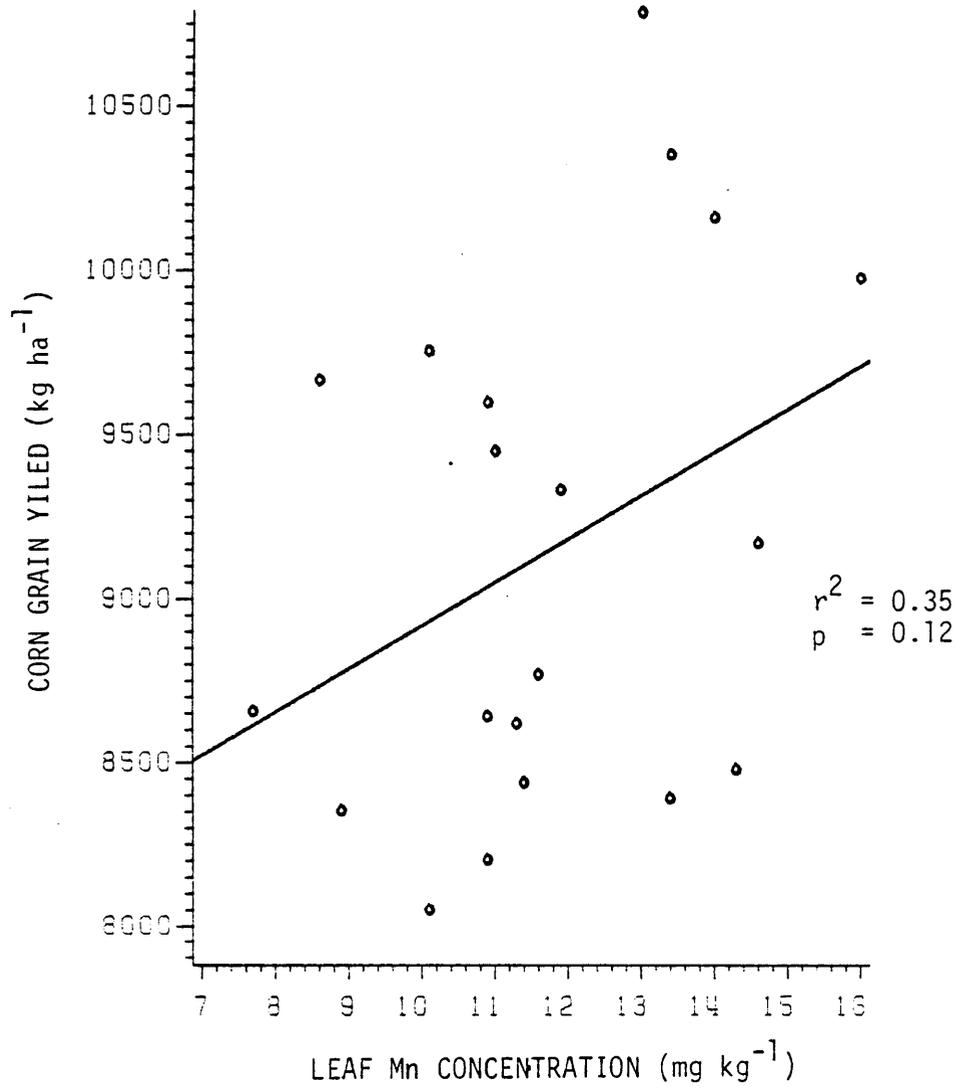


Figure 10. The relationship between Mn concentrations in the ear leaf (X) and corn grain yield (Y) on the Dragston (C) fine sandy loam.

Table 8. Nutrient concentration in corn ear leaves at the early silk growth stage as affected by broadcast Mn application on two soils.

