MICRONUTRIENT DEFICIENCIES IN MANITOBA CROPS

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Previous to 1975 very little information was available on micronutrient nutrition of crops and soils in Manitoba. This paper will report on micronutrient research since that time. Soils and crops which may exhibit deficiencies of copper, zinc, manganese and iron have been identified and improvements in interpretation of plant tissue analysis have been made for several crops. Critical levels of extractable soil micronutrient concentrations have been investigated but require further clarification. Investigations of the efficiencies of various micronutrient carriers and methods of fertilizer placement have identified rates and methods of applying micronutrient fertilizers to correct deficiencies. Other work has determined that soil properties such as temperature and moisture influence the plant availability of micronutrients in soils. Since 1974 much has been learned regarding the micronutrient status of Manitoba soils and crops, but a great deal more work will be required, especially in developing soil micronutrient diagnostic services.

Copper

Previous research had established that copper deficiencies are most likely to occur on organic (peat) soils and on acidic, leached sandy podzolic, brunisolic and gray Luvisolic mineral soils such as Pine Ridge, Menisino and Sandilands. Other neutral to slightly acidic sandy soils containing little or no lime such as Miniota, Stockton and Marringhurst might also be deficient in copper. Carrots and onions grown on organic soils in Manitoba had responded to copper fertilizer (2). In addition, in a greenhouse experiment on Pine Ridge sand, flax had responded to copper and the critical copper concentration in eight-week old flax seedling shoots was found to be 3 ppm (7). These figures obviate the need to further determine the extent and severity of Cu deficiency in Manitoba soils.

Copper was applied in 1976 as copper sulphate ($CuSO_4 \cdot 5H_2O$) with the seed of wheat, barley, oats and flax on Pine Ridge sand, 26 kilometers southeast of Steinbach. Copper sulphate and disodium copper ethylene diamine tetraacetetate (Na_2 Cu EDTA) were banded with the seed and mixed throughout the surface 15 centimeters on Menisino sand in 1977 and Pine Ridge sand in 1978. The experiment in 1977 and 1978 were located near the 1976 experiment. The levels of DTPA (diethylenediamine pentaacetic acid) extractable soil copper were 0.56 ppm, 0.24 ppm and 0.32 ppm in 1976, 1977 and 1978, respectively. In 1976, barley responded to copper fertilizer, but in 1977 and 1978 there were no responses to copper. The lack of response to copper and the low yields may have resulted at least partially from army worm damage in 1977 and from hail in 1978. Since the DTPA extractable copper levels in 1977 and 1978 were lower than in 1976, responses to copper were expected in 1977 and 1978.

Barley in the growth chamber on soil obtained from the 1976 field site responded to copper fertilization (Table 1), indicating that the soil DTPA critical level for mineral soils was at least 0.56 ppm. The critical copper concentration in shoots of six-week old barley was estimated at 5.2 ppm in the growth chamber. (1). Addition of copper in the growth chamber experiment decreased plant zinc concentrations (Table 1) to levels below the 12.5 ppm critical level (1) for barley, suggesting that copper may induce zinc deficiency. However, addition of zinc along with copper did not increase barley yields above those obtained with copper alone. The soil in the growth chamber experiment contained 1.2 ppm DTPA extractable zinc, whereas the soils in the 1977 and 1978 field experiments contained 0.46 ppm and 1.1 ppm zinc, respectively. Addition of zinc along with copper in the 1977 and 1978 field experiments also did not increase yields above those obtained with copper alone. Further research is needed in order to determine how environmental conditions other than the supply of copper influence incidence of copper deficiency and to develop more reliable copper soil test methods on sandy mineral soils. In addition, possible interactions between copper and other macro-and micronutrients need to be more thoroughly investigated.

Mixing copper sulphate throughout the soil was slightly more effective in increasing copper uptake in barley shoots than banding copper sulphate with the seed and far more effective than banding copper sulphate in a point below the seed. (Table 1). In experiments on organic soils in 1977 and 1978 mixing copper sulphate with the surface 15 centimeters was much more effective in increasing copper uptake by barley than banding copper sulphate with the seed. Similar but less dramatic results were obtained with Na_2 Cu EDTA on organic soils in 1977 and 1978 on Pine Ridge sand in 1977. Na_2 Cu EDTA was approximately five times as effective as copper sulphate in increasing copper uptake of barley on organic soils in 1977 and 1978 and on Pine Ridge sand in 1977. The aforementioned effects of copper fertilizer placement and type of carrier upon copper fertilizer efficiency are illustrated well by the data in Table 2 from the 1978 field trial on organic soil near Piney.

