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EFFECT OF BORON, MANGANESE AND FERTILIZERS ON YIELD, QUALITY AND NUTRITION OF SUGARBEETS (Beta vulgaris L.)

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EFFECT OF BORON, MANGANESE AND FERTILIZERS ON YIELD, QUALITY AND NUTRITION OF SUGARBEETS (BETA VULGARIS L.)

By

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ABSTRACT

EFFECT OF BORON, MANGANESE AND FERTILIZERS ON YIELD, QUALITY AND NUTRITION OF SUGARBEETS (BETA VULGARIS L.)

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The occurrence of B deficiencies on sugarbeets (Beta vulgaris L.) has gone from frequent to nonexistant over the past four decades. The two possible reasons for this are the use of improved varieties, and the increased use of B fertilizers with a subsequent buildup of soil B levels. The boron studies were designed to test the responsiveness of an open pollinated multigerm variety (Sp 633269-0) to the currently used monogerm hybrid variety (US H20), and to test the effect of soil and foliar applied B on the yield, quality and B concentration of sugarbeets.

The two varieties were not found to respond differently to applied B. In the soil applied boron studies, 2-4 kg B/ha was found to produce the highest yields. Plant B concentrations were found to reflect treatment. No response was found to foliar applied B.

Mn deficiencies occur sporadically on sugarbeets even though Mn fertilizers are commonly used. Environment, fertilizer source and placement and Mn source have all been implicated as affecting Mn availability. The Mn studies were designed to determine the effects of Mn and fertilizer source, Mn and fertilizer band placement, N-Mn interactions and foliar applied Mn on the yield, quality and Mn nutrition of sugarbeets. Laboratory, greenhouse and field studies were used.

In a soil-fertilizer incubation study, banded fertilizer depressed band pH and increased extractable Mn after three weeks. At a seven week sampling, the level of extractable Mn had decreased markedly even though the pH levels remained depressed. Band pH was significantly correlated with 0.1 $\underline{N}$ H_3PO_4 extractable Mn but not with DTPA extractable Mn.

Banded monocalcium phosphate and banded Mn both increased extractable and plant available Mn in a greenhouse study, however, the greatest availability was produced when the fertilizer and Mn were banded together. Plant available Mn was found to be more highly correlated with 0.1 $\underline{N}$ H_3PO_4 extractable Mn than with DTPA extractable Mn.

In field studies, MnEDTA tended to be less available than other sources of Mn. In one study, petiole Mn was higher for an alkaline source of fertilizer than for an acid source.

Increasing N decreased Mn uptake in a hydroponics study with constant substrate pH while various Mn levels had no effect on N uptake. The same results were observed in three years of field data.

In a fertilizer-Mn placement study, a band placement of 5 cm to the side and 5 cm below the seed was found to be equal to placing the band 7.6 cm directly below the seed.

Foliar applied Mn was not reflected in beet yields, quality or petiole Mn concentrations.

To Mary

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Table of Contents

List of Tables

Key to Abbreviations and Unique Quantities

Abbreviations

AN = Ammonium nitrate

AS = Ammonium sulfate

DAP = Diammonium phosphate

MAP = Monoammonium phosphate

MCP = Monocalcium phosphate

CJP = Clear juice purity

Unique Quantities

Amino N = Alpha amino nitrogen, (meq/100 ml beet juice) 100

CJP = (52 mm polarity x 100)/(RDS x Density)

52 mm polarity = % sugar in juice by weight

RDS x Density = refractometric dry substances (volume) x density
= total dry solids (weight)

$$\text{Recoverable sugar/t} = [(19.6 \times \%\ \text{sugar}) - 14)]\ \left[2.5 - \frac{150}{\text{CJP} - 0.7}\right](0.5)$$

Recoverable sugar/ha = (yield, t/ha)(recoverable sugar/t)

Chapter 1

Introduction

The inclusion of B and Mn in sugarbeet fertilizers has been recommended in Michigan for approximately four decades. These two micronutrients have become an integral part of the fertilizer programs of most Michigan sugarbeet farmers and thus the subject of this dissertation is in the area of B and Mn fertilization of sugarbeets (Beta vulgaris L.).

The current recommendations for B are not based on routine soil testing, rather on a blanket recommendation for all sugarbeet production where soil pH levels are above 6.8. Michigan State University recommends 2.2 to 3.3 kg B/ha while Michigan Sugar Company recommends a fertilizer containing 0.25 percent B (Warncke, Christenson, and Lucas, 1976 and Michigan Sugar Company, 1976). Under such a program the recommendations need to be periodically evaluated to determine their accuracy. Thus, the objective of the research on B was to determine the influence of soil and foliar applied B on yield, quality and B content of sugarbeet plants.

Recommendations for Mn are based on soil test levels and applications of Mn can be tailored for a particular field's requirement. However, there are numerous factors other than the amount of extractable Mn present that can influence the availability of Mn to plants. These factors can be instrumental in determining whether adequate Mn is available for optimum plant growth, even if Mn has been applied. It has been observed that fertilizer placement can have an influence on the early Mn status of sugarbeets and that fertilizer source can influence the Mn content of sugarbeets. Environmental factors also influence Mn availability.

The research on Mn falls into three categories, with the following objectives: 1) to determine the effect of fertilizer and Mn source on the yield, quality and composition of sugarbeets and on the pH and extractable Mn of the soil closely associated with the fertilizer band; 2) to determine the effect of carryover and applied N and Mn on yield, quality and composition of sugarbeets as well as the direct influence of N on the availability of Mn; and 3) to determine the effect of fertilizer and Mn soil placement, and foliar applied Mn on the yield, quality and composition of sugarbeets. Field, greenhouse and laboratory studies were included in the research on Mn.

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Chapter 2

Responses of Sugarbeets to Applied Boron

Boron was found to stimulate plant growth as early as 1910, but it was not proven to be an essential element until 1923 (Hewitt and Smith, 1974). Kotila and Coons (1935) reported that in 1931 Brandenburg of Germany was the first researcher to demonstrate that the disease of sugarbeets commonly known as heart rot was a B deficiency symptom. Since that time, the symptoms of B deficiency on sugarbeets have been well documented (Ulrich and Hills, 1969 and Cook, 1940).

Boron deficiencies on sugarbeets in Michigan were first observed by Kotila in 1932. At that time, symptoms were found to be "here and there" in fields in a rather large area in Michigan and "occasionally" in Ohio (Kotila and Coons, 1935).

The discovery of B deficiencies led to attempts to characterize problem soils. Kotila and Coons (1935) observed that in Michigan and Ohio, B deficiencies were most prevalent on sandy or gravelly loam soils underlain by a porous subsoil. These observations were supported by Cook (1937) who also reported that wherever deficiencies occurred on rolling or hilly fields, it always occurred in soils near or at the top of the hills or ridges.

Later research showed that B availability was related to soil pH and Ca content as well as texture. Cook and Millar (1939) did an extensive study in Michigan to determine the soil factors that effect B availability by analyzing soil samples from deficient and nondeficient beet fields. They observed that heart rot was more severe where a sandy layer was near the soil surface or a thick sand layer occurred in the soil profile. Heart rot was also found to be more prevalent on alkaline than on acid soils; however the greatest correlation was found between exchangeable Ca and B deficiencies. Deficient areas were found to have greater exchangeable Ca than nondeficient areas, regardless of the pH of the soil. Wear and Patterson (1962) found that as the pH of the soil decreases, each unit change in the water soluble B of the soil causes a greater change in the plant B concentration. They also found that a greater change in plant B concentration per unit change in water soluble B was obtained for coarser than for finer textured soils. The former authors found no correlation between heart rot and readily soluble soil B while the latter authors concluded that the water soluble B content of soil is a good indicator of available B only if soils of similar texture and pH are compared.

Liming of acid soils has a significant influence on plant available B (Naftel, 1937a, 1937b). Studies on Coastal Plains soils show that over-liming could occur and that at pH values greater than 6.8 injury occurred to the plants. The causative agent was found to be B deficiency and that the injury could be corrected with B additions. The water soluble B content of the soil decreased directly with the amount of lime added. Similar results have been found by others. Jones and Scarseth (1944) report that when a soil is limed, B uptake increased less with each increment of added borax than at the lower pH values. Gupta (1972) found lime to reduce B availability to barley. Deficiencies were increased with lime while toxic levels of B were reduced with additions of lime.

Cook and Millar (1939) tested the relationship between lime and B by applying borax to soybeans, a sensitive crop, and observing toxicity symptoms. It was found that $CaCO_3$ applied to the soil reduced the toxicity symptoms, but that Na_2CO_3 used in place of $CaCO_3$ did not have the same affect, even though the pH was increased. From this study, they concluded that B fixation is not entirely a matter of pH. In another study, they compared carbonates and sulfates of Ca, Mg, and Na. Magnesium carbonate had the same influence as $CaCO_3$, but toxicity symptoms were more severe than the B only treatment when Na_2CO_3 was used. Sodium sulfate had no effect and Ca and Mg sulfates were partially effective in controlling toxicity. The authors suggest that the fixation of B is purely chemical since Ca and Mg borates are less soluble than Na borates. They also concluded that pH does have some effect on B availability since the sulfates were less effective than carbonates. Fox (1968) came to the same conclusion using sand culture techniques. He found that an increase in pH and Ca concentration lowered B absorption in cotton more than did an increase in either factor alone. Using the same technique, Chandler (1944) reported that B deficiency symptoms of broccoli were more common and more severe in solutions with high Ca, but that 3 levels of N, K and Mg had no effect.

Colewell and Cummings (1944) report that low soil moisture, high pH, and a high concentration of cations, particularly Ca, all tend to accentuate B deficiencies in plants and also tend to favor the formation of condensed borates. They suggest that the slow dissolution rate of Ca metaborate is responsible for reduced B adsorption by plants whenever a soil medium undergoes pronounced fluctuations in moisture. The acid radical of Ca metaborate is reported to be an endless chain of BO_3 groups, whereas the acid radical of Na and K metaborate is smaller and of discrete size, thus more B is tied up by Ca than by Na and K.

At low levels of hot water soluble B, the degree of brown-heart in rutabagas was found to be more severe at high soil pH than at low soil pH, while at high B levels pH had no effect (Gupta and Cutcliffe, 1972). It was concluded that a higher level of hot water soluble B was necessary with increasing pH levels of the soil to give equal plant uptake.

Berger and Truog (1945) observed that organic matter influences B availability more than pH. They found that available B increased as the pH increased from 4.7 to 6.7 and decreased from pH 7.1 to 8.1, and that organic matter content and available B were positively correlated at pH values less than 7.0, but were not correlated above 7.0. They concluded that pH and available B are correlated at pH values less than 7.0 because the organic matter content decreases with increasing acidity and that in alkaline soils, organic matter fails to keep B in an available form as pH increases.

In a greenhouse study on Norfolk sand, Drake, Sieling and Scarseth (1941) found that B deficient and normal plants had the same B concentration but that the B starved plants had higher levels of Ca. They also observed that where a high concentration of sulfate ion was present, the Ca adsorption by the plant was lower and resulted in a healthier plant. When soil pH levels were varied from 4.1 to 11.5 with $Ca(OH)_2$, all added B as H_3BO_3 was recovered by the Truog and Berger method. They concluded that H_3BO_3 did not form insoluble complexes with $Ca(OH)_2$ in solution. They also concluded that B is not fixed by soil humus or by the clay fraction and is not rendered insoluble by the Ca in the soil.

Rajaratnam (1972) found B adsorption to be positively correlated with pH and soil Al content. Adsorption was increased by the removal of organic matter and by liming. Using samples from A_p, B_2 and B_3 horizons of podzolic soils, Catani, Alcorde and Kroll (1971) found that sorption of B increased with increasing B content in an equilibrium solution at constant pH, and with increasing pH at constant B concentration. On an amorphous soil, a maximum in adsorption was found at pH values of 8 to 9 by Bingham, et al. (1971). Under pH 5, adsorption decreased while little change occurred between pH 5-7. Ortho boric acid predominates in the pH range 5 to 7 with a buildup of $H_3BO_4^-$ from pH 7 to 9; however the authors feel that part of the increased adsorption could be due to increased adsorption sites under alkaline conditions. Boron adsorption was highly correlated with Al_2O_3, but not with Fe_2O_3 or SiO_2. On hydromorphic soils, Oliver, et al. (1974) found that raising the soil pH aided in the fixation of applied B and sometimes caused B already present in the soil to become available.

Biggar and Fireman (1960) conclude that B probably forms surface compounds with soluble Al, Si, and Fe and that an exchange of borate ions for hydroxyl ions on the soil surface results in the fixation of B to the Al, Si and Fe of the crystal lattice.

Working on the adsorption mechanism for B in layer silicates, Sims and Bingham (1967, 1968a, 1968b) concluded that B is adsorbed in soils by hydroxy Fe and Al compounds. They established that hydroxy Fe and Al materials have a marked, though pH dependent, affinity for B by precipitating Fe and Al from solution in the presence of B. They also found that B retention in nine soils at pH 6 was mainly a response to their free Fe and Al oxide contents. For a more complete discussion in this area, Hodgson (1963) and Ellis and Knezek (1972) should be consulted.

Certain plants have been found to tolerate much lower levels of plant available B than others. Differences between genotypes and varieties have also been observed. Harris and Gilma (1957) reported that B is more beneficial for one variety of peanuts than another. Cotton was found to have a lowered B adsorption with a combined increase in the pH value and Ca concentration of the soil but no effect was observed on alfalfa (Fox, 1968). The variance in absorption was reported to be a difference in the physiological response of the two species to high pH and high Ca concentrations.

Oertli and Roth (1969) found that B sensitivity is in the order of soybeans greater than cotton greater than sugarbeets. On identical treatments, the B content in the tops was highest for soybeans and lowest for sugarbeets. Response to B was found to be the result of B uptake rather than of different tissue sensitivities.