Treatment kg ha <sup>-1</sup>	Ear leaf nutrient concentrations†				
	N	P	K	Cu	Zn
	----- gm kg <sup>-1</sup> -----			-- mg kg <sup>-1</sup> ---	
	<u>Dragston (C) fine sandy loam</u>				
0	30.6	2.9	17.7	11.4	46.6
6	29.6	2.8	18.7	11.3	44.5
12	29.4	2.7	19.2	10.6	45.0
18	29.4	2.6	17.9	10.1	44.7
24	29.0	2.8	16.7	11.1	45.8
	<u>Slagle fine sandy loam</u>				
0	28.2	3.2	20.7	10.9	55.4
6	30.5	3.3	20.7	12.5	55.3
12	28.0	3.2	21.2	11.4	63.1
18	27.5	3.2	20.6	11.5	61.0
24	28.7	3.2	20.9	11.6	60.5

†Each value represents the average of four replications.

## CORN GRAIN YIELD VERSUS CORN GRAIN MANGANESE

The differences between yields on the Dragston (C) and Slagle soils could not be explained by variations in the Mn concentrations in corn grain. The coefficients of correlation between corn grain yield and Mn content in the corn grain were very low at both sites (Table 7). For the Slagle site, the Mn content in the corn grain was above the critical level of  $4.9 \text{ mg kg}^{-1}$ . The lack of association between yield and Mn concentration in the corn grain, as in the case of ear leaves, was probably due to luxury consumption of Mn by corn plants from this soil. For the Dragston site, the concentrations of Mn in corn grain were below the critical level of  $4.9 \text{ mg kg}^{-1}$ . These low levels of Mn in corn grain are evidence that Mn deficiency of corn occurred on the Dragston (C) soil and that the various rates of broadcast Mn did not correct the deficiency.

## EXTRACTABLE MANGANESE VERSUS CORN GRAIN YIELD

Even though Mehlich I and Mehlich III extractable Mn used as independent variables with pH in polynomial regression equations explained Mn uptake from the Dragston (C) and Slagle fine sandy loams, these independent variables in polynomial regression equations were not related to corn grain yields on the two soils. Both Mehlich I and III extractable

Mn were higher in the Dragston soil than in the Slagle soil. However, Mn uptake was lower and grain yield was higher for the Dragston soil (Table 6). This anomaly reflects the lower pH in the latter soil (Table 6).

#### EAR LEAF MANGANESE VERSUS GRAIN MANGANESE

The Mitscherlich plant growth model was used to describe the relationship between concentrations of Mn in corn ear leaves and grain. Data from all plots of the band studies and from all plots on the Dragston (C) and Slagle soils were used to establish this relationship. A close association was obtained ( $r^2 = 0.96$ ,  $p = 0.01$ ) between the two variables (Fig. 11). The relationship was described by the following equation:

$$Y = 7.1 (1 - 0.85e^{-0.055X}),$$

where Y = Mn concentration in the corn grain and X = Mn concentration in the ear leaf. Manganese concentrations in the corn grain increased with an increase in Mn concentration in the ear leaf up to  $7.1 \text{ mg kg}^{-1}$  (asymptotic value in the equation) and then became constant. The shape of the line of best fit (Fig. 11) indicates that the Mn concentration in the ear leaf would be a better indicator of the amount of uptake Mn than Mn concentration in corn grain. It also can be concluded, based on the line of best fit between the va-