Copper was applied to wheat, barley, oats and flax on organic soils near Piney in 1977 and 1978 and to wheat on organic soils near Marchand and Stead. Wheat, oats and flax at Piney in 1977 and flax at Piney in 1978 did not mature well because of frost and/or disease. Barley yields were very high (5 t/ha) at Piney in 1977 but there was little or no response to copper. At Piney in 1978 no harvested grain yields of wheat were obtained without fertilizer. (Table 3). Application of macronutrients resulted in yields of 1060, 1540 and 2750 Kg/ha of wheat, oats and barley, respectively. Adding copper as well as macronutrients nearly doubled oat yields and slightly increased barley yields. Apparently the barley was not as sensitive to copper deficiency as was wheat and oats. The response in wheat yield to copper at Marchand was not as dramatic as that at Piney, while at Stead wheat yield was decreased by the application of macronutrients without copper but increased when both macronutrients and copper were applied. Yields at all three locations were not influenced by zinc and manganese fertilizers. The results suggest that organic soils are likely to be

Table 1[1] Influence of Cu SO_4 placement method upon dry matter yield and Cu uptake of 6-week old barley shoots early heading in the growth chamber.[2]

Treatment Description	Dry Matter Yield (g/6 shoots)	Cu Conc. (ppm)	Cu Uptake (µg/6 shoots)	Zn Conc. (ppm)
0 Cu SO_4	15.4	2.8	43.1	16.2
4 ppm Cu, point below seed	15.4	3.5	53.9	11.1
4 ppm Cu, banded below seed	16.1	4.1	66.0	10.5
4 ppm Cu, banded with seed	18.0	5.7	103	11.5
4 ppm Cu, mixed throughout	18.3	7.1	130	10.5

1. Data from Akinyede, F.A. 1978. Effect of rate and method of placement of Cu SO_4 and Zn SO_4 on dry matter yield and nutrient uptake of barley (<u>Hordeum vulgare</u> L. var. Conquest). M.Sc. Thesis, University of Manitoba.

2. The soil was a sand classified as a Gleyed Eluviated Eutric Brunisol from the Pine Ridge Association having a pH of 6.3 and containing 0.06% Ca CO_3 (equivalent) as well as 0.56 ppm and 1.2 ppm DTPA extractable Cu and Zn, respectively.

Table 2.[1] Effect of application method and source of Cu on barley grain yield and on Cu concentration in barley shoots at heading.[2]

Treatment Description	Barley Grain Yield Kg/ha	Cu conc. (ppm)
0 Cu	2750	3.3
2 Kg Cu/ha, Na_2 Cu EDTA mixed with surface 15 cm[3]	3170	6.8
2 Kg Cu/ha, Na_2 Cu EDTA in seed row[3]	3100	5.7
10 Kg Cu/ha, Cu SO_4 mixed with surface 15 cm[3]	2920	6.2
10 Kg Cu/ha Cu SO_4 in seed row	3210	3.7

1. Data from D. McAndrew and L. Loewen-Rudgers, Dept. of Soil Science, University of Manitoba.

2. Soil was a deep forest peat (Typic Mesisol) located 3 kilometers south of Piney, Manitoba. Experiment conducted in summer of 1978.

3. "Mixed" treatment involved dissolving Cu carrier in water, spraying on surface and then mixing soil.

Table 3.[1] Effect of macronutrients and Cu on grain yields of wheat, barley and oats on Manitoba organic soils in 1978.