The site of the differential uptake has been found to be in the root. Haas (1945), using grafting experiments with citrus trees, showed that the rootstock regulated the boron content of the leaves regardless of whether they were a part of the budded scion or a part of the original seedling. Similarly, Brown and Ambler (1973) found the controlling mechanism of B uptake in tomatoes to be in the root. An efficient and inefficient cultivar, with respect to B uptake, were found to have the same B requirement in the tops for optimum growth. Furthermore, Oertli and Kohl (1961) found that the minimum B concentration in the tissue that caused toxicity symptoms was of the same order of magnitude for 29 species tested, regardless of their ability to accumulate B.

Early recommendation of B on sugarbeets in Michigan were for 7 to 10 pounds of borax per acre (Cook, 1948). Recommendations later called for 0.25 percent B in sugarbeet fertilizers (Cook, et al., 1957). These recommendations have largely remained unchanged. Currently, Michigan Sugar Company recommends 0.25 percent B in the fertilizer while Michigan State University recommendations call for 2.2 to 3.3 kg B/ha (Michigan Sugar Company, 1976, and Warncke, Christenson, and Lucas, 1976).

Since these recommendations are based on past research and not on routine soil tests, they need to be periodically reevaluated to determine their accuracy. The objectives of these studies were to evaluate the effect of soil and foliar applied B on yield, quality and B concentration of sugarbeets and the effect of applied B on two varieties of sugarbeets.

Materials and Methods

A study to evaluate the response of two sugarbeet varieties to applied B was conducted at the Saginaw Valley Bean and Sugarbeet Research Farm in 1973 and 1974. The study was a split plot design with main plots of 0 or 3.36 kg B/ha as sodium pentaborate and subplots of either variety US H20 or SP 633269-0 (269). Applied N, P_2O_5 and Mn was 22.4, 224 and 8.9 kg/ha, respectively. The fertilizer along with the B was applied with belt applicators in a band at planting.

From 1974 through 1976, several studies were conducted throughout the sugarbeet growing areas and consisted of B treatments of 0, 2.24, 4.48 and 6.72 kg/ha. The treatments were all applied as liquid Solubor ($Na_2B_4O_7 \cdot 5H_2O + Na_2B_{10}O_{16} \cdot 10H_2O$) injected into the fertilizer band at planting. All plots received 530 kg of 8-32-16 + 2% Mn per ha.

In 1975 a foliar B study was conducted at the Ben DuRussell farm. The basic fertilizer was 8-32-16 + 2% Mn at 530 kg/ha. Boron was applied with a hand carried applicator as liquid Solubor. Treatments consisted of B rates of 0, 0.112, 0.224 and 0.448 kg/ha. Times of application were June 13, September 8 or both dates.

The characteristics of the soils and soil B levels for all of the B studies are given in Appendix Tables 1 and 2, respectively. The fertilizer band placement was 5 cm below and 5 cm to the side of the seed. A row spacing of 71 cm was used in all studies.

At approximately 12 weeks of growth, plant tissue samples were collected for B analysis. Petiole samples were taken in 1973 through 1975 and leaf blade samples were taken in 1976. The samples were collected in plastic bags, dried at $60^{\circ}C$ in a forced air oven and ground in a

Wiley mill. The 1973 through 1975 samples were dry ashed for four hours at 500°C and the ash taken up in 1N HCl. The HCl solution was filtered and stored in plastic bottles for analysis. All 1976 plant samples were analyzed by emission spectroscopy at International Minerals and Chemicals, Libertyville, Illinois.

Soil samples were taken from the plow layer shortly after planting. Boron was extracted from the soil by the hot water method of Jackson (1958).

A modified carmine method was used for B analysis (Hatcher and Wilcox, 1950 and Technicon Auto Analyser II, 1973). The color reagent consisted of 0.5 g of carmine dissolved in 2 ℓ of concentrated H_2SO_4. The reagent was maintained near 0°C to minimize the heat of reaction when the reagent and sample were mixed and to slow degradation during storage. For color development, 1 ml of sample was pipetted into a plastic beaker and 10 ml of color reagent slowly added. With the hot water extract, one drop of concentrated HCl was added to the 1 ml of sample before the color reagent was added. The color was allowed to develop for at least 45 minutes before readings were made on a Bausch and Lomb Spectronic 20 spectrophotometer at 585 nm. Because of the low B concentration in the samples from the soil extracts, a Beckman DB-G grating spectrophotometer with 4 x 1 x 4 cm matched rectangular cuvettes was used to determine B concentration. The readings were compared to standards ranging from 0 to 10 ppm.

Results and Discussion

The B study at the Saginaw Valley Bean and Beet Research Farm in 1973 and 1974 was designed to evaluate the response of two sugarbeet varieties to applied B. The first variety (US H20) is a monogerm hybrid that is currently used in Michigan. The second is an open pollinated multigerm variety (SP 633269-0 or "269") that was used in Michigan before monogerm hybrids came into use.

The lack of a significant response to added B at the Bean and Beet farm shows that no deficiency occurred for either variety, thus no conclusions can be drawn about the responsiveness of the two varieties to added B (Table 1). However, the results would suggest that the two varieties do not differ in their abilities to accumulate B since the plant B levels of the two varieties did not significantly differ. These observations are in agreement with Christenson (1973) who, by using sand cultures in the greenhouse, found the two varieties to respond the same to applied B. However, in a greenhouse study using soil, he did observe that variety 269 developed B deficiency symptoms with no applied B on a low B soil, whereas, no symptoms developed on variety US H20.

Both years variety US H20 produced a significantly higher yield of beets and sugar per hectare than variety 269. It also had a significantly higher recoverable sugar per ton and clear juice purity in 1974 and for the combined data for both years. The sugar percentage in the beets was the same for both varieties (Table 1).

Data for all off-station B studies are given in Table 2. These studies were designed to test the influence of soil applied B on yield, quality and plant B concentration of sugarbeets at several locations in 1974 through 1976.

Table 1. Effect of applied B on sugarbeets, Bean-Beet Research Farm.

Variety	Applied B	Yield	Sugar	CJP	Recoverable Sugar		Petiole B
	kg/ha	t/ha	------%	------	kg/t	kg/ha	ppm
				1973			
US H20	0	54.0	19.0	95.3	164	8835	26.8
	3.36	56.7	19.4	95.9	169	9547	26.8
269	0	36.3	19.1	93.7	160	5784	28.8
	3.36	37.6	18.8	94.7	159	5964	31.3
LSD (0.05)[a]		ns	ns	ns	ns	ns	ns
LSD (0.05)[b]		ns	ns	ns	ns	ns	ns
Boron Level							
	0	45.2	19.0	94.5	162	7309	27.8
	3.36	47.0	19.1	95.0	164	7756	29.0
LSD (0.05)		ns	ns	ns	ns	ns	ns
Variety							
US H20		55.3	19.1	95.6	166	9191	26.8
269		37.0	19.0	93.6	159	5873	30.0
LSD (0.05)		3.6	ns	0.6	5	599	2.4
				1974			
US H20	0	37.2	18.4	95.6	160	5929	37.0
	3.36	40.1	18.2	95.5	158	6335	35.7
269	0	30.7	18.0	95.0	154	4720	35.3
	3.36	31.4	18.3	95.0	157	4920	36.7
LSD (0.05)[a]		ns	ns	ns	ns	ns	ns
LSD (0.05)[b]		ns	ns	ns	ns	ns	ns
Boron Level							
	0	33.8	18.2	95.3	157	5324	36.2
	3.36	35.7	18.3	95.3	157	5627	36.2
LSD (0.05)		ns	ns	ns	ns	ns	ns
Variety							
US H20		38.8	18.3	95.6	159	6132	36.3
269		30.9	18.2	95.0	156	4819	36.0
LSD (0.05)		1.8	ns	ns	ns	450	ns
				Combined Analysis			
US H20	0	45.9	18.7	95.5	162	7461	32.0
	3.36	49.0	18.8	95.7	163	8025	30.8
269	0	33.9	18.5	94.3	157	5312	31.5
	3.36	33.0	18.6	94.6	158	5365	33.8
LSD (0.05)[a]		ns	ns	ns	ns	ns	ns
LSD (0.05)[b]		ns	ns	ns	ns	ns	ns
Boron Level							
	0	39.3	18.6	94.9	159	6387	31.8
	3.36	41.5	18.7	95.1	160	6695	32.3
LSD (0.05)		ns	ns	ns	ns	ns	ns
Variety							
US H20		47.4	18.7	95.6	162	7743	31.4
269		33.9	18.6	94.5	157	5339	32.7
LSD (0.05)		2.3	ns	0.5	2	465	ns

[a] For the comparison of two B rates within a variety.
[b] For the comparison of any two means.

Table 2. Effect of applied B on sugarbeets.

Location (year)	Applied B	Yield	Sugar	CJP	Recoverable Sugar		Plant[a] B
	kg/ha	t/ha	-----%-----		kg/t	kg/ha	ppm
Abraham (74)	0	47.2	17.4	94.7	147.6	6965	26.5
	2.24	52.8	17.4	94.3	147.2	7780	29.5
	4.48	53.4	17.3	94.5	146.2	7822	30.3
	6.72	50.1	17.5	94.6	148.8	7450	31.3
Schmidt (75)	0	52.1	17.6	97.0	156.4	8141	34.0
	2.24	53.3	17.5	96.4	153.8	8808	34.5
	4.48	56.9	17.7	96.8	156.4	8893	37.5
	6.72	56.3	17.3	96.9	156.8	8839	36.3
DuRussell (75)	0	58.0	14.9	96.4	129.4	7511	36.5
	2.24	63.9	14.5	96.2	125.6	8045	36.0
	4.48	62.7	14.6	96.2	126.3	7936	35.3
	6.72	58.5	14.1	95.9	121.1	7101	37.5
Abraham (76)	0	47.9	19.9	96.4	175.8	8415	46.3
	2.24	50.9	19.9	96.1	174.8	8905	53.3
	4.48	46.2	19.5	95.9	169.9	7845	54.3
	6.72	47.6	19.8	96.2	173.4	8273	60.8
Hecht (76)	0	34.0	17.4	96.8	153.8	5239	56.8
	2.24	35.1	17.4	97.0	154.9	5426	56.8
	4.48	31.9	17.5	96.8	154.5	4934	72.5
	6.72	33.3	17.4	96.9	153.8	5129	94.8
LSD (0.05)[b]		ns	ns	ns	ns	ns	25.4
LSD (0.05)[c]		ns	ns	ns	ns	ns	
Boron Rate			Simple Effects				
	0	47.8	17.5	96.3	152.6	7254	
	2.24	52.0	17.4	96.0	151.3	7793	
	4.48	50.2	17.3	96.1	150.3	7486	
	6.72	49.2	17.3	96.1	150.8	7360	
LSD (0.05)		ns	ns	ns	ns	ns	
Location							
Abraham (74)		50.9	17.4	94.5	147.0	7507	
Schmidt (75)		55.6	17.7	96.8	155.9	8670	
DuRussell (75)		60.8	14.5	96.2	125.6	7648	
Abraham (76)		48.1	19.8	96.2	173.5	8359	
Hecht (76)		33.6	17.5	96.9	154.3	5182	
LSD (0.05)		2.8	0.5	0.5	9.7	392	

[a] Petioles in 1974 and 1975, leaf blades in 1976.
[b] For the comparison of B rates within a location.
[c] For the comparison of any two means.

No significant differences were produced due to added B, however, there was a strong trend for differences in yield of beets ($P = 0.053$). At all locations the highest yield of beets and recoverable sugar was with 2.24 or 4.48 kg of added B/ha. The results suggest that there was an increase in yield with applied B but that 6.72 kg/ha was an excessive rate.

The plant B concentration tended to increase at all locations with applied B, especially in 1976. In 1976, leaf samples were taken as opposed to petiole samples the previous two years which could account for differences in response. Since different parts of the plant were sampled, combined statistical analysis were not possible for plant B content.

Significant differences occur for all parameters from location to location. This reflects differences in other properties and probably is not related to the B status of the soils.

The results of this study suggest that the current MSU recommended rate of 2.24 to 3.36 kg B/ha is optimum for sugarbeet production in Michigan.

In 1975, a foliar B study was conducted at the DuRussell farm and was designed to test B rate and application date effects on beet yield, quality and plant B content. All parameters were unaffected by foliar applied B (Table 3).

Table 3. Effect of foliar applied B on sugarbeets, DuRussell farm, 1975.

Application Dates	Boron per application	Yield	Sugar	CJP	Recoverable Sugar		Petiole[a] B
	kg/ha	t/ha	-----%-----		kg/t	kg/ha	ppm
	0	61.3	14.8	96.4	128.7	7046	31.0
June 13	0.112	55.9	15.3	96.5	133.7	7500	
June 13	0.244	57.3	15.0	96.4	125.9	7239	32.5
June 13	0.448	58.4	14.6	96.6	126.9	7404	32.0
Sept. 8	0.224	56.9	14.8	96.5	128.6	7316	
Sept. 8	0.448	59.9	14.7	96.9	129.4	7765	
June 13-Sept. 8	0.112	55.2	14.4	96.0	124.4	7352	
June 13-Sept. 8	0.224	55.8	14.3	96.3	123.8	6902	
LSD (0.05)		ns	ns	ns	ns	ns	ns

[a] Samples were taken after the first application only.

Summary

The results of the studies at the Saginaw Valley Bean and Beet farm did not show that an open pollinated multigerm variety of beet (Sp 633269-0) responded differently to applied B than the currently used hybrid variety (US H20). Variety US H20 was found to produce a much higher yield than Sp 633269-0.