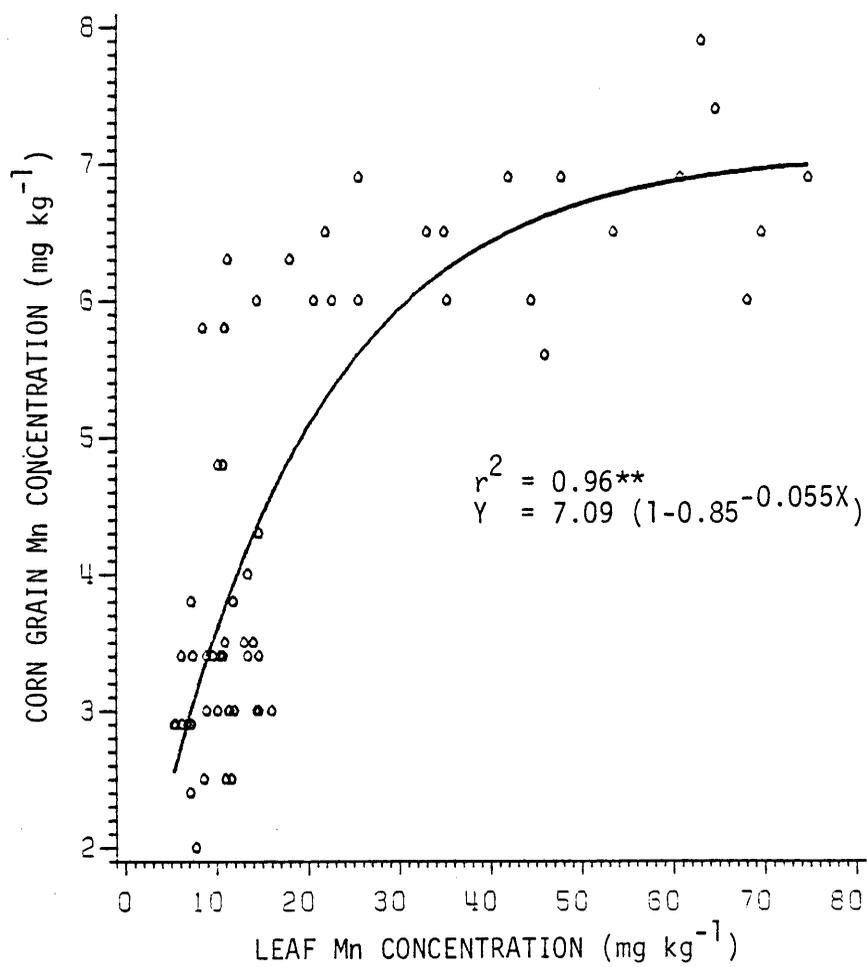


Figure 11. The relationship between Mn concentrations in the corn ear leaf (X) and grain (Y).

riables, that toxic levels of Mn in plant tissue would be difficult to detect based corn grain analyses.

## SUMMARY

Manganese deficiencies in corn were suspected to occur in corn on soils where Mn applications had previously increased soybean seed yields. Two studies were conducted on Atlantic Coastal Plain soils, on which Mn application had increased soybean yields, to evaluate the response of corn to different rates of broadcast  $\text{MnSO}_4$  applications. Five treatments ranging from 0 to 24 kg Mn  $\text{ha}^{-1}$  were applied to Dragston and Slagle fine sandy loams. Manganese concentrations in ear leaves from plants on both soils increased with increases in Mehlich I or III extractable Mn. The Mn concentrations in the corn grain, however, were less sensitive to increasing amounts of extractable Mn. Multiple regression analysis indicated that soil extractable Mn and soil pH were the two most important factors related to Mn uptake by corn plants under field conditions. Grain yield responses to broadcast Mn were not obtained on either soil. The lack of response on the Dragston soil was explained by the fact that the deficiency was not completely corrected by the broadcast Mn as indicated by the low levels of Mn in the tissue. The opposite occurred on the Slagle soil where the Mn uptake was so high, that the Mn concentrations in the tissue were above critical levels, even where Mn was not applied.