Treatment Description	Grain Yield				
	Piney[2]			Marchand[2]	Stead[2]
	Neepawa Wheat	Hudson Oats	Conquest Barley	Neepawa Wheat	Neepawa Wheat
			Kg/ha		
No Fertilizer	0	---	---	231	329
Macronutrients (NPKS)	1060	1540	2750	515	0
Macronutrients plus Cu	1840	2990	3140	778	780

1. Data from G. Racz and D. McAndrew, Dept. of Soil Science, University of Manitoba.

2. Soils were a deep forest peat (Typic Mesisol) at Piney, a shallow (45 to 60 cm) fen peat over sand at Marchand and a shallow (75 to 90 cm) fen peat over day at Stead.

extremely deficient in macronutrients as well as copper. Although application of macronutrients with copper greatly increased yields, only oats and barley yields at Piney were satisfactory. The small increase in plant copper concentrations when copper was applied (Table 4) suggest that the low yields of wheat may have resulted from the application of insufficient copper. The data in Table 4 also suggest

Table 4.[1] Effect of Cu fertilization on Cu concentration in wheat, barley and oat shoots at heading on Manitoba organic soils in 1978.[2]

Treatment Description	Cu. conc. in shoots at heading				
	Piney			Marchand	Stead
	Neepawa Wheat	Hudson Oats	Conquest Barley	Neepawa Wheat	Neepawa Wheat
			(ppm)		
Macronutrients (NPKS)	1.7	1.8	3.3	1.4	1.3
Macronutrients plus Cu	2.8	3.5	5.6	1.4	1.4

1. Data from G. Racz and D. McAndrew.
2. Data from same experiments as those in Table 3.

that barley was more efficient in taking up copper than wheat and oats.

Barley, wheat and Canola were grown in 1979 on organic soils at Piney, Marchand and Stead and fertilized with 0, 5 10, 20 and 40 Kg Cu/ha as $CuSO_4 \cdot 5H_2O$ which was broadcast and mixed in the top 15 centimeters of soil (12). Barley yields (Table 5) were variable and generally not influenced by copper fertilization even though the Cu concentrations in barley shoots (Table 6) were increased by copper additions. These findings provide further evidence that barley is quite tolerant to low copper supply in the soil. Wheat and Canola yields (Table 5) were only slightly increased by copper fertilization despite the fact that copper fertilization increased plant copper concentrations (Table 6) to adequate levels at all locations. It was observed in these studies that manganese concentrations in plant shoots were low and probably have limited yields.

In a greenhouse experiment using an organic soil from Stead, McAndrew determined low ranges of copper concentrations in barley, oats, wheat, flax and Canola (6) (Table 7). Concentrations below these ranges were considered deficient.

In the 1979 field experiments on organic soils, plant copper concentrations in barley, wheat and Canola were related to extractable soil copper when values for both fertilized and unfertilized soils were used. The best relationship between observed and predicted plant copper concentrations in barley and wheat (Table 8) were obtained when 1M HCL extractable soil copper was used ($r^2 = 0.61$ and $r^2 = 0.49$, respectively) whereas Na_2 DP provided the best relationship for Canola (Table 8) ($r^2 = 0.67$). However, none of the extractants studied adequately assessed plant available soil copper in organic soils not fertilized with copper.

Table 5.[2] Yields of barley, wheat and Canola are affected by copper fertilization of organic soils, 1979. (Kg/ha).

Treatment Description	Barley Grain Yields		
	Marchand	Piney	Stead
0 Cu	2443 a[1]	1612 a	3131 ab
5 Kg Cu/ha	2722 a	1590 a	3469 ab
10 Kg Cu/ha	2689 a	1760 a	3067 b
20 Kg Cu/ha	2361 a	1282 a	3698 a
40 Kg Cu/ha	2686 a	1731 a	3227 ab

1. Duncan's Multiple Range Test. Values followed by the same letter are not statistically different at the 5% probability level.

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Table 5 continued.

Treatment Description	Wheat Grain Yields		
	Marchand	Piney	Stead
0 Cu	26 c[1]	185 a	94 b
5 Kg Cu/ha	391 b	219 a	371 a
10 Kg Cu/ha	502 a	236 a	428 a
20 Kg Cu/ha	384 b	232 a	445 a
40 Kg Cu/ha	313 b	243 a	334 a

1. Duncan's Multiple Range Test. Values followed by the same letter are not statistically different at the 5% probability level.