The off-station research shows that beets tend to respond to added B in the 2-4 kg/ha range but that rates higher than 6 kg/ha have a tendency to reduce yields.

No response was found to foliar applied B in one study.

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Chapter 3

Effect of Fertilizer Reaction and Mn Source on Plant Available Mn

Soil pH can significantly influence plant available Mn and considerable literature has been published in this area. Reduced availability after liming is adequately documented, however, the specific concern in Michigan sugarbeet production is insufficient Mn availability related to high pH soils. The effects of an acidic fertilizer band has shown promise in liberating unavailable Mn to an available form and warrants specific consideration in Michigan (Murphy and Walsh, 1972).

The Mn solubility - pH relationship is produced by the effect of H ions on MnO_2 according to the following equation:

$$MnO_2(s) + 2H^+ \rightleftarrows Mn^{2+} + 1/2\ O_2 + H_2O.$$

Manganic oxide is the most stable oxide of Mn in the soil and its solubility can greatly influence plant available Mn^{2+}. It is apparent from the above equation that increasing acidity drives the equilibrium to the right and increases Mn^{2+} concentration. Manganese (II) in solution increases 100 fold for each unit decrease in pH and helps explain why Mn can be toxic in acid soils and deficient in neutral and alkaline soils (Lindsay, 1972).

With respect to Mn, liming is generally used to reduce toxicity. White, Doll and Melton (1970) found that liming an acid soil to pH 6.5 or above, reduced Mn toxicity symptoms on potatoes. Similar results were reported by Parker et al. (1969) in a greenhouse study. They also found that Mn toxicity only occurred in the field when commerical fertilizer was applied and that the toxicity was less severe when lime was added. Follett and Lindsay (1971) found Mn fertilizers to remain available in highly acid soils but became unavailable under neutral and alkaline conditions as measured by DTPA extractions. Sanchez and Kamprath (1959) reported that the addition of lime resulted in a smaller increase in the exchangeable Mn content following the addition of Mn than when no lime was added.

Associated cations have also been found to influence Mn availability. Parker et al. (1969) reported that associated salts, as well as the pH of applied fertilizer, was correlated with Mn availability. Exchangeable Ca and Mg, along with exchangeable and easily reducible Mn and pH, were found to correlate with plant leaf Mn by Rich (1956). Salcedo (1976) found pH and the (Ca + Mg)/K ratio were correlated with available Mn as measured by several extracting agents.

Mehlich (1957) researched the area of associated cation effects on Mn solubility. He found that when saturated $Ca(OH)_2$ was added to 0.1$\underline{N}$ $MnSO_4$, Mn was precipitated above pH 8.5. When normal concentrations of H_2SO_4, $Al_2(SO_4)_3$, $FeSO_4$, $FeCl_3$, $CuSO_4$ or $ZnSO_4$ were included in the $MnSO_4$ solution, Mn precipitation occurred at pH levels 8.5, 5.8, 6.8, 5.8, 7.8, and 7.8 respectively. A comparison of Al/Mn ratios showed that Mn in solution decreased with an increasing ratio at pH levels between 6 and 8.5. Also, H^+, Al^{3+} and Fe^{3+} saturated soils were compared with respect to $(NH_4)_2SO_4$ extractable Mn. Liming of the H-soil to pH 6, 7 and 8 resulted in a slight reduction in the exchangeable Mn level at pH 7 and 8, while in the case of the Al^{3+} and Fe^{3+} soils, a very substantial suppression of the exchangeable Mn level was found. The author concluded that the precipitation of Mn at lower pH levels in the presence of Al and Fe oxide hydrates is due to an effective supply of OH ions at pH values as low as 5.8.

Much work has been done on the effects of banded fertilizers on Mn availability. On an unlimed acid soil, White et al. (1970) found that plant Mn concentration was unaffected by an acidic fertilizer band. However, increased Mn uptake by plants is generally found when an acidic fertilizer is banded in a soil with a pH near neutrality or above. Mortvedt and Giordano (1970) found that banding ortho and polyphosphate in a soil with pH 6.8 eliminated Mn deficiencies and improved Mn uptake. Similar results were obtained by Randall, Schulte and Corey (1975) using mono- and diammonium phosphate in greenhouse and field studies. Kroetz et al. (1977) report that the plant Mn level can be increased by applying a fertilizer high in P and that the inclusion of Mn in the row fertilizer did not increase yields over row fertilizer alone. The added Mn did increase plant Mn concentration.

Elemental S has also been used as an acidifying agent to increase Mn availability. Tisdale and Bertramson (1950) reported that applied S increased the Mn content of plants more than applied $MnSO_4$ while Ludwick, Sharpee, and Attoe (1968) found that Mn sources fused with S produced higher levels of plant available Mn than the Mn sources alone. It is suggested by the latter authors that S granules could increase Mn availability for several months, or even years. Garey and Barber (1952) found that added S increased yields in proportion to changes in pH but that the Mn content of the plants showed an additional increase over that due to pH. They suggest that the oxidation of S by S bacteria causes an accompanying reduction of manganic Mn and a subsequent increase in availability. Sulfate ions had no effect on the Mn concentration of the plants.

Another area of Mn fertilization that has received considerable attention has been the effectiveness of various Mn carriers. Manganese sulfate is the most common carrier and is usually used as the standard by which others are judged (Murphy and Walsh, 1972).

Considerable work on Mn carriers has been done in Michigan on a Houghton muck soil. Shepard, Lawton and Davis (1960) found Mn carriers of sulfate, oxide, frit, EDTA and sulfate-carbonate to all be effective in increasing yield when the soil was limed to induce Mn deficiency. In another study, Knezek and Davis (1971) found $MnSO_4$ to be superior to MnO in increasing plant growth, Mn concentration, Mn uptake and yield. In a greenhouse study, Rumpel et al. (1967) found $MnSO_4$ and MnO to both be effective, however, the sulfate form tended to be superior to oxide. The same general results were observed in the field, however, MnEDTA was not found to influence yields when banded with an acid fertilizer but was found to significantly reduce yields when banded with a moderately acid or neutral fertilizer. The yield reduction was related to a lowered Mn uptake. It was later reported that the ineffectiveness of MnEDTA was due to a rapid substitution of Fe for Mn on the chelate molecule which greatly increased Fe availability while Mn was complexed by soil organic matter (Knezek and Greinert, 1971).

On a mineral soil, Kroetz et al. (1977) found 0.58 kg Mn/ha as EDTA to be less effective than 8.96 kg Mn/ha as sulfate in increasing Mn content of soybean plants. $MnCO_3$ was reported to be superior to MnO_2 in increasing plant available Mn when fused with S (Ludwick et al., 1968).

For soil applied Mn, $MnSO_4$ is generally considered the most effective, followed by MnO, $MnCO_3$, frits and MnO_2. MnEDTA has not generally been found to be an effective Mn carrier. Murphy and Walsh (1972) should be consulted for a more complete discussion of Mn carriers.

This paper reports on the influence of fertilizer and Mn sources on plant available Mn. Field, greenhouse and laboratory research is included. The objective of the field research was to test the influence of fertilizer acidity and Mn source on yield, quality and Mn concentration of sugarbeets at several locations. The objective of the greenhouse study was to determine the influence of N source, N placement, P placement and added Mn on dry matter production and elemental concentration and uptake of sugarbeets and on the extractable Mn level of the soil. The influence of specific fertilizer sources on the pH and extractable Mn content of the soil with time was tested in a laboratory incubation study.

Materials and Methods

Incubation study

A soil-fertilizer incubation study was conducted to test the influence of fertilizer source on pH and extractable Mn of soil. The soil was from the Cliff Stockmeyer farm and had a history of Mn deficiency (Appendix Table 1). The study was carried out in the laboratory using 40 x 16 cm plastic window boxes as containers and arranged in a randomized complete block design. Treatments consisted of a control and four fertilizer sources mixed in a 1-1-1 (N, P_2O_5, K_2O) ratio to give the equivalent of 67.2 kg of nutrient/ha in a band based on a 71 cm row width. Fertilizer sources were: 1) DAP, urea and KCl; 2) MAP, urea and KCl; 3) ammonium nitrate, monocalcium phosphate and KCl and 4) ammonium sulfate, monocalcium phosphate and KCl.

The fertilizer was added to the soil in a band and covered with 5 cm of soil. At two week intervals the pots were weighed and water added to obtain a soil moisture tension of 100 cm of H_2O (42% soil moisture). At the end of the two week watering cycle the soil moisture was at approximately 22%. Soil samples were taken at three, five and seven weeks from a 4 cm layer of soil containing the fertilizer band. The soil samples were air dried, ground with a plastic pestle and extracted with DTPA (diethylenetriaminepentaacetic acid) and 0.1 $\underline{N}$ H_3PO_4. The DTPA extractant consisted of 3.96 g of DTPA (90% acid free), 2.22 g $CaCl_2$, 29.84 g triethanolamine and sufficient H_2O to obtain a volume of 2ℓ. Soil-extractant ratio and shaking time for the DTPA extractant was 1:4 and 2 hours, respectively, and 1:5 and 1 hour, respectively for the H_3PO_4 extractant. Soil pH levels were determined on a 1:1.5 soil:water mixture.

Greenhouse study

A greenhouse study was conducted to test the influence of N source, N and P placement and added Mn on dry matter production and nutrient status of sugarbeet (Beta vulgaris L.) plants and on soil pH and extractable Mn, Fe, Zn and Cu. The same soil source and containers used in the incubation study were used in this experiment, however, extensions were added to the pots to increase the soil depth to 18 cm. Four replications were used and arranged in a randomized complete block design. The experiment was a complete factorial set of treatments consisting of N sources of urea and ammonium sulfate, N and P placements of band and mixed, and Mn treatments of with or without banded Mn. Mixed treatments were blended with the entire volume of soil and band treatments were added in the same manner as in the incubation study. Fertilizer rates were figured on a soil volume basis for the mixed treatments and a rate/linear unit basis for the band treatments. Thus, the amount of nutrient added to a pot for the band treatments were greater than for the mixed treatments. Nutrient rates are equivalent to 100.8 kg P/ha, 50.4 kg N/ha and 13.4 kg Mn/ha.

Fifteen beet seeds were planted in a row over the fertilizer band and thinned to nine plants per pot after emergence. Water was added as necessary to maintain the moisture content near field capacity. The plant leaves and petioles were harvested six weeks after emergence, dried in a forced air drier at $60^{o}C$, weighed for yield and ground for plant analysis. At the same time, soil samples were taken above, through and below the fertilizer band. The soil samples were extracted with DTPA and 0.1 $\underline{N}$ H_3PO_4 and tested for pH using the same procedure as for the incubation study. The wet oxidation procedure of Parkinson and Allen (1975) was used to digest the plant tissue.

The large differences between the with and without Mn treatments for DTPA and 0.1 N H_3PO_4 extractable Mn produced significantly unequal cell variances. In this case, a student's t test for unequal variances was used to test for significance (Steel and Torre, 1960). Differences that are not indicated by the LSD but are significant by the t test are denoted in footnotes in the appropriate tables.

Field studies

Two fertilizer - Mn source field studies were conducted in 1975 at the Ben DuRussell and Don Abraham farms (Appendix Table 1). Ten treatment combinations consisting of an initially acid (33-0-0, 0-46-0, and 0-0-60) and an initially alkaline (18-46-0, and 0-0-60) fertilizer source and five Mn sources (no Mn, granular $MnSO_4$, MnEDTA solution, Mangasol and granular MnO). N-P_2O_5-K_2O rates of 22-56-28 kg/ha were applied. Manganese was applied at 8.96 kg/ha for all sources except EDTA, which was applied at 1.12 kg/ha. The experiments were arranged in a randomized complete block design with four replications. All fertilizer except MnEDTA was weighed out before planting and applied with belt applicators at planting in a band 5 cm below and 5 cm to the side of the seed. MnEDTA was applied as a liquid with the same placement. Row spacings of 71 cm were used in all field studies.

In 1976 a similar fertilizer - Mn source study was carried out at the Don Abraham farm (Appendix Table 1). The basic procedure was the same as the 1975 studies, however, an initially slightly acid (12-62-0, 45-0-0, and 0-0-60) fertilizer was also used. A 1-1-1 fertilizer ratio applied at 56 kg nutrient (N, P_2O_5, K_2O)/ha was used. Fritted Mn at 8.96 kg Mn/ha as a Mn source, and $MnSO_4$ at 4.48 and 13.44 kg Mn/ha with the slightly acid fertilizer source were included.

All field studies were planted at approximately 5 cm seed spacings and thinned to 20 cm after emergence. Pyrimin and TCA herbicides were applied post-plant and pre-emergence at the recommended rates (Meggitt, 1976).

Plant tissue samples (petioles in 1975, leaf blade in 1976) were taken at approximately 12 weeks after planting, dried in a forced air oven at 60^{o}C, ground and stored in plastic bags. The plots were mechanically harvested, the beets weighed for yield and 10 representative beets saved for quality analysis. Juice for quality analysis was extracted from the 10 beets by sawing the beets lengthwise and squeezing the juice from the resultant pulp. The juice was kept frozen until it was analyzed by Michigan Sugar Company's analytical laboratory.

The soil samples were extracted with DTPA and analyzed for Mn, Zn, Fe and Cu using the same procedure outlined above. The plant samples were analyzed by International Minerals and Chemical Corporation in Libertyville, Illinois using emission spectroscopy.

Results and Discussion

Incubation study

The fertilizer incubation study was designed to determine the effect of several fertilizer sources on DTPA and 0.1 N H_3PO_4 extractable Mn and soil pH. Soil pH was significantly depressed and extractable Mn significantly increased by banded fertilizer at the three week sampling (Table 1). There was a significant correlation between soil pH and H_3PO_4 extractable Mn, but not between soil pH and DTPA extractable Mn (Table 2).