## LITERATURE CITED

- Alley, M. M., C. I. Rich, G. W. Hawkins, and D. C. Martens. 1978. Correction of manganese deficiency in soybeans. *Agron. J.* 70:35-38.
- Boswell, F. C., K. Ohki, M. B. Parker, L. M. Shuman, and D. O. Wilson. 1981. Methods and rates of applied manganese for soybeans. *Agron. J.* 73:904-912.
- Donohue, S. J., and G. W. Hawkins. 1974. Sampling instructions and nutrient sufficiency ranges for plant tissue analysis. Extension Division, Virginia Polytechnic Institute and State University MA 211.
- Gettier, S. W., D. C. Martens, D. L. Hallock, and M. J. Stewart. 1984. Residual Mn and associated soybean yield response from  $MnSO_4$  application on a sandy loam soil. *Plant Soil* 81:101-110.
- Gettier, S. W., D. C. Martens, and S. J. Donohue. 1985. Soybean yield response prediction from soil test and tissue manganese levels. *Agron. J.* 77:63-67.
- Jones, J. B. 1972. Plant tissue analysis for micronutrients p. 319-346. In J. J. Mortvedt, P. M. Giordano, and W. L. Lindsay (ed.) *Micronutrients in agriculture*. Soil Science Society of America, Madison, WI.
- Makarim, A. K., and F. R. Cox. 1983. Evaluation of the need for copper with several soil extractants. *Agron. J.* 75:493-496.
- Mascagni, H. J., and F. R. Cox. 1984. Diagnosis and correction of manganese deficiency in corn. *Commun. Soil Sci. Plant Anal.* 15:1323-1333.
- McKenzie, H. A., and H. S. Wallace. 1954. The Kjeldahl determination of N: a critical study of digestion conditions - temperature, catalyst and oxidizing agent. *Aust. J. Chem.* 7:55-70.
- Mehlich, A. 1957. Aluminum, iron, and pH in relation to lime induced manganese deficiencies. *Soil Sci. Soc. Am. Proc.* 21:625-628.

- Nelson, W. L., A. Mehlich, and E. Winters. 1953. The development, evaluation and use of soil tests for phosphorus availability. In W. H. Pierre and A. G. Norman (ed.) Soil and fertilizer phosphorus in crop nutrition. Agronomy 4:153-188. Academic Press, New York, NY.
- Ott, L. 1977. An introduction to statistical analysis. Duxburg Press, Boston, MA.
- Ponnamperuma, F. N., T. A. Loy, and E. M. Tianco. 1969. Redox equilibria in flooded soils. II. The manganese oxide systems. Soil Sci. 108:48-57.
- Robertson, W.K., L. G. Thompson, and F. G. Martin. 1973. Manganese and copper requirements for soybeans. Agron. J. 65:641-644.
- SAS Institute Inc. 1982. SAS user's guide: statistics, 1982 edition, SAS Institute, Inc., Cary, NC.
- The Council on Soil Testing and Plant Analysis. 1980. Handbook on reference methods for soil testing. p. 1-130. 1111 Plant Sci. Bldg., Univ. of Georgia, Athens, GA.
- Ware, G. O., K. Ohki, and L. C. Moon. 1982. The Mitscherlich plant growth model for determining critical nutrient deficiency levels. Agron. J. 74:88-91.
- Woodruff, J. R. 1979. Soil test Mn, soybean leaf Mn and grain yields as influenced by rate and method of Mn fertilization. Agron. Abstr., American Society of Agronomy, Madison, WI. p. 186.

## CONCLUSIONS

The response of corn to Mn applications was evaluated on five field experiments located in the Atlantic Coastal Plain region. Broadcast and band applications of Mn were evaluated in the field experiments. Laboratory analyses were conducted to estimate the concentration of various nutrients in soil and plant tissue. Statistical analyses were conducted to determine effects of Mn application on corn grain yield and to establish relationships between various soil and plant parameters. Specific conclusions reached during the course of this research are summarized as follows:

1. Band applied  $\text{MnSO}_4 \cdot \text{H}_2\text{O}$  increased corn grain yields on three soils. The mean increase in yield was 960 kg of corn grain  $\text{ha}^{-1}$ . These yield responses were associated with very low levels of extractable soil Mn and with soil pH values above 5.7.
2. Corn grain yields were not increased by broadcast application of up to 24 kg Mn  $\text{ha}^{-1}$  as  $\text{MnSO}_4$  on two soils. Where band Mn application increased corn grain yields on three soils, Mn concentrations in young corn plants from control treatments contained from 8.0 to 14.8 mg  $\text{kg}^{-1}$ . In contrast, young corn

plants from controls where broadcast Mn did not increase grain yields on two soils contained from 25.4 to 26.8 mg Mn kg<sup>-1</sup>. The young plants sampled for the Mn determination were approximately 30 cm tall.