	Canola Seed Yields		
0 Cu	793 c	652 a	704 a
5 Kg Cu/ha	1359 a	650 a	840 a
10 Kg Cu/ha	1079 b	632 a	853 a
20 Kg Cu/ha	747 c	679 a	909 a
40 Kg Cu/ha	927 bc	639 a	804 a

1. Duncan's Multiple Range Test. Values followed by the same letter are not statistically different at the 5% probability level.

2. Data from Tokarchuk, J.M. 1982. Availability of Copper to Plants and Methods of Evaluating Plant Available Copper in Organic Soils. M.Sc. Thesis. University of Manitoba.

Table 6. Copper concentration in barley, wheat and Canola shoots as affected by copper fertilization of organic soils - 1978.

Treatment Description	Cu con. in Barley (ppm)		
	Marchand	Piney	Stead
0 Cu	1.8 c	2.4 d	2.1 c
5 Kg Cu/ha	3.6 b	3.6 c	3.2 b
10 Kg Cu/ha	3.8 ab	4.0 bc	3.7 ba
20 Kg Cu/ha	4.6 a	4.4 ab	4.2 a
40 Kg Cu/ha	4.5 a	5.0 a	4.1 a

1. Duncan's Multiple Range Test. Values followed by the same letter are not statistically different at the 5% probability level.

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Table 6 continued.

Treatment Description	Cu con. in Wheat (ppm)		
	Marchand	Piney	Stead
0 Cu	1.0 c	1.9	1.3 c
5 Kg Cu/ha	1.7 bc	3.0 a	2.1 b
10 Kg Cu/ha	2.1 bc	3.6 a	2.3 b
20 Kg Cu/ha	2.3 bc	3.5 a	2.6 ba
40 Kg Cu/ha	3.0 a	3.6 a	3.3 a

1. Duncan's Multiple Range Test. Values followed by the same letter are not statistically different at the 5% probability level.

	Cu con. in Canola		
0 Cu	1.5 a	2.2 b	2.0 c
5 Kg Cu/ha	2.3 a	3.0 c	2.9 b
10 Kg Cu/ha	2.2 a	3.2 bc	3.0 b
20 Kg Cu/ha	2.8 a	3.5 b	3.1 b
40 Kg Cu/ha	2.8 a	4.0 a	3.7 a

1. Duncan't Multiple Range Test. Values followed by the same letter are not statistically different at the 5% probability level.

2. Data from same experiments as those in Table 5.

Table 7.[1] Low ranges of copper concentrations in barley, oats, wheat, flax and Canola grown on organic soil[2] in the growth chamber.

Crop	Low range[2] (ppm)
barley	2.3 - 3.7
oats	1.7 - 2.5
wheat	3.0 - 4.9
flax	2.4 - 3.5
Canola	1.7 - 2.7

Data from McAndrew, D.W. 1979. Copper and zinc nutrition of cereals and oil seed crops in Manitoba. M.Sc. Thesis. University of Manitoba.

Table 8[1] Relationships between the calculated and observed concentration of copper in barley, wheat and Canola shoots grown on Manitoba organic soils - 1979.

Extractant	Crop		
	Barley	Wheat	Canola
1 M HCL	0.61 **[2]	0.49 **	0.56 **
DTPA	0.48 **	0.46 **	0.50 **
1% Na_2 EDTA	0.56 **	0.41 **	0.56 **
2% Na_2 EDTA	0.46 **	0.48 **	0.62 **
Na_2 DP	0.53 **	0.44 **	0.67 **

1. From Tokarchuk, J.M. 1982. Availability of Copper to Plants and Methods of Evaluation Plant Available Copper in Organic Soils. M.Sc. Thesis, University of Manitoba.

2. Statistically significant at the 1% level of probability.

Zinc

Previous research had suggested that zinc deficiency is most likely to occur on high lime soils such as Lakeland, Balmoral, Plum Ridge, Fort Garry and Emerson, particularly when subsoil is exposed and in crops such as field beans (Phaseolus vulgaris), soybeans (Glycine max), corn and flax which are most susceptible to zinc deficiency. In a greenhouse experiment on Plum Ridge sandy loam, flax had responded to zinc fertilization and the critical zinc concentration in eight-week old flax seedling shoots found to be 13 ppm (7). The critical level of DTPA extractable soil zinc for flax was estimated at 1.3 ppm. Surveys of corn ear leaves in 1974 and 1975 suggested that nearly half of the corn in Manitoba was deficient in zinc (11). This conclusion, however, was based upon a plant zinc critical level established in the United States under growing conditions vastly different from those in Manitoba. In the middle 1960's both zinc and copper were applied to four corn and two sunflower trials in the Carman area. Zinc and copper alone resulted in small statistically insignificant increases in corn yields at one location (10). However, prior to initiation of the current research, there had been no confirmed responses to zinc in the field in Manitoba.