A factor in addition to pH appears to be influencing extractable Mn since the fertilizer sources containing MCP produced the lowest pH levels but not the highest level of extractable Mn. This factor could be due to the associated cations (Ca^{2+} vs NH_4^+) as described by Mehlich (1957) who found that Mn^{+2} in solution precipitates at a lower pH when in the presence of certain cations. Bingham and Garber (1960) also found that Mn was more available when $NH_4H_2PO_4$ was banded than when $Ca(H_2PO_4)_2$ was banded, however, they found a lower pH for the $NH_4H_2PO_4$ than for the $Ca(H_2PO_4)_2$ treatments. Associated salt effects were also observed by Hamilton (1966).

Extractable Mn decreased with time (Table 1). This most likely reflects reprecipitation of Mn, possibly as manganese phosphates or manganese ammonium phosphate as the acid soil solution very near the fertilizer band equilibrates with the alkaline soil solution (Hossner and Richards, 1968 and Hossner and Blanchar, 1968, 1970). At the seven week sampling, DTPA extractable Mn for both treatments containing MCP were significantly lower than the control, even though the pH remained

Table 1. The effect of several fertilizer sources on soil characteristics, incubation study.

Fertilizer Source[a]	DTPA Mn	H_3PO_4 Mn	pH	DTPA Mn	H_3PO_4 Mn	pH	DTPA Mn	H_3PO_4 Mn	pH
	ppm	ppm		ppm	ppm		ppm	ppm	
Sampling time	--------3 weeks--------			--------5 weeks--------			--------7 weeks--------		
Control	2.23	0.250	7.5	2.43	0.350	7.6	1.90	0.350	7.7
DAP-UREA-KCl	10.6	0.875	7.3	3.50	0.525	7.2	2.33	0.425	7.3
MAP-UREA-KCl	9.43	0.950	7.3	3.10	0.575	7.2	1.78	0.425	7.3
AN-MCP-KCl	3.15	0.600	7.2	1.85	0.475	7.3	1.45	0.375	7.4
AS-MCP-KCl	5.13	0.950	7.1	2.38	0.575	7.1	1.43	0.400	7.2
LSD (0.05)	1.19	0.171	0.1	0.54	0.101	0.1	0.22	ns	0.1

[a] Fertilizer mixed in a 1-1-1 (N, P_2O_5, K_2O) ratio.

Table 2. Correlations for Mn(extractable) = $b_o + b_1$ (pH). Incubation study.

Extractant	week	b_o	b_1	R^2
DTPA	3	42.8	-5.05	0.06
	5	12.0*	-1.28	0.13
	7	0.30	0.20	0.01
0.1N H_3PO_4				
	3	9.76**	-1.24**	0.51**
	5	3.68**	-0.44**	0.61**
	7	1.47**	-0.15*	0.29*

*, ** Significance at the 5 and 1% levels, respectively.

significantly depressed. This is unexpected, however, Mehlich (1957) pointed out that freshly dissolved Al^{3+} and Fe^{3+} were effective in precipitating Mn at pH values as low as 5.8. In this case, the very acid nature of the MCP fertilizer band could have solubilized Al and Fe near the fertilizer band. Later, as the fertilizer band pH increases, Mn^{2+} would be precipitated. In the control, no freshly dissolved Al^{3+} or Fe^{3+} would be present to promote Mn^{2+} precipitation. Only DTPA extractable Mn for the DAP-urea-KCl treatment was significantly higher than the control. This most likely reflects the residual acidity of DAP and urea.

Greenhouse study

The greenhouse study was designed to test the effect of N source, N placement, P placement and added Mn on growth and nutrient uptake by sugarbeet seedlings and on the level of extractable Mn in the soil. Overall treatment effects are given in Appendix Table 3.

The fertilizer band pH was significantly affected by all simple effects (Table 3). The pH levels for the various treatments were: urea > AS, mixed N > banded N, mixed P > banded P, and no banded Mn > banded Mn.

Extractable levels of Mn with DTPA and 0.1 N H_3PO_4 were higher for banded P than for mixed P for both levels of Mn, however, the magnitude was much greater when Mn was added (Table 4). Added Mn increased DTPA and 0.1 N H_3PO_4 extractable Mn at both P placements, however, the difference was significantly greater for banded P than for mixed P.

Manganese levels extracted with 0.1 N H_3PO_4 are higher for banded P than for mixed P for both N sources and placements (Table 5). When P

Table 3. Simple effect results in the greenhouse study.

Simple Effects	Band pH	Dry Weight	Plant N	
		grams	%	mg/pot
N source				
UREA	7.49	12.0	4.11	596
AS	7.39	12.2	4.15	506
LSD (0.05)	0.08	ns	ns	ns
N placement				
Band	7.37	13.4	4.19	558
Mixed	7.51	10.9	4.07	444
LSD (0.05)	0.08	0.7	ns	34
P placement				
Band	7.27	12.3	4.15	511
Mixed	7.61	11.9	4.11	491
LSD (0.05)	0.08	ns	ns	ns
Mn added				
Yes	7.38	12.7	4.16	526
No	7.50	11.6	4.10	476
LSD (0.05)	0.08	0.7	ns	34

Table 4. P placement and added Mn interactions, greenhouse study.

P Placement	Mn Added	Extractable Mn		Plant Mn	
		DTPA	H_3PO_4	Concentration	Uptake
		ppm	ppm	ppm	μg/pot
Band	Yes	191.2	20.8	75.2	948
	No	3.29	0.844	24.3	304
Mixed	Yes	52.6	1.68	20.7	292
	No	2.68	0.650	12.3	136
LSD (0.05)	Interaction	37.4[a]	2.47[a,b]	5.7	78

[a] Banded P significantly different from mixed P by t test (1%). See materials and methods for procedure.

[b] Added Mn different from no Mn for mixed P by t test.

Table 5. N source and N and P placement interactions, greenhouse study.

N source	N Placement	P Placement	H_3PO_4 Mn	Plant Mn Concentration	Plant Mn Uptake	P Uptake
			ppm	ppm	µg/pot	mg/pot
UREA	Band	Band	9.70	42.6	543	31.5
		Mixed	1.84	14.8	199	38.5
	Mixed	Band	11.7	49.4	593	29.2
		Mixed	0.775	16.0	169	30.6
AS	Band	Band	14.6	61.6	856	35.3
		Mixed	1.23	17.8	244	38.4
	Mixed	Band	7.40	45.3	512	28.5
		Mixed	0.825	17.4	186	34.0
LSD (0.05)	Interaction		3.49[a]	8.1	110	3.8

[a] Banded N significantly different from mixed N for urea and mixed P by t test (5%). See materials and methods for procedure.

was mixed, banded urea produced a significantly higher level of 0.1 N H_3PO_4 extractable Mn than mixed urea. No significant differences occurred between N sources or placements for 0.1 N H_3PO_4 Mn. When P was banded, 0.1 N H_3PO_4 extractable Mn was higher for banded AS than for mixed AS or banded urea.

Added Mn increased 0.1 N H_3PO_4 extractable Mn for both N sources and placements (Table 6). When no Mn was added, N source and placement had no effect on extractable Mn. With added Mn, these levels were uneffected by urea placement, but were by AS placement. Extractable Mn was greater for banded AS than for mixed AS or banded urea.

Dry weights of the sugarbeets were higher for banded N than for mixed N and for added Mn than for no Mn (Table 3). Plant N uptake was significantly increased by the same factors but N concentration was not affected by any of the treatments. The N placement response is most likely a reflection of the greater amount of N in the pots for the banded treatments than for the mixed treatments. Added Mn caused an increase in growth which was reflected in N uptake.

The Mn concentration and uptake in the plant was significantly increased by added Mn vs no Mn and by banded P vs mixed P, however, added Mn with banded P increased Mn concentration more than either factor alone (Table 4). Mn uptake was greater for AS than for urea when N and P were both banded, and was greater for banded P vs mixed P regardless of the N source or placement (Table 5).

Ammonium sulfate produced a higher P uptake than urea but only if N and P were both banded (Table 5). Phosphorus uptake was higher for banded vs mixed N for both N sources if P was mixed, which reflects the increased growth with banded N. Mixed P produced a significantly higher P uptake than banded P only when urea was banded or AS was mixed.

Table 6. N source and placement and Mn added interaction, greenhouse study.

N Source	N Placement	Mn Added	H_3PO_4 Mn
			ppm
UREA	Band	Yes	10.8
		No	0.713
	Mixed	Yes	11.8
		No	0.675
AS	Band	Yes	14.9
		No	0.863
	Mixed	Yes	7.44
		No	0.738
LSD (0.05) Interaction			3.49

Mixed P produced a higher P concentration in the plant than banded P and mixed N produced a higher concentration of P in the plant than banded N only when P was mixed (Table 7).

Simple correlations show that a significant relationship exists between soil band pH and plant Mn, Mn uptake and extractable Mn (Table 8). The results agree with Salcedo (1976) who also found that 0.1 N H_3PO_4 is superior to DTPA as an extracting agent for plant available Mn.

The results of the greenhouse study suggests that the greater amount of N present in the band placement promoted growth over that for mixed N and resulted in a lowered level of some nutrients in the plant due to a dilution effect. Mixed P proved to be more available than banded P under the conditions of this study. This is most likely a result of more plant roots coming into contact with the fertilizer P for the mixed placement. The results of the incubation study would suggest that initially there was an increase over the control in Mn availability with banded MCP but that this effect would have diminished at soil sampling time (six weeks). On the other hand, the concentration of Mn in the plant still reflected this early increased availability and is significantly higher for banded P vs mixed P with no added Mn. Added Mn increased plant available Mn in all treatment combinations, however, the Mn remained much more available when applied with an acidic P band.

Field studies

Mn applied as $MnSO_4$ tended to be the most available to plants in both fertilizer - Mn source studies in 1975 (Table 9). At the Schmidt farm, the alkaline source of fertilizer produced a higher plant Mn content than the acid source. This is opposite of what was expected but

Table 7. N and P placement interactions, greenhouse study.

N placement	P Placement	Plant P
		%
Band	Band	0.251
	Mixed	0.288
Mixed	Band	0.255
	Mixed	0.312
LSD (0.05) Interaction		0.012

Table 8. Simple correlation matrix, greenhouse study.

	Dry Weight	Plant Nutrient Concentration			Soil	Soil Mn		Plant Nutrient Uptake		
		N	P	Mn	pH	DTPA	H_3PO_4	N	P	Mn
Dry weight	1.00									
N concentration	0.06	1.00								
P concentration	-0.35**	0.01	1.00							
Mn concentration	0.22	0.04	-0.37**	1.00						
Soil pH	-0.25*	0.01	0.50**	-0.63**	1.00					
DTPA Mn	0.07	-0.09	-0.22	0.80**	-0.51	1.00				
H_3PO_4	0.19	0.01	-0.34**	0.89**	-0.60**	0.84**	1.00			
N uptake	0.90**	0.48**	-0.30*	0.20	-0.20	0.01	0.16	1.00		
P uptake	0.75**	0.07	0.35**	-0.05	0.09	-0.09	-0.07	0.68**	1.00	
Mn uptake	0.35**	0.02	-0.40**	0.98**	-0.63**	0.76**	0.88**	0.31*	0.06	1.00

Table 9. Simple effects of fertilizer reaction and Mn source on sugarbeets, 1975.

Simple Effects	Yield	Sugar	CJP	Recoverable Sugar		Amino N	Plant Nutrient Concentration				
							P	K	Ca	Mg	Mn
	t/ha	-----%-----		kg/t	kg/ha	meq/100s	--------%--------				
DuRussell farm											
Fertilizer pH											
Acid	60.0	14.3	96.3	123	7391	3.86	0.199	4.23	0.681	0.328	23.1
Alkaline	59.6	13.9	96.2	120	7167	3.90	0.188	4.28	0.728	0.336	22.8
LSD (0.05)	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Mn Source											
$MnSO_4$	63.4	14.1	96.0	122	7711	3.91	0.191	4.25	0.726	0.330	27.7
MnEDTA	56.2	14.0	96.5	121	6805	3.53	0.201	4.11	0.628	0.320	21.9
Mangasol	60.8	14.3	96.1	124	7514	4.14	0.206	4.29	0.694	0.328	20.8
MnO	58.8	14.0	96.3	121	7086	3.94	0.176	4.37	0.770	0.351	21.5
LSD (0.05)	ns	ns	ns	ns	ns	ns	0.018	ns	0.102	ns	3.6
Schmidt farm											
Fertilizer pH											
Acid	55.7	17.4	96.2	152	8436	6.09	0.219	4.71	0.606	0.251	5.08
Alkaline	54.8	17.4	96.4	152	8353	5.33	0.253	4.98	0.615	0.249	5.83
LSD (0.05)	ns	ns	ns	ns	ns	ns	0.030	ns	ns	ns	0.67
Mn Source											
$MnSO_4$	56.4	17.4	96.4	153	8627	5.42	0.241	5.03	0.640	0.270	6.75
MnEDTA	55.1	17.2	96.0	149	8227	6.32	0.228	4.92	0.605	0.250	4.58
Mangasol	56.5	17.5	96.3	153	8648	6.11	0.238	4.92	0.606	0.253	5.28
MnO	53.0	17.4	96.3	152	8076	4.94	0.239	4.51	0.590	0.226	5.21
LSD (0.05)	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	0.95

does agree with the results of the incubation study where the initially alkaline source of fertilizer (urea - DAP - KCl) produced a higher level of extractable Mn than initially acid fertilizers. This is also a function of the P carrier since ammoniated phosphates promote Mn availability over monocalcium phosphate (Bingham et al., 1960 and Hamilton, 1966). Overall treatment results are given in Appendix Table 4.