3. The critical level for Mn deficiency in the ear leaf at the early silk growth stage was determined to be 10.8 mg kg<sup>-1</sup>. To establish this critical level, the Mitscherlich plant growth model was used and 90% of maximum yield was taken as the threshold for Mn deficiency.
4. A critical level for Mn deficiency based on the Mn concentration in the corn grain was determined with the Mitscherlich plant growth model. It was found that a decrease in grain yield of 10% or more occurred at Mn concentrations levels in the corn grain below 4.9 mg kg<sup>-1</sup>.
5. Manganese concentrations in corn grain tended to increase with increases in Mn concentration in the ear leaf up to 7.1 mg kg<sup>-1</sup> and then became constant. This indicates the presence of a mechanism to control the translocation of Mn into the grain.
6. Manganese concentrations in the ear leaf were a better predictor of corn grain yields than the Mn

concentrations in the corn grain. This was evidenced by the better fit of the Mistcherlich model when Mn ear leaf levels were correlated with yields.

7. Higher levels of extractable Mn favored a higher Mn uptake; however, the effect was more pronounced with a decrease in soil pH.
8. Mehlich I and III extractions solutions were used to estimate available soil Mn. The amounts of Mn extracted by the two solutions were highly correlated. However, the Mehlich III extractant was a stronger solution and, therefore, extracted almost 50% more Mn than the Mehlich I extractant.

**The vita has been removed from  
the scanned document**

RESPONSE OF CORN TO MANGANESE  
APPLICATION ON ATLANTIC  
COASTAL PLAIN SOILS

by

Eduardo Uribe B.

Committee Co-chairmen: David C. Martens and Daniel E. Brann  
Agronomy

(ABSTRACT)

Although corn plants are tolerant of low levels of available soil Mn, Mn deficiencies in corn were suspected on soils where Mn applications had previously increased soybean seed yields. Five experiments were conducted in farmer's fields to evaluate the response of corn to Mn applications. Three band Mn and two broadcast Mn studies were conducted in five field experiments on Atlantic Coastal Plain soils. The mean increase in corn grain yield in the band studies on three soils was 960 kg ha<sup>-1</sup>. Corn grain yields were not increased in the broadcast Mn studies on Slagle and Dragston fine sandy loams. Manganese uptake from the Slagle soil was so high that Mn deficiency did not occur; whereas, Mn uptake from the Dragston soil was so low that the deficiency was not completely corrected by up to 24 kg Mn ha<sup>-1</sup> as broadcast MnSO<sub>4</sub>. The critical level for the Mn

concentration in the ear leaf at the early silk growth stage was  $10.8 \text{ mg kg}^{-1}$  and for corn grain was  $4.9 \text{ mg kg}^{-1}$ . These critical levels were based on the Mitscherlich plant growth model and on 90% of maximum corn grain yield. Manganese uptake by corn plants increased with an increase in either Mehlich I or III extractable Mn and with a decrease in soil pH. Manganese concentration in corn grain was less sensitive to an increase in amounts of extractable Mn, as compared with the Mn concentration in ear leaves. The Mn concentration in corn grain increased with an increase in Mn concentration in the ear leaf up to  $7.1 \text{ mg kg}^{-1}$  and then became constant. Mehlich I and Mehlich III extractable Mn were highly correlated, but the Mehlich III procedure extracted almost twice as much Mn as the Mehlich I procedure.