Zinc was applied to black beans (Phaseolus vulgaris) grown in the field on several high lime soils in 1976 and 1977. Zinc fertilization increased bean grain yields in 1976 (Tables 10 and 11) but had no effect upon bean yields in 1977 (Table 12 and 13) which was surprising since the DTPA extractable soil level was higher in 1976 (1 and 1.4 ppm) than in 1977 (0.36 and 0.52 ppm). Although black beans in the 1977 field study 2 did not respond to zinc, grain yields were increased by the application of copper (Table 13). Application of zinc in the field to black beans, soybeans and fababeans in 1978 did not influence yields.

Zinc and copper were applied to corn at two locations in 1978. At location 1, the surface soil contained 0.68 ppm and 0.95 ppm DTPA extractable zinc and copper, respectively, whereas at location 2 the soil contained 1.2 ppm and 0.44 ppm DTPA extractable zinc and copper, respectively. Zinc and copper alone did not influence yields at either location (Table 14 and 15). However, at location 2, zinc and copper together increased silage yields by approximately 20%, although the increases were not statistically significant at the 10% level. The response to copper at location 2 was not too surprising since the DTPA extractable copper level was quite low at that location. However, on the basis of the DTPA extractable soil zinc level, a greater zinc response was expected at location 1 than at location 2. It should also be noted that zinc concentrations in corn ear leaves were higher at location 1, even though the soil at location 1 contained less DTPA extractable zinc than the soil at location 2.

Zinc was applied in the field to wheat, oats, barley and flax in 1976 and to wheat, barley, flax and rapeseed in 1977 and 1978 on Lakeland clay loam containing 0.29 ppm, 0.51 ppm and 1.2 ppm DTPA extractable zinc in 1976, 1977 and 1978, respectively. There was no response in grain yields to zinc fertilization.

Table 10.[1] Soil characteristics in 1976 black bean field trials.

Soil Type	Soil Subgroup	pH[2]	$CaCO_3$[2] equivalent	DTPA[2] Extractable Zn
			(%)	(ppm)
Almasippi sandy loam	Gleyed Carbonated Rego Black	7.9	1.4	1.4
Reinland fine sandy loam	"	7.8	2.7	1.0
Hordean clay loam	"	7.7	2.5	1.0

[1] Data from R.J. Soper, Dept. of Soil Science, University of Manitoba.

[2] pH, $CaCO_3$ equivalent and DTPA extractable Zn in surface 30 cm.

Table 11.[1] Effect of Zn fertilization upon grain yield of black beans in 1976 field trials.

Treatment Description	Yield of Black Beans		
	Almasippi sandy loam	Reinland fine sandy loam	Hordean clay loam
		(kg/ha)	
0 Zn	1090[2]	1220[2]	1470
1 kg Zn as Na_2Zn EDTA side banded	1140	1510	1860
5 kg Zn as $ZnSO_4$ side banded	1020	1200	1460
5 kg Zn as $ZnSO_4$ mixed	881	1410	1710

[1] Data from R.J. Soper, Dept. of Soil Science, University of Manitoba

[2] Differences not significant at 5% level.

Table 12.[1] Effect of Zn carrier and placement method upon black bean grain yield and Zn uptake into 6-week old black bean shoots (early podding) in 1977 field study 1.[2]

Treatment Description	Grain Yield	Zn Conc.	Zn Uptake	Cu Conc.
	(kg/ha)	(ppm)	(g/ha)	(ppm)
0 Zn	1920[3]	13.6	21.3	5.1
10 kg Zn as $ZnSO_4$ side banded	1780	13.1	21.5	5.2
10 kg Zn as $ZnSO_