In a fertilizer - Mn source study in 1976, an alkaline source of fertilizer tended to be inferior to a slightly acid and acid source with respect to beet yields (Table 10). A fritted Mn carrier tended to be the superior Mn source while EDTA produced the poorest results. Overall treatment results are given in Appendix Table 5.

Table 10. Simple effects of fertilizer reaction and Mn source on sugarbeets, Abraham farm, 1976.

Simple Effects	Yield	Sugar	CJP	Recoverable Sugar		Amino N	Plant Nutrient Concentration				
							P	K	Ca	Mg	Mn
	t/ha	-----%-----		kg/t	kg/ha	meq/100s	-------------%-------------				ppm
Fertilizer pH											
Acid	40.4	19.2	96.0	168	6776	3.58	0.317	4.81	1.21	1.08	107
Slightly Acid	41.2	19.2	95.9	167	6866	3.38	0.310	4.83	1.23	1.08	101
Alkaline	37.9	19.1	95.9	166	6315	3.20	0.300	4.78	1.25	1.09	93.1
LSD (0.05)	ns	ns	ns	ns	ns	ns	0.002	ns	ns	ns	ns
Mn Source											
$MnSO_4$	38.5	19.3	96.1	169	6493	2.88	0.314	4.82	1.21	1.07	98.3
MnO	41.5	18.9	95.8	164	6810	3.59	0.302	4.84	1.33	1.20	109
Mangasol	40.1	19.0	96.0	166	6657	3.36	0.317	4.98	1.24	1.09	101
Mn Frit	41.2	19.4	96.2	170	7007	3.58	0.301	4.60	1.21	1.01	114
MnEDTA	37.9	19.2	95.6	166	6294	3.54	0.311	4.80	1.19	1.06	80.0
LSD (0.05)	ns	ns	ns	3	ns	ns	ns	ns	ns	0.11	16.0

Summary

In a soil-fertilizer band incubation study, banded fertilizer was effective in depressing band pH and increasing extractable Mn after three weeks. The lowest pH levels were produced by fertilizers containing monocalcium phosphate but the highest level of extractable Mn was produced by ammoniated phosphates. After seven weeks, the level of extractable Mn had decreased markedly even though pH levels remained depressed. Band pH was significantly correlated with 0.1 $\underline{N}$ H_3PO_4 extractable Mn but not with DTPA extractable Mn.

Band placement of monocalcium phosphate increased extractable and plant available Mn in a greenhouse study. Banded Mn increased plant available and extractable Mn, however, banded Mn along with an acidic fertilizer source proved to be superior to either factor alone. Plant available Mn was found to be more highly correlated with 0.1 $\underline{N}$ H_3PO_4 than DTPA extractable Mn.

Results of the 1975 fertilizer - Mn source field studies show that $MnSO_4$ tends to be superior to MnEDTA, Mangasol and MnO as a Mn source. At one location, an alkaline fertilizer source produced a significantly higher Mn content in beet petioles than an acid source while in 1976 an initially alkaline source of fertilizer tended to be inferior to an acid and slightly acid source with respect to beet yield. In 1976, plant Mn concentration was greatest for a fritted source of Mn and lowest for EDTA while $MnSO_4$, MnO and Mangasol were intermediate in effectiveness.

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Chapter 4

Nitrogen-Manganese Relationships in Sugarbeet Nutrition

The impetus for this research was primarily from field observations where Mn nutrition of sugarbeets is found to be improved by row fertilizer and where Mn deficiency and N deficiency can be confused, but Mn deficient plants test high in nitrate.

The concept that a high plant N level is necessary for efficient Mn uptake has been expressed by personnel within the sugarbeet industry (personal communication) as well as by researchers (Kroetz, 1975 and Kroetz and Schmidt, 1977). This would imply a N - Mn interaction within the plant which would be independent of fertilizer effects in the soil. Another opinion that has been expressed is that N is not efficiently utilized by sugarbeets if Mn is in short supply. Any direct effect of Mn on N uptake or nitrate reduction by the plant is unlikely, however Mn does effect many aspects of metabolism which could indirectly influence N metabolism. Specifically, Mn effects oxygen evolution by chloroplasts which could lead to nitrite accumulation and a feedback repression of nitrate reductase. Manganese is also prominent as an activator of enzymes mediating reactions of the Krebs cycle as well as other enzymes in the plant (Epstein, 1972 and Hewitt and Smith, 1974).

Nitrogen has been implicated in affecting Mn toxicity. Ouellette and Genereux (1965) found that fertilizers containing high levels of N reduce Mn toxicity. Cheng and Ouellette (1968) found that applied KCl favored the development of Mn toxicity symptoms over the other K sources because the plants were low in N when in the presence of a high chloride concentration.

The anions associated with N and K salts have been found to influence Mn uptake. Cheng et al. (1968) reported that Mn uptake was greater for KCl and K_2SO_4 treated plants than for K_2CO_3 treated plants. Hamilton (1966) found Mn uptake of N treated plants to be in the order $NH_4Cl > (NH_4)_2SO_4 > NH_4NO_3$. Both authors suspected a relationship between high fertilizer chloride and greater Mn uptake. Cheng felt that the interaction of KCl and Mn toxicity depended largely on the level of available N in the substrate.

Further proof that N can influence the uptake of Mn by plants is presented by Cheng and Ouellette (1970). In sand cultures with constant pH they found that plants supplied with neutral and basic N compounds contained appreciably less Mn than those receiving acid compounds. Furthermore, it did not make much difference whether N was in the nitrate or ammonium form.

Cheng and Doiron (1974) found that NH_4NO_3 had a positive effect on the exchangeable Mn level in the soil but a negative effect on the easily reducible Mn. Rinne, et al. (1974) reported that heavy applications of N reduce Mn concentration in ley grass but that uptake was increased due to stimulated growth by the added N.

Reaction products between ammonium and Mn have been found in soil (Hossner and Blanchar, 1968 and 1970). When ammonium phosphates and Mn were reacted with soil a water insoluble ammonium phosphate manganese product was obtained. Decreased availability of Mn was observed with increasing pH and pyro- to orthophosphate ratio. Reaction products formed at the site of placement were found to be available to the plants when blended with the soil.

The objective of this research was to test the direct interactive effects of N and Mn in sugarbeet nutrition.

Materials and Methods

Greenhouse hydroponics study

A hydroponics study with N levels of 70, 140 and 210 ppm and Mn levels of 0, 0.125, 0.25, 0.5 and 1.0 ppm was conducted using a complete factorial set of treatments. The treatments were replicated four times and arranged in a randomized complete block design. Two liters of a Hoaglands nutrient solution was used in each pot and the pH was maintained near 6.0 with NaOH or H_2SO_4. The nutrient solution was changed after two and three weeks and the solution pH was adjusted every two days.

Sugarbeet seeds were germinated in vermiculite and 21 seedlings transferred to each pot. After two weeks of growth, 12 plants were harvested and after four weeks the remaining nine plants were harvested (eight leaf stage). The harvested plants were rinsed in deionized water, dried in a forced air oven at $60^{o}C$, weighed for dry matter production and analyzed for nutrient concentration.

Field studies

A split-split plot design was used to evaluate two carryover N levels, four row N levels and four row Mn levels. Carryover N level was the main plot, row N level the subplot and Mn level the sub-subplot. Row N and Mn rates were 0, 22.4, 44.8 and 89.6; and 0, 4.48, 8.96 and 13.44 kg/ha, respectively for all years. Carryover N (previous year's N) rates for 1974, 1975 and 1976 were 0 and 67.2; 67.2 and 189.2; and 28 and 95.2 kg/ha following beans, corn and beans, respectively. Fertilizer carriers were ammonium nitrate, triple superphosphate, muriate of potash and manganese sulfate. The treatments were replicated four times.

All treatments were applied with belt applicators on a four row planter. The row spacing was 71 cm and the beets hand thinned to 20 cm after emergence. Plant tissue (petioles in 1974 and 1975, leaf blades in 1976) samples were taken from each plot at 12 weeks of growth, dried at 60^{o}C, ground and analyzed for Mn concentration. Two 8.06 meter rows per plot were mechanically harvested, the beets weighed for yield and 10 representative beets taken for quality analysis. Quality analyses were done by Michigan Sugar Company's laboratory.

Appendix Table 1 lists the characteristics of the soil used in this study.

Laboratory procedures

The method of Parkinson and Allen (1975) was used to digest all plant samples. Total N and P were determined colormetrically using an autoanalyzer, K determined by flame photometry and Ca, Mg, Mn, Fe, Zn and Cu determined by atomic absorption spectroscopy.

Results and Discussion

Hydroponics study

The hydroponics study was designed to determine the interactive effects of N and Mn without the complicating influence of soil factors or pH effects due to fertilizer treatment. Plant samples were taken after two and four weeks of growth.

No interactive effects were observed between N and Mn after two weeks of growth (Table 1). Increasing N rate had no effect on N concentration and uptake while increasing Mn increased the Mn concentration and uptake of the plants. Dry matter production was significantly greater for the 140 ppm N treatment than for the 210 ppm N treatment. Applied Mn had no significant effect on dry matter production.

After four weeks of growth (eight leaf stage), fresh weight and dry weight of leaves and petioles were both significantly increased with increasing N and Mn (Table 2). The N concentration of the plants decreased while N uptake was unchanged with increasing N. Increasing Mn had no effect on the N concentration of the plant tops but caused an increase in N uptake. This is primarily a reflection of increased growth. The Mn content and uptake in the plant tops was reduced by increasing N, however, the Mn level was high in all cases. Plant Mn also increased with increasing substrate Mn. Similar results were obtained for the root samples at the four week harvest (Table 3).

Results of the hydroponics study indicate that Mn has no direct effect on the N nutrition of the plants. N uptake was increased by increasing Mn, however, this reflects increased growth. Plant Mn was reduced by increasing N which most likely reflects a decreased ability

Table 1. Simple effects on whole sugarbeet plants after two weeks of growth, hydroponics study.

N Level	Mn Level	Dry Weight	N	P	K	Ca	Mg	Mn	Fe	Zn	Cu
--------ppm	---------	grams	Plant Nutrient Concentration								
			--------%--------					--------ppm--------			
N effects											
70		5.17	5.82	0.705	12.6	1.22	1.16	177	1768	70.5	13.2
140		5.52	5.73	0.678	12.5	1.22	1.21	162	1746	65.6	14.0
210		5.01	5.90	0.666	11.6	1.66	1.24	177	1958	68.1	12.9
LSD (0.05)		0.40	ns	ns	0.5	0.14	ns	ns	ns	ns	ns
Mn effects											
	0	5.00	5.65	0.706	12.0	1.43	1.22	102	1836	78.6	14.5
	0.125	5.42	5.77	0.671	12.4	1.32	1.18	130	1838	68.4	14.2
	0.25	5.37	5.87	0.703	12.1	1.40	1.18	163	1636	66.0	13.3
	0.5	5.03	5.83	0.675	12.4	1.31	1.23	200	1995	66.2	13.2
	1.0	5.33	5.95	0.658	12.5	1.38	1.21	265	1815	61.2	11.7
LSD (0.05)		ns	ns	ns	ns	ns	ns	66	ns	4.1	ns
			Plant Nutrient Uptake								
			--------mg/pot--------					--------µg/pot--------			
N effects											
70			301	36.4	651	62.0	60.4	036	9252	363	68.5
140			315	37.4	690	67.3	66.1	881	9505	362	76.9
210			294	33.4	579	82.9	61.9	880	9878	340	63.6
LSD (0.05)			ns	3.2	52	6.4	ns	ns	ns	ns	9.6
Mn effects											
	0		280	35.3	599	70.5	60.7	480	9073	391	72.6
	0.125		312	36.5	678	69.9	63.8	708	9926	369	77.3
	0.25		315	37.8	649	75.4	63.6	873	8954	354	70.7
	0.5		293	34.0	627	66.1	61.8	1012	10142	333	66.1
	1.0		315	35.0	647	71.9	64.0	1423	9630	327	61.6
LSD (0.05)			ns	ns	ns	ns	ns	331	ns	37	ns

Table 2. Simple effects on sugarbeet tops after four weeks of growth, hydroponics study.

N Level	Mn Level	Fresh Weight	Dry Weight	N	P	K	Ca	Mg	Mn	Fe	Zn	Cu
-----ppm-----		-----grams----		Plant Nutrient Concentration								
				%, N–Mg					ppm, Mn–Cu			
N effects												
70		43.6	3.67	5.55	0.735	13.0	0.918	0.985	185	216	79.8	11.1
140		53.8	4.18	5.37	0.686	13.8	0.894	1.13	149	185	68.9	8.03
210		53.3	4.23	5.24	0.665	11.7	1.15	1.06	129	190	48.7	8.27
LSD (0.05)		4.8	0.36	0.23	0.041	1.0	0.084	0.067	26	ns	8.8	2.51
Mn effects												
	0	31.9	2.58	5.51	0.822	12.0	1.06	1.18	9.42	211	84.2	15.1
	0.125	53.8	4.30	5.36	0.653	13.6	0.592	1.06	97.6	167	63.8	7.77
	0.25	51.8	4.30	5.21	0.666	13.0	0.968	0.999	157	165	61.8	8.40
	0.5	55.1	4.25	5.51	0.667	12.8	1.00	1.06	236	195	61.5	7.68
	1.0	58.6	4.69	5.33	0.667	12.9	0.948	0.988	270	246	56.1	6.57
LSD (0.05)		6.2	0.47	ns	0.052	ns	ns	0.087	33.14	55	11.4	3.24
				Plant Nutrient Uptake								
				mg/pot, N–Mg					µg/pot, Mn–Cu			
N effects												
70				203	26.8	480	33.6	35.7	731	780	284	37.3
140				223	37.7	583	36.9	46.7	683	766	275	31.3
210				221	27.5	503	48.0	44.4	586	795	197	32.9
LSD (0.05)				ns	ns	73	4.7	5.1	89	ns	39	ns
Mn effects												
	0			142	21.1	305	27.6	30.1	23.8	539	211	37.5
	0.125			230	28.1	593	40.8	45.8	415	720	273	33.2
	0.25			223	28.5	564	41.6	43.4	659	699	261	35.4
	0.5			233	28.1	541	43.0	45.4	990	821	257	32.5
	1.0			249	30.9	606	44.5	46.5	1247	1122	255	30.8
LSD (0.05)				20	3.5	95	6.0	6.0	115	219	ns	ns

Table 3. Simple effects on sugarbeet roots after four weeks of growth, hydroponics study.

