YIELD, QUALITY AND TISSUE N AND Mn LEVELS AS AFFECTED BY INTERACTIONS BETWEEN APPLIED N and Mn*

R. D. Voth and D. R. Christenson

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INTRODUCTION

The impetus for this work arises from field observations where banded or sidedressed N increased the Mn concentration of sugarbeets. These observations have led to the conclusion that high levels of N are necessary for efficient Mn uptake and utilization by sugarbeets (8, 9). Plants deficient in Mn show symptoms similar to N deficiency, but test high in nitrate. This suggests that Mn may be necessary for the proper utilization of nitrate by the plant.

Any direct effect of Mn on nitrate reduction by the plant is unlikely. However, Mn does affect many aspects of metabolism which may indirectly influence N utilization. Specifically, O_2 evolution by chloroplasts is reduced by Mn deficiency which could lead to nitrite accumulation and a feedback repression of nitrate reductase. Manganese also is prominent as an activator of enzymes mediating reactions of the Krebs cycle as well as other enzymes in the plant (4, 5).

The most likely site of a N-Mn interaction is in the soil or at the site of nutrient absorption. Fertilizer band pH can have a large influence on Mn availability, however, it is not the only controlling factor. It is reported that ammonium phosphate fertilizers promote Mn availability over monocalcium phosphate (MCP) even though the lowest pH is produced by the latter source (6, 11, 15).

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Physiologically acid N compounds are reported to promote Mn uptake by plants over physiologically neutral and basic compounds in sand cultures (2). Mn toxicity symptoms can be reduced by providing high levels of N (1, 12).

Thus, some evidence exists to support the hypothesis that there are direct interactive effects between N and Mn. The objective of this research was to determine the interactive effects between N and Mn on yield, quality and tissue N and Mn status of sugarbeets.

MATERIAL AND METHODS

Hydroponics Study

A hydroponics study with N levels of 70, 140 and 210 ppm N (5, 10 and 15 mM) and Mn levels of 0, 0.125, 0.25, 0.5 and 1.0 ppm Mn (0, 2.3, 4.6, 9.1 and 18.2 μM) was conducted in a greenhouse using a complete factorial set of treatments. Nitrogen source was NH_4NO_3 and Mn source was $MnSO_4$. The experiment was replicated four times and arranged in a randomized complete block design. Two liters of Hoaglands nutrient solution was used in each 15.2 cm diameter plastic container. The solution contained in addition to the treatment, 1.0 mM P, 5.0 mM K, 2.5 mM Ca, 6.5 mM S, 2.0 mM Mg, 50 μM B, 0.80 μM Zn, 0.31 μM Cu 0.10 μM Mo per liter. Solution pH was adjusted every two days to pH 6.0 with NaOH or H_2SO_4. The nutrient solution was changed after two and again after three weeks.

Sugarbeet seeds were germinated in vermiculite and 21 seedlings transferred to each pot. After two weeks of growth, 12 whole plants were harvested and after four weeks (eight leaf stage) the remaining nine plants were harvested. The latter samples were separated into roots and tops. The harvested plants were rinsed in deionized water, dried in a forced air oven at 60° C and weighed for dry matter production.

Field Studies

A split-split plot design with four replications was used to evaluate two previously applied N levels, four band applied N levels and four band applied Mn levels. Previously applied N was the main plot, band applied N was the subplot and band applied Mn the sub-subplot. Previously applied N was the rate of

N applied to the crop preceding sugarbeets. The experiment was conducted for four years with two following navy beans and two following corn. Rates of N on navy beans were 30 and 67 kg/ha while on corn, 67 and 180 kg/ha. Band applied N and Mn rates on sugarbeets were 0, 22, 45 and 90; 0, 4.5, 9.0 and 13.4 kg element/ha, respectively for all years. Fertilizer carriers were ammonium nitrate, concentrated super-phosphate, and manganese sulfate. Row spacings were 71 cm and the beets were hand thinned to 20 cm after emergence. Leaf blade tissue samples were taken from each plot at 12 weeks of growth, dried at 60°C, ground and analyzed. Two 8.06 meter rows per plot were mechanically harvested, the beets weighed for yield and ten representative beets taken for quality analysis. The soil was a Charity clay (*Aeric Haplaquept*) with a pH of 7.9 and a 0.1 *N* HCl extractable Mn level of 32 ppm.

Laboratory Procedures

The method of Parkinson and Allen (13) was used to digest all plant samples. Nitrogen was determined colormetrically using an auto-analyzer. Mn was determined by atomic absorption spectroscopy.

Raw juice was extracted from the brei obtained by sawing the beets lengthwise. The juice was frozen immediately after extraction and analyzed following procedures described by Dexter, Frakes and Snyder (3). Quality measurements were percent sugar and clear juice purity. Recoverable sugar was based on a formula for fresh beets.