N Level	Mn Level	Dry Weight	N	P	K	Ca	Mg	Mn	Fe	Zn	Cu
--------ppm---------		grams	Plant Nutrient Concentration								
			%					ppm			
N effects											
70		0.966	4.01	0.956	7.60	0.757	0.644	639	10148	136	27.8
140		0.993	3.78	0.872	6.72	1.17	1.32	634	10958	131	26.7
210		1.21	3.38	2.98	6.06	3.75	1.58	551	9658	100	22.3
LSD (0.05)		0.119	0.45	0.635	1.12	0.768	0.526	ns	ns	21	ns
Mn effects											
	0	0.750	3.49	1.78	6.05	2.17	1.11	165	15408	163	34.7
	0.125	1.08	3.74	1.89	7.36	2.01	1.42	190	8588	110	24.8
	0.25	1.10	3.74	1.48	6.67	1.81	1.18	427	8756	109	23.6
	0.5	1.11	3.86	1.28	7.88	1.65	1.04	839	9092	127	23.8
	1.0	1.24	3.60	1.48	6.00	1.83	1.15	1421	9428	105	20.9
LSD (0.05)		0.154	ns	ns	1.44	ns	ns	142	3303	27	6.5
			Plant Nutrient Uptake								
			mg/pot					µg/pot			
N effects											
70			38.5	9.07	73.9	7.12	5.66	714	9688	128	26.7
140			37.8	8.65	66.8	11.5	14.4	677	10485	123	24.9
210			41.0	36.6	72.3	48.0	19.3	708	10812	120	25.6
LSD (0.05)			ns	8.40	ns	10.26	5.85	ns	ns	ns	ns
Mn effects											
	0		25.8	16.3	44.2	19.4	9.85	123	11510	120	25.4
	0.125		42.1	22.1	78.0	23.9	15.6	210	9374	117	26.5
	0.25		40.4	17.8	71.8	22.5	13.2	457	9412	115	25.1
	0.5		42.7	15.2	87.2	20.5	12.0	916	9883	138	26.0
	1.0		44.4	19.2	73.8	24.8	14.7	1791	11446	129	25.7
LSD (0.05)			7.3	ns	18.9	ns	ns	228	ns	ns	ns

of the plant to absorb Mn when N is high. The same results were observed by Rinne et al. (1974).

Field studies

The field studies were designed to evaluate the effects of carryover N, row applied N and Mn and the interactive effects of N and Mn on sugarbeets. The results are given in Table 4, 5 and 6.

Beet and recoverable sugar yields increased with increasing row N all three years of the study. Increasing carryover N increased beet yields two of the three years and increased recoverable sugar per ha one of the three years. Increasing row applied Mn had no effect on beet yields but did influence the yield of recoverable sugar in 1976.

The yield data shows that the beets responded to carryover and row applied N. Yields generally were not affected by row applied Mn which would indicate that no severe Mn deficiencies occurred in the plots. Leaf blade Mn levels in 1976 would support this contention (Table 6). The quality components of sugar percentage, clear juice purity and recoverable sugar per ton were generally reduced by increased row applied N but were largely uneffected by carryover N and row applied Mn. Amino N in the beets was significantly increased with row applied N but was not significantly altered by carryover N or row applied Mn.

Row applied N increased plant N all three years. Plant N was increased by carryover N one of the three years while Mn had no affect. Plant P was significantly influenced by row N all three years. Plant Mn decreased with applied N and increased with row applied Mn.

The results of the field study show that sugar production responded to applied and carryover N and that the highest level of applied N was

Table 4. Simple effects of carryover N and row N and Mn on sugarbeets, 1974.

Previous year's N	Row N	Row Mn	Yield	Sugar	CJP	Recoverable Sugar		Amino N	Petiole Nutrients N	P	Mn
----------kg/ha----------			t/ha	------%------		kg/t	kg/ha	meq/100s	----%----		ppm
Carryover N effects											
0			50.7	17.7	96.5	311	7890	5.54	1.45	0.331	9.88
67.2			52.2	17.9	96.6	315	8222	5.89	1.46	0.323	9.91
LSD (0.05)			ns	ns	ns	ns	ns	ns	ns	ns	ns
Row N effects											
	0		47.7	17.7	96.9	313	7481	4.23	1.29	0.347	11.2
	22.4		51.6	18.0	96.6	317	8183	5.05	1.29	0.317	10.2
	44.8		52.4	17.9	96.8	316	8293	5.03	1.45	0.318	9.53
	89.6		54.0	17.6	96.0	306	8267	8.53	1.79	0.325	8.72
LSD (0.05)			1.5	ns	0.3	4	633	0.30	0.12	0.014	1.28
Row Mn effects											
		0	51.4	17.8	96.4	313	8049	6.03	1.46	0.336	8.44
		4.48	51.6	17.7	96.7	312	8047	5.51	1.49	0.332	9.41
		8.96	51.6	17.9	96.5	314	8108	5.73	1.40	0.322	9.91
		13.44	51.0	17.8	96.7	313	8020	5.58	1.47	0.328	11.8
LSD (0.05)			ns	ns	ns	ns	ns	ns	ns	0.011	0.74

Table 5. Simple effects of carryover N and row N and Mn on sugarbeets, 1975.

Previous year's N	Row N	Row Mn	Yield	Sugar	CJP	Recoverable Sugar		Amino N	Petiole Nutrients N	P	Mn
----------kg/ha----------			t/ha	------%------		kg/t	kg/ha	meq/100s	----%----		ppm
Carryover N effects											
67.2			60.3	18.2	94.7	155	9311	11.1	2.36	0.215	10.2
179.2			67.9	17.7	94.3	150	10153	12.3	2.80	0.205	9.02
LSD (0.05)			6.3	0.3	ns	ns	347	ns	0.21	ns	1.04
Row N effects											
	0		57.8	18.3	94.6	156	8976	10.2	2.29	0.229	10.4
	22.4		58.6	18.0	94.8	153	8923	10.6	2.32	0.204	9.97
	44.8		66.3	18.0	94.6	153	10161	11.3	2.53	0.194	8.72
	89.6		73.9	17.6	94.0	148	10869	14.6	3.19	0.213	9.44
LSD (0.05)			5.8	0.3	0.4	3	570	1.3	0.13	0.020	0.17
Row Mn effects											
		0	62.5	18.0	94.4	152	9463	11.9	2.56	0.213	8.94
		4.48	64.5	18.0	94.4	153	9818	11.6	2.62	0.207	9.13
		8.96	64.3	17.9	94.6	152	9753	11.6	2.59	0.204	9.81
		13.44	65.1	18.0	94.5	153	9895	11.7	2.56	0.216	10.6
LSD (0.05)			ns	ns	ns	ns	ns	ns	ns	ns	0.56

Table 6. Simple effects of carryover N and row N and Mn on sugarbeets, 1976.

Previous year's N	Row N	Row Mn	Yield	Sugar	CJP	Recoverable Sugar		Amino N	Leaf Blade Nutrients N	P	Mn
----------kg/ha----------			t/ha	------%------		kg/t	kg/ha	meq/100s	----%----		ppm
Carryover N effects											
28.0			43.1	19.9	96.5	167	7205	4.75	3.70	0.323	28.8
95.2			47.4	19.0	96.4	167	7900	4.89	3.96	0.325	26.7
LSD (0.05)			3.9	ns	ns	ns	ns	ns	ns	ns	ns
Row N effects											
	0		39.5	19.0	96.6	167	6606	3.94	3.52	0.323	33.6
	22.4		43.2	19.0	96.5	167	7212	4.29	3.63	0.317	30.2
	44.8		46.2	19.1	96.4	168	7753	4.65	3.91	0.321	25.3
	89.6		52.0	19.0	96.3	166	8638	6.05	4.26	0.336	21.9
LSD (0.05)			1.7	ns	0.2	ns	319	0.50	0.12	0.011	3.1
Row Mn effects											
		0	45.6	18.9	96.3	166	7571	5.03	3.88	0.327	23.0
		4.48	44.5	19.0	96.5	168	7454	4.70	3.85	0.324	26.3
		8.96	46.5	19.1	96.5	168	7798	4.58	3.74	0.320	29.7
		13.44	44.3	18.9	96.5	167	7387	4.62	3.84	0.324	31.9
LSD (0.05)			ns	ns	ns	ns	285	ns	ns	ns	2.4

not enough to maximize yields. Applied Mn generally did not influence sugar production. Plant analysis results indicate that Mn has no effect on the N uptake and utilization by the plant but that increased applied N reduces the Mn content of the plants. These results agree with the results of hydroponics study.

Summary

The results of this research indicates that Mn has no direct effect on N uptake by the plant but that increased N tends to reduce the Mn content of the plants. Under conditions of the field study, sugar production was increased by nitrogen applications up to at least 89.6 kg/ha but was not influenced by applied Mn even though beet petiole Mn was only 8-10 ppm at 12 weeks of growth. Increased carryover N tended to increase sugar production. Quality components tended to decrease with applied N but were unaffected by row applied Mn.

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Chapter 5

Effect of Fertilizer and Mn Band Placement and Foliar Applied Mn on Sugarbeets

The most critical period for Mn deficiencies on sugarbeets (Beta vulgaris L.) in Michigan is early in the growing season. This implies that the limited root systems of the young plants must come into contact with the fertilizer band Mn to obtain optimum benefit from its increased availability. This has led some people to advocate placing the fertilizer band directly below the seed to insure good root-fertilizer band contact early in the growing season (Kroetz, 1973, 1975 and Kroetz and Schmidt, 1977). However, there are some possible detrimental effects of placing the fertilizer directly below the seed, i.e. reduced germination from fertilizer salts and unfavorable soil physical properties resulting from the fertilizer opener disturbing the soil where the seed will be placed. Thus, the objective of the fertilizer-Mn placement study was to compare the effects of placing the fertilizer directly below the seed to placing it below and to the side of the seed.

Another method that is frequently used to correct Mn deficiencies is foliar treatments. Foliar sprays are usually considered effective, however, differences exist in the literature on the number and frequency of applications necessary to correct Mn deficiencies (Murphy and Walsh, 1972). Kroetz et al. (1973) found that two or three sprays on soybeans was not superior to one spray while Christenson (1973) recommended that repeated applications may be needed on sugarbeets. The number and frequency of sprays undoubtedly depends on whether the expanding roots intercept adequate Mn as they grow.

The distribution of foliar applied Mn within the plant is different from soil applied Mn. Jaham and Amin (1967) showed that in cotton added Mn only moves in an acropetal manner and that foliar applied Mn will not move to the roots or to lower parts of the plant. Substrate Mn was found to move to all parts of the plant. A similar response was observed by Labanauskas (1962) who reported that foliar applied $MnSO_4$ corrected Mn deficiency symptoms on the foliage sprayed but was not translocated to new growth.

Many Mn carriers have been evaluated for foliar sprays but $MnSO_4$ and MnEDTA are the most common. Both sources are reported to be effective by many researchers (Murphy and Walsh, 1972), however, there is not universal agreement. Labanauskas (1962) and Kroetz et al. (1973) both found $MnSO_4$ to be effective and MnEDTA to be ineffective in correction Mn deficiencies. Ozaki (1955) found the relative effectiveness of Mn carriers as foliar sprays dependent upon the source and the crop, i.e. sulfate was superior to EDTA, oxide and oxysulfate on beans but all sources were equal on peas.

The purpose of the Mn foliar studies was to evaluate the effectiveness of $MnSO_4$ and MnEDTA as foliar sprays at several rates and frequencies of application.

Materials and Methods

The Mn-fertilizer placement studies were located at the Ben DuRussell, Dale Smith and Wally Koeppendorfer farms in 1975 and at the Don Abraham and Kenny Hecht farms in 1976 (Appendix Table 1). All studies were identical and consisted of six treatments; two with row fertilizer only with placements of either 7.6 cm below the seed or 5 cm to-the-side and 5 cm below the seed with the remaining four treatments consisting of all combinations of placing the fertilizer and Mn at the two possible placements. The below-the-seed fertilizer placement was accomplished by positioning an extra fertilizer opener directly in front of the seed opener. Mn was applied as liquid $MnSO_4$ at 9 kg Mn/ha. Boron was applied to all plots at 2.24 kg/ha as liquid solubor. Location and fertilizer sources were as follows: Koeppendorfer, 16-41-23 consisting of 21-53-0 and 0-0-60; Smith, manufactured 6-24-12; DuRussell, 8.3-23-15 consisting of 33-0-0, 0-46-0 and 0-0-60; and Hecht and Abraham, 14.5-14.5-14.5 consisting of 33-0-0, 0-46-0 and 0-0-60. All were applied at 530 kg fertilizer per ha.

The foliar Mn studies were located at the Gordy Bierlein, Ike Schmidt and Ben DuRussell farms in 1975 and at the Don Abraham and Kenny Hecht farms in 1976 (Appendix Table 1). All studies were planted with row fertilizer at 530 kg/ha and 2.24 kg B/ha as liquid solubor. Row fertilizer was 6-24-12 in 1975 and 12-12-12 in 1976. The foliar treatments were applied using a hand held two row applicator consisting of a spray boom, a 12 ℓ stainless steel source tank and a small CO_2 tank as a pressure source. The solution was applied at 187 ℓ/ha. Approximately one gram of laboratory detergent per 10 ℓ of foliar spray was used as a wetting agent.

All research plots were planted with a 5 cm seed spacing in 71 cm rows. After emergence, the plants were thinned to a 20 cm spacing. The Mn placement studies consisted of four row plots while the foliar studies were two row plots. Harvestable rows were 13.7 m long on all studies. Pyrimin and TCA herbicides were applied at planting at all locations at the recommended rates (Meggitt, 1976). Plant petiole samples were taken 12 weeks after planting from each plot. All plots were mechanically harvested, beets weighed for yield and 10 beets taken for quality analysis. Quality analyses were carried out by the Michigan Sugar Company's Laboratory.

Petiole samples were dried in a forced air drier at 60°C, ground and digested using the wet oxidation procedure of Parkinson and Allen (1975). Plant Mn concentration was determined using atomic absorption spectroscopy.

Results and Discussion

Results for the Mn-fertilizer placement study are given in Table 1 and results for the foliar Mn studies are given in Tables 2-5. No significant response to treatment was observed in any of the studies. This shows that no significant Mn deficiency occurred under the conditons of these studies and that no conclusions can be made concerning the effectiveness of any of the treatments. No Mn deficiency symptoms were observed in the plot areas.

The lack of an increase in the petiole Mn with added Mn in the foliar study is unexpected. Apparently very little of the spray was intercepted by the petioles and any increase in Mn in the leaf blades would not be translocated to the petiole since Mn only moves acropetally in plants. This supposition is supported by other research at Michigan State University where it was found that foliar Mn treatments were reflected in leaf blade samples of sugarbeets and soybeans only if the tissue sampled was present to intercept the spray, i.e. leaves developing after the Mn was applied did not reflect treatment (D. R. Christenson and R. D. Voth, 1977. Efficacy of foliar applied Zn and Mn as compared to inorganic salts. Presented before Div. S-4, Soil Sci. Soc. Amer. Abstracted in Agron. Abstracts, Amer. Soc. Agron.).

Table 1. Effect of fertilizer and manganese band placement on sugarbeets.

Placement[a]					Recoverable Sugar			
Fertilizer	Manganese	Yield	Sugar	CJP			Amino N	Petiole Mn[b]
		t/ha	-------%------		kg/t	kg/ha	meq/100s	ppm
Ben DuRussell Farm (1975)								
side	---	51.1	14.2	96.0	123	6263	3.63	23.5
below	---	61.9	14.5	96.2	125	7753	3.31	21.1
side	side	60.9	14.4	96.7	126	7619	2.17	18.0
below	side	52.7	13.8	96.4	120	6397	3.25	20.3
side	below	59.3	14.1	96.2	122	7196	3.27	20.3
below	below	48.0	14.2	95.6	121	5801	4.00	22.7
LSD (0.05)		ns	ns	ns	ns	ns	ns	ns
cv		17.7	4.5	0.5	5.1	18.7	20.3	16.8
Dale Smith Farm (1975)								
side	---	71.1	16.7	93.5	139	9823	13.9	40.7
below	---	57.5	16.6	93.4	137	7891	14.4	56.8
side	side	67.3	17.0	94.0	142	5882	14.5	31.0
below	side	57.7	16.8	93.4	139	8064	14.5	45.0
side	below	65.0	16.9	93.6	140	5408	14.7	45.8
below	below	69.5	17.1	93.7	143	9906	14.6	22.4
LSD (0.05)		ns	ns	ns	ns	ns	ns	ns
cv		13.3	2.3	0.4	3.0	40.8	11.9	42.9
Wally Koeppendorfer Farm (1975)								
side	---	58.2	16.6	94.8	141	8193	10.8	30.3
below	---	54.7	17.0	94.8	145	7913	9.96	17.5
side	side	54.4	16.6	94.7	141	7672	10.7	26.6
below	side	55.2	16.9	94.6	143	7891	9.65	27.8
side	below	54.1	16.8	94.4	141	7654	12.4	23.0
below	below	49.2	16.5	94.6	139	6874	11.1	26.1
LSD (0.05)		ns	ns	ns	ns	ns	ns	ns
cv		9.0	2.7	0.4	3.6	7.9	16.2	37.0

Table 1. (cont'd).

Placement[a]								
Fertilizer	Manganese	Yield	Sugar	CJP	Recoverable Sugar		Amino N	Petiole Mn[b]
		t/ha	-------%------		kg/t	kg/ha	meq/100s	ppm
Don Abraham Farm (1976)								
side	---	45.1	19.3	94.4	167	7506	5.53	
below	---	42.9	19.8	95.4	171	7347	6.58	
side	side	44.3	19.6	96.0	172	7605	4.62	
below	side	44.3	19.2	95.6	166	7392	5.52	
side	below	42.2	19.4	95.7	169	7099	5.80	
below	below	41.4	19.5	95.6	169	6995	5.94	
LSD (0.05)		ns	ns	ns	ns	ns	ns	
cv		10.5	2.2	0.5	2.5	11.5	35.6	
Kenny Hecht Farm (1976)								
side	---	48.8	18.7	96.5	164	8040	3.33	
below	---	43.3	18.4	96.3	162	7014	3.88	
side	side	52.3	18.6	96.5	164	8560	3.51	
below	side	49.2	18.7	95.8	163	8007	3.65	
side	below	47.2	18.4	96.4	162	7610	3.39	
below	below	51.4	18.5	96.8	164	8416	3.59	
LSD (0.05)		ns	ns	ns	ns	ns	ns	
cv		9.2	2.6	0.5	3.0	9.8	21.0	

[a] Side = 5 cm to-the-side and 5 cm below the seed. Below = 7.6 cm directly below the seed.

[b] No petiole samples were taken in 1976.

Table 2. Effect of foliar applied Mn on sugarbeets, Bierlein farm, 1975.

Mn Source	Rate per spraying	Number of sprayings	Yield	Sugar	CJP	Recoverable Sugar		Amino N	Petiole Mn[a]
			t/ha	------%------		kg/t	kg/ha	meq/100s	ppm
---	0	0	81.3	14.7	93.0	120	9717	20.6	18.6
$MnSO_4$	1.12	1	80.8	14.3	92.7	116	9351	22.2	23.6
	0.56	2	76.5	14.7	93.0	121	9256	21.3	
	0.37	3	83.3	14.7	92.7	119	9905	22.1	
	2.24	1	81.0	14.5	93.0	118	9577	20.2	19.0
	1.12	2	81.4	14.0	92.1	112	9124	22.4	
	0.75	3	85.3	14.4	92.4	116	9908	24.0	
	4.48	1	78.2	14.7	93.9	122	9559	18.3	16.9
	2.24	2	76.2	14.5	92.4	117	8880	23.6	
	1.12	3	77.8	14.7	93.0	120	9294	20.3	
MnEDTA	0.56	1	78.4	14.2	92.5	114	8920	20.7	17.7
	0.28	2	79.2	13.7	91.1	107	8493	27.2	
	0.19	3	81.5	14.3	92.5	116	9447	23.0	
	1.12	1	81.1	14.7	92.1	120	9780	22.2	19.0
	0.56	2	82.4	14.9	93.5	123	10125	18.9	
	0.37	3	81.6	13.9	91.2	109	8933	28.8	
	2.24	1	81.8	14.7	92.9	120	9785	19.3	22.2
	0.75	3	82.6	15.1	93.4	124	10230	19.2	
LSD (0.05)			ns	ns	ns	ns	ns	ns	ns

[a] Tissue samples were taken after the first spray.

Table 3. Effect of foliar applied Mn on sugarbeets, Schmidt farm, 1975.

Mn Source	Rate per spraying	Number of sprayings	Yield	Sugar	CJP	Recoverable Sugar		Amino N	Petiole Mn[a]
			t/ha	------%	------	kg/t	kg/ha	meq/100s	ppm
---	0	0	56.0	17.2	96.7	151	8483	5.26	7.60
$MnSO_4$	1.12	1	57.1	17.4	97.2	154	8834	4.53	7.85
	0.56	2	58.8	17.3	96.5	152	8912	6.89	
	0.37	3	62.9	16.9	96.5	148	9313	7.51	
	2.24	1	56.5	17.3	96.9	153	8624	5.79	8.83
	1.12	2	63.2	17.2	96.7	152	9585	6.91	
	0.75	3	65.2	17.1	96.7	151	9810	7.01	
	4.48	1	56.7	17.5	96.7	155	8755	6.60	8.23
	2.24	2	64.4	17.0	96.2	149	9533	7.91	
	1.12	3	59.2	17.3	96.6	152	8984	6.81	
MnEDTA	0.56	1	57.8	17.4	96.7	153	8832	6.06	7.40
	0.28	2	54.7	17.7	97.0	157	8549	5.26	
	0.19	3	53.3	17.2	97.1	151	8105	6.21	
	1.12	1	56.6	16.9	96.9	150	8485	5.73	8.20
	0.56	2	62.7	16.9	96.2	147	9237	8.14	
	0.37	3	61.2	17.3	96.6	152	9283	6.39	
	2.24	1	61.2	17.2	96.6	151	9212	6.75	10.1
	1.12	2	57.5	17.2	96.7	152	8729	6.18	
	0.75	3	53.2	17.3	96.6	152	8082	6.27	
LSD (0.05)			ns	ns	ns	ns	ns	ns	ns

[a] Tissue samples were taken after the first spray.

Table 4. Effect of foliar applied Mn on sugarbeets, DuRussell farm, 1975.

Mn Source	Rate per spraying	Number of sprayings	Yield	Sugar	CJP	Recoverable Sugar		Amino N	Petiole Mn[a]
	kg/ha		t/ha	------%	------	kg/t	kg/ha	meq/100s	ppm
---	0	0	62.4	13.8	96.2	120	7450	3.46	15.9
$MnSO_4$	3.36	1	58.7	14.3	97.1	126	7379	2.36	15.4
	1.68	2	61.6	13.7	96.6	119	7336	2.74	
	6.72	1	56.8	13.6	96.7	118	6715	2.45	15.0
	3.36	2	53.7	14.0	96.6	122	6565	2.75	
MnEDTA	0.56	1	59.4	14.0	96.4	122	7230	2.77	15.0
	1.12	1	61.8	13.5	96.2	116	7201	3.03	
	0.56	2	50.3	13.5	96.6	117	5903	2.87	
LSD (0.05)			ns	ns	ns	ns	ns	ns	ns

[a] Tissue samples were taken after the first spray.

Table 5. Effect of foliar applied Mn on sugarbeets, 1976.

Mn Source	Rate per spraying	Number of sprayings	Yield	Sugar	CJP	Recoverable Sugar		Amino N
	kg/ha		t/ha	-------%-------		kg/t	kg/ha	meq/100s
Abraham Farm								
---	0	0	38.8	19.6	95.2	169	6568	3.77
$MnSO_4$	0.45	1	37.7	19.7	96.1	173	6515	3.79
	0.45	2	37.9	19.7	95.9	172	6496	3.96
	1.12	1	34.9	19.7	96.2	173	6026	3.58
	1.12	2	39.4	19.9	96.9	174	6855	4.37
	1.12	3	37.3	19.6	96.1	172	6440	3.60
MnEDTA	0.45	1	39.3	19.7	96.0	172	6781	3.55
	0.45	2	36.6	19.7	96.4	173	6343	3.91
	0.45	3	36.8	19.5	96.0	170	6439	3.76
LSD (0.05)			ns	ns	ns	ns	ns	ns
Hecht Farm								
---	0	0	44.7	17.7	96.9	157	7002	2.53
$MnSO_4$	0.45	1	46.8	17.9	97.1	159	7436	2.47
	0.45	2	44.3	17.6	97.0	156	6937	2.97
	1.12	1	44.8	17.8	97.1	158	7089	2.43
	1.12	2	45.2	17.9	96.9	159	7162	2.56
	1.12	3	42.9	17.5	97.3	156	6665	2.04
MnEDTA	0.45	1	44.2	17.7	97.2	158	6970	2.48
	0.45	2	45.8	17.8	97.0	157	7219	2.16
	0.45	3	44.3	17.9	96.8	158	6976	3.11
LSD (0.05)			ns	ns	ns	ns	ns	ns

Summary

No responses were observed because adequate Mn was available for optimum growth at all locations so no conclusions can be drawn concerning the effectiveness of the treatments.

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APPENDIX

Table 1. Soil characteristics of research sites.

Cooperator	Year	County	Township	Section	Soil Type	pH	P	K	Ca	Mg	Mn HCl	Mn DTPA
							---------kg/ha--------				--ppm---	
I. Schmidt	1974	Bay	Frankenlust	11	Parkhill cl.l.	8.1	68	232	7266	1122		0.7
D. Abraham	1974	Saginaw	Blumfield	31	Kawkawlin l.	7.8	130	239	5887	940		2.0
B. DuRussell	1975	Bay	Merritt	35	Parkhill cl.l.	7.8	72	255				1.2
G. Bierlein	1975	Tuscola	Tuscola	29	Kibbie si.l.	7.7	72	248				1.8
I. Schmidt	1975	Bay	Frankenlust	11	Parkhill cl.l.	8.1	68	232	7266	1122		0.7
D. Smith	1975	Gratiot	Emerson	10	Selfridge si.l.	6.3	116	206	4032	336	33	1.9
W. Koeppendorfer	1975	Tuscola	Tuscola	18	Parkhill cl.l.	7.4	108	296	6272	853	50	1.1
D. Abraham	1976	Saginaw	Blumfield	31	Kawkawlin l.	7.2	90	296	5675	766	91	
K. Hecht	1976	Tuscola	Tuscola	3	Brookston l.	7.7	83	296	6869	780	64	
Bean & Beet Farm		Saginaw	Swan Creek	9	Charity cl.	7.9	45	464	10744	1794	32	
C. Stockmeyer[a]		Tuscola	Gilford	30	Tappan l.	7.9	3	367	18449	2079	10	

[a] Soil used in the incubation and greenhouse studies.