RESULTS

Hydroponics Study

The hydroponics study was designed to determine the interactive effects of N and Mn on N and Mn absorption by sugarbeets seedlings without the complicating influence of soil factors or pH effects due to fertilizer treatment. No interactive effects were shown between N and Mn on yield, Mn concentration and uptake or N concentration and uptake at either sampling date, except for Mn concentration in beet tops at four weeks.

Increasing N rate had no effect on N or Mn concentration and uptake by whole plants at two weeks (Table 1). Dry matter

Table 1. Simple effects of N and Mn on yield and nutrient status of sugarbeet seedlings at two sampling dates when grown in a hydroponics study.

N Level	Mn Level	Dry Weight	Plant Nutrient Concentration		Plant Nutrient Uptake	
			N	Mn	N	Mn
ppm		g/culture	%	ppm	mg/culture	µg/culture
Whole plants - 2 weeks						
N Effect						
70		5.17ab+	5.82a	177a	301a	836a
140		5.52b	5.73a	162a	315a	881a
210		5.01a	5.90a	177a	294a	880a
Mn Effect						
	0	5.00a	5.65a	102a	280a	480a
	0.125	5.42a	5.77a	130ab	312a	708ab
	0.25	5.37a	5.87a	163ab	315a	873b
	0.50	5.03a	5.83a	200bc	293a	1012b
	1.00	5.33a	5.95a	265c	315a	1423c
Plant tops - 4 weeks						
N Effect						
70		3.67a	5.55b	185‡	203a	731b
140		4.18b	5.37ab	149	223a	683b
210		4.23b	5.24a	129	221a	586a
Mn Effect						
	0	2.58a	5.51a	9.42‡	142a	23.8a
	0.125	4.30b	5.36a	97.6	230b	415b
	0.25	4.30b	5.21a	157	223b	659c
	0.50	4.25b	5.51a	236	233b	990d
	1.00	4.69b	5.33a	270	249b	1247e
Plant Roots - 4 weeks						
N Effect						
70		0.966a	4.01b	639a	38.5a	714a
140		0.993a	3.78ab	634a	37.8a	677a
210		1.21b	3.38a	551a	41.0a	708a
Mn Effect						
	0	0.750a	3.49a	165a	25.8a	123a
	0.125	1.08b	3.74a	190a	42.1b	210a
	0.25	1.10b	3.74a	427b	40.4b	457b
	0.50	1.11b	3.86a	839c	42.7b	916c
	1.00	1.24b	3.60a	1421d	44.4b	1791d

+ Any two column means within one sampling time followed by the same letter are not significantly different at the 5% level according to Duncan's Multiple Range Test.

‡Significant N x Mn interaction, see Table 2.

production tended to be increased at 140 ppm N over 70 ppm, but the difference was not statistically significant. Dry matter was reduced at 210 ppm N below that produced at 140 ppm. Dry matter, N concentration and N uptake were not affected by increasing Mn rates. However, increasing Mn rates increased both Mn concentration and uptake (without a yield increase), not reaching a maximum which suggests luxury consumption of Mn.

After four weeks of growth (eight leaf stage), dry weight of plant tops was significantly increased with increasing N and Mn (Table 1). The N concentration of the plant tops and roots decreased while N uptake was unchanged with increasing N. Increasing Mn had no effect on the N concentration of the plant tops and roots, but caused an increase in N uptake. This is a reflection of the increased growth with added Mn. Uptake of Mn also increased with increasing solution Mn.

Yield of roots was increased by 210 ppm N and N concentration in roots decreased with increasing rates of N (Table 1). The other parameters were not affected by N rate. Mn increased yield, Mn concentration, N uptake and Mn uptake. Only Mn concentration and uptake were increased by successive Mn levels above the 0.125 ppm level.

The effect of the N x Mn interaction on Mn concentration in plant tops is shown by a reduction in Mn concentration at rates above 0.25 ppm Mn with increasing N rate (Table 2). The same trend was apparent in roots, but the differences were not statistically significant.

Table 2. Interaction of N and Mn concentration in sugarbeet tops at four weeks.

Mn Level	N Level (ppm)		
	70	140	210
ppm	ppm Mn		
0	10.0	9.5	8.8
0.125	114	85	94
0.25	198	149	125
0.50	267	236	204
1.00	336	264	210
LSD (5%)		40	

Field Studies

The field studies were designed to evaluate the effects of previously applied nitrogen, currently banded N and Mn and their interactions on yield, quality and leaf tissue N and Mn of sugarbeets. There were no significant interactive effects between previously applied N, banded N, or banded Mn.

Yield and recoverable sugar were increased by the previous high N treatment after corn and tended to be after navy beans (Table 3). The higher previous N treatment increased percent N in the leaf tissue, but decreased the Mn level when corn was the previous crop. A similar trend existed after navy beans, but the differences were not significant.

Table 3. Effect of previously applied N on yield, recoverable sugar and leaf tissue N and Mn concentration for sugarbeets grown following navy beans and corn.

Nitrogen on Previous Crop	Yield	Recoverable Sugar	Nutrient Concentration N	Nutrient Concentration Mn
kg/ha	t/ha	kg/ha	%	ppm
		After Navy Beans		
30	46.8a[+]	7548a	2.57a	19.4a
67	49.7a	8061a	2.71a	18.3a
		After Corn		
67	60.0a	9192a	3.06a	23.3b
180	68.8b	10283b	3.59b	18.6a

[+]Any two column means within one previous crop followed by the same letter are not significantly different at the 5% level according to Duncan's Multiple Range Test.

Table 4. Effect of band applied N on yield, sugar concentration, clear juice purity (CJP), and leaf tissue N and Mn concentration for sugarbeets grown following navy beans and corn.

Banded Nitrogen	Yield	Sugar Concentration	CJP	Recoverable Sugar	Nutrient Concentration N	Nutrient Concentration Mn
kg/ha	t/ha	%	%	kg/ha	%	ppm
			After Navy Beans			
0	43.7a	18.3a	96.7a	7044a	2.41a	22.4d
22	47.5b	18.5a	96.5a	7697b	2.46a	20.2c
45	49.3c	18.5a	96.6a	8023b	2.68b	17.4b
90	52.9d	18.3a	96.1a	8453c	3.03c	15.3a
			After Corn			
0	59.4a	17.8b	95.9b	9158a	2.92a	24.3c
22	60.7a	17.5b	95.8b	9208a	3.08a	21.9b
45	65.9b	17.6b	95.8b	10059b	3.37b	19.7a
90	71.7c	17.2a	95.2a	10525c	3.96c	18.1a

[+]Any two column means within one previous crop followed by the same letter are not significantly different at the 5% level according to Duncan's Multiple Range Test.

Yields and tissue N were increased up to 90 kg N (Table 4). Mn concentration was decreased by increasing N rates following both crops. Beet quality was reduced at the highest banded rate after corn, but not sufficiently to reflect in recoverable sugar.

Tissue Mn concentration was increased with increasing rates of banded Mn, but tissue N was not affected (Table 5). Yield and recoverable sugar were increased by applied Mn after corn at the 4.5 kg/ha rate.

Table 5. Effect of band applied Mn on yield, recoverable sugar and leaf tissue N and Mn concentration for sugarbeets grown following navy beans and corn.

Banded Manganese	Yield	Recoverable Sugar	Nutrient Concentration N	Nutrient Concentration Mn
kg/ha	t/ha	kg/ha	%	ppm
		After Navy Beans		
0	48.6a+	7809a	2.67a	15.7a
4.5	47.9a	7750a	2.67a	17.9b
9.0	49.1a	7953a	2.57a	19.8c
13.5	47.7a	7703a	2.65a	21.8d
		After Corn		
0	62.7a	9484a	3.35a	17.0a
4.5	65.0b	9883b	3.38a	19.0b
9.0	65.0b	9830b	3.33a	22.8c
13.5	64.7b	9752b	3.25a	25.3d

+Any two column means within one previous crop followed by the same letter are not significantly different at the 5% level according to Duncan's Multiple Range Test.

DISCUSSION

Differences in yields between the two sets of field trials (following corn or navy beans) can be attributed mainly to differences in nitrogen nutrition. Linear correlations (r) between N application and yield were 0.99 and 0.95 for previously applied N and banded N, respectively. Even though maximum yields were not apparently reached as a result of banded N rates, we feel the objectives of evaluating interactions of N and Mn were met. Wide ranges in apparent N levels were established with inherent differences in Mn levels in plants.

Results of hydroponics and field studies show that Mn accumulation in foliar portions of sugarbeet plants is reduced by increasing levels of applied N. The results are in agreement with

Rinne et al (14) who observed decreased Mn uptake with high rates of N. However, solution and applied Mn did not seem to influence N levels in the plant.

One must conclude from these results and a companion paper (15) that increased Mn uptake associated with ammoniated phosphate, as compared to monocalcium phosphate (MCP) is due to chemical reactions in the soil increasing Mn availability. Even tnough MCP produces a lower pH than ammoniated phosphates, reaction products as a result of the increase in pH with diffusion away from the band actually precipitate Mn in unavailable forms (10, 11). With ammonium phosphates the acidity isn't as intense, Mn precipitation enhanced by dissolved Al and Fe is eliminated and the formation of NH_4 Mn-phosphates serves to keep Mn in a plant available form (6, 7).

One of the initial ideas in these studies was that increased Mn supply may serve to reduce the adverse effects of applied N on percent sugar and clear juice purity. Based on the results of the field studies, we reject this hypothesis. There were no significant interactions between applied N and applied Mn on any of the quality measurements. Applying additional Mn to compensate for high N on sugarbeets does not appear to be a reasonable management practice.

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