Table 2. Mean soil boron levels for boron research sites.

Location	Year	B	Standard Deviation
		ppm	
Bean-Beet Farm	1973	0.63	0.23
Bean-Beet Farm	1974	0.66	0.23
I. Schmidt	1974	1.10	0.15
D. Abraham	1974	1.09	0.16
B. DuRussell	1975	1.11	0.21
B. DuRussell (Foliar)	1975	1.03	0.24
I. Schmidt	1975	1.61	0.25
D. Abraham	1976	0.91	0.24
K. Hecht	1976	0.89	0.13

Table 3. Treatment effects, greenhouse fertilizer-Mn placement study.

N	Placement		$MnSO_4$	Dry	Plant Nutrient Concentration							
Source	N	P	Rate	Weight	N	P	K	Ca	Mg	Mn	Fe	Zn
			g/pot	g/pot	---------	---------	%	---------	---------	---------	ppm	---------
Urea	Band	Band	1.05	12.6	4.42	0.248	5.28	1.70	1.07	63.3	129	51.8
			0	12.9	4.20	0.245	5.63	1.09	1.10	22.0	109	40.3
		Mixed	1.05	13.9	4.18	0.295	5.43	1.78	1.03	17.3	105	55.3
			0	12.9	4.04	0.283	5.46	1.84	1.06	12.3	99.0	47.3
	Mixed	Band	1.05	12.0	4.02	0.248	6.28	1.69	0.960	74.8	89.8	44.0
			0	11.6	4.02	0.248	5.53	1.79	1.00	24.0	139	47.0
		Mixed	1.05	11.4	4.22	0.293	5.94	1.57	0.963	20.0	120	42.5
			0	8.72	3.81	0.320	5.74	1.70	1.04	12.0	120	51.3
AS	Band	Band	1.05	13.9	4.10	0.258	5.54	1.77	1.02	88.3	82.8	33.8
			0	13.8	4.18	0.253	5.48	1.84	1.10	35.0	97.8	38.3
		Mixed	1.05	14.8	4.13	0.295	5.58	1.73	1.03	23.0	99.8	33.5
			0	12.1	4.25	0.280	5.48	1.78	1.02	12.5	94.5	71.5
	Mixed	Band	1.05	11.8	4.05	0.263	6.02	1.60	1.03	74.5	88.5	57.3
			0	10.0	4.19	0.260	6.57	1.95	0.950	16.0	92.3	40.5
		Mixed	1.05	10.9	4.17	0.320	5.79	1.74	1.05	22.5	131.3	46.8
			0	10.6	4.13	0.315	5.91	1.59	0.973	12.3	84.5	41.5
LSD (0.05)				0.9	ns	0.012	0.32	0.16	ns	5.7	ns	ns

Table 3 (cont'd).

N Source	Placement N	Placement P	$MnSO_4$ Rate	Plant Cu	Soil pH Surface	Soil pH Band	Soil pH Bottom	DTPA Extractable Mn	DTPA Extractable Fe	DTPA Extractable Zn	DTPA Extractable Cu	H_3PO_4 Mn
			g/pot	ppm				ppm				
UREA	Band	Band	1.05	7.58	7.93	7.20	7.68	160.4	66.3	5.03	109	10.6
			0	6.85	7.85	7.38	7.70	3.63	71.3	5.18	107	0.825
		Mixed	1.05	7.35	7.70	7.53	7.73	27.7	70.3	5.38	99.5	3.08
			0	6.85	7.75	7.58	7.70	2.60	71.3	5.55	101	0.600
	Mixed	Band	1.05	7.90	7.90	7.23	7.93	239.6	75.5	5.58	118	22.6
			0	8.35	7.88	7.48	7.88	3.30	79.0	4.85	119	0.750
		Mixed	1.05	7.28	7.93	7.68	7.85	59.9	67.0	5.05	106	0.950
			0	7.05	7.75	7.85	7.93	2.88	75.0	5.48	105	0.600
AS	Band	Band	1.05	7.75	7.93	7.05	7.75	195.8	54.8	4.63	104	28.1
			0	7.90	7.83	7.25	7.80	3.10	61.8	4.75	101	1.00
		Mixed	1.05	7.03	7.75	7.55	7.75	61.9	50.3	4.10	92.8	1.73
			0	6.75	7.40	7.43	7.78	2.60	54.0	4.60	93.5	0.725
	Mixed	Band	1.05	6.78	7.80	7.25	7.75	169.1	75.3	6.00	115	13.9
			0	7.13	7.73	7.33	7.70	3.13	77.3	4.80	114	0.800
		Mixed	1.05	6.83	7.78	7.60	7.78	61.0	68.5	5.05	105	0.975
			0	7.20	7.70	7.70	7.78	2.65	71.0	5.45	100	0.675
LSD (0.05)				ns	ns	0.11	0.08	37.41	3.2	ns	5.9	2.467

Table 3 (cont'd).

N Source	Placement N	Placement P	$MnSO_4$ Rate	Plant Nutrient Uptake N	P	K	Ca	Mg	Mn	Zn	Fe	Cu
			g/pot	mg/pot					µg/pot			
UREA	Band	Band	1.05	558	31.2	664	215	135	799	1632	656	95.5
			0	543	31.8	727	219	142	287	1413	511	88.6
		Mixed	1.05	582	40.6	757	244	142	238	1445	769	102
			0	522	36.4	707	235	138	159	1252	610	87.5
	Mixed	Band	1.05	480	29.7	748	203	116	906	1088	526	95.5
			0	467	28.7	641	207	117	281	1581	537	96.3
		Mixed	1.05	480	33.3	678	177	110	232	1366	497	83.0
			0	333	28.0	500	150	91.0	106	1012	427	61.0
AS	Band	Band	1.05	566	35.7	764	244	141	1224	1155	467	107
			0	578	35.0	756	253	151	487	1349	534	110
		Mixed	1.05	610	43.2	822	255	151	338	1477	493	104
			0	509	33.5	660	213	122	150	1115	853	80.7
	Mixed	Band	1.05	478	30.8	712	185	120	864	1036	661	79.6
			0	421	26.2	653	196	96.7	160	930	407	72.3
		Mixed	1.05	454	34.8	631	189	114	241	1423	429	74.4
			0	437	33.3	625	167	103	130	894	440	75.9
LSD (0.05)				49	2.7	56	21	11.9	77	ns	ns	9.3

Table 4. Treatment effects, fertilizer-Mn source study, 1975.

Fertilizer Reaction	Mn Source	Yield	Sugar	CJP	Recoverable Sugar		Amino N	Plant Concentration						
					kg/t	kg/ha		P	K	Ca	Mg	Mn	Fe	Zn
		t/ha	-----%----		kg/t	kg/ha	meq/100s	-----------%-----------				-------ppm------		
DuRussell Farm														
Acid	---	57.4	14.2	96.4	124	7086	3.48	0.205	4.11	0.690	0.325	21.5	78.3	6.13
Alkaline	---	58.7	14.0	96.4	121	7109	3.61	0.185	4.30	0.725	0.310	21.5	73.5	4.73
Acid	$MnSO_4$	65.0	14.2	95.7	122	7930	4.30	0.193	4.17	0.680	0.330	25.8	75.9	5.90
Alkaline		61.8	14.0	96.3	121	7491	3.53	0.190	4.33	0.773	0.330	29.5	75.9	4.88
Acid	MnEDTA	54.7	13.9	96.8	121	6611	3.40	0.200	4.08	0.580	0.290	22.2	80.7	7.13
Alkaline		57.7	14.0	96.2	122	7000	3.67	0.203	4.14	0.675	0.350	21.5	90.3	13.9
Acid	Mangasol	60.0	14.8	96.4	129	7712	3.74	0.228	4.33	0.715	0.320	21.5	107	5.35
Alkaline		61.7	13.8	95.8	119	7316	4.55	0.185	4.26	0.673	0.335	20.1	80.7	3.83
Acid	MnO	60.3	14.1	96.2	122	7311	4.02	0.178	4.36	0.750	0.373	23.0	54.5	6.30
Alkaline		57.3	13.9	96.3	120	6861	3.86	0.175	4.38	0.790	0.330	20.1	54.5	7.10
LSD (0.05)		ns	ns	ns	ns	ns	ns	0.024	ns	ns	ns	5.3	ns	4.83
Schmidt Farm														
Acid	---	56.4	17.5	96.2	153	8596	6.33	0.203	4.60	0.643	0.265	5.63	62.6	11.9
Alkaline	---	54.1	17.6	96.5	155	8363	5.42	0.260	4.59	0.610	0.230	6.20	73.3	11.6
Acid	$MnSO_4$	57.4	17.4	96.2	152	8703	6.01	0.223	4.97	0.698	0.290	6.23	71.1	12.9
Alkaline		55.4	17.5	96.6	154	8554	4.83	0.260	5.09	0.583	0.259	7.28	55.6	10.6
Acid	MnEDTA	57.6	17.2	95.9	150	8584	6.87	0.195	4.63	0.575	0.253	4.23	55.6	9.00
Alkaline		52.7	17.1	96.2	149	7870	5.78	0.260	5.21	0.635	0.248	4.93	63.3	11.1
Acid	Mangasol	56.1	17.6	96.3	154	8644	6.25	0.228	4.80	0.610	0.248	4.93	59.8	9.30
Alkaline		56.9	17.4	96.3	152	8652	5.96	0.248	5.05	0.603	0.260	5.63	57.7	10.4
Acid	MnO	51.7	17.3	96.2	151	7814	5.23	0.233	4.45	0.540	0.215	4.93	58.4	10.6
Alkaline		54.2	17.5	96.5	153	8339	4.74	0.245	4.57	0.640	0.238	5.50	68.8	11.8
LSD (0.05)		ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	1.57	ns	ns

Table 5. Treatment effects, fertilizer-Mn source study, Abraham farm, 1976.

Mn Rate	Fertilizer Source	Mn Source	Yield	Sugar	CJP	Recoverable Sugar		Amino N	Plant Concentration								
									P	K	Ca	Mg	Mn	Fe	Cu	Zn	B
kg/ha			t/ha	-----%-----		kg/t	kg/ha	meq/100s	------------%------------				--------------ppm--------------				
0	Alkaline	---	36.1	19.3	95.7	168	6062	3.91	0.308	5.23	1.15	1.03	108	240	14.8	40.3	78.0
0	Acid	---	43.1	19.4	95.9	169	7286	3.74	0.320	4.76	1.20	1.06	78.5	199	14.8	36.0	80.3
0	Sl. Acid	---	38.2	19.0	95.6	165	6305	3.72	0.310	4.88	1.32	1.18	98.8	204	16.0	37.3	82.0
4.48	Sl. Acid	$MnSO_4$	44.4	19.3	95.6	167	7427	4.21	0.330	4.45	1.24	1.07	75.0	227	15.8	39.8	81.0
8.96	Sl. Acid	"	39.9	19.2	96.2	169	6706	2.91	0.300	4.88	1.22	1.03	112	203	15.0	45.0	87.8
13.4	Sl. Acid	"	43.6	19.5	96.0	171	7440	4.10	0.298	4.99	1.32	1.15	117	214	14.8	41.3	83.3
8.96	Alkaline	"	36.7	19.2	96.3	169	6193	2.23	0.338	4.65	1.16	1.06	82.5	242	16.0	41.3	74.8
"	Acid	"	39.0	19.4	95.9	169	6581	3.50	0.395	4.94	1.26	1.11	100	214	15.0	41.3	83.0
"	Alkaline	MnO	39.8	18.7	95.4	161	6423	3.24	0.305	4.88	1.33	1.22	129	245	14.3	43.0	83.0
"	Sl. Acid	"	44.4	19.0	95.7	165	7333	3.89	0.298	4.79	1.35	1.20	113	221	14.0	39.3	97.3
"	Acid	"	40.2	19.0	96.2	166	6674	3.62	0.303	4.84	1.31	1.18	84.5	214	14.8	39.5	75.8
"	Alkaline	Mangasol	40.7	19.1	95.9	166	6768	4.02	0.320	5.01	1.20	1.04	102	200	14.5	40.0	81.3
"	Sl. Acid	"	39.3	18.8	96.0	164	6453	2.63	0.325	4.99	1.26	1.12	96.3	232	15.0	41.3	76.8
"	Acid	"	40.3	19.1	96.1	167	6750	3.43	0.305	4.93	1.26	1.10	104	191	15.0	47.5	84.3
"	Alkaline	MnFrit	38.1	19.3	96.4	170	6504	3.07	0.305	4.71	1.22	1.06	134	279	14.8	42.5	101
"	Sl. Acid	"	42.7	19.5	95.9	170	7249	4.28	0.313	4.49	1.19	1.02	110	216	15.3	42.8	88.0
"	Acid	"	42.8	19.4	96.2	170	7270	3.39	0.285	4.62	1.22	0.995	99.5	184	15.0	42.8	84.8
1.40	Alkaline	MnEDTA	34.5	19.2	95.4	166	5690	3.46	0.318	4.81	1.19	1.06	87.8	212	14.5	40.3	90.0
"	Sl. Acid	"	39.5	19.2	95.7	167	6588	3.20	0.313	5.01	1.15	1.03	75.3	205	15.5	40.0	74.8
"	Acid	"	39.6	19.2	95.7	167	6603	3.95	0.303	4.58	1.23	1.09	77.0	234	14.8	40.8	77.3
LSD (0.05)			ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	28.0	ns	ns	ns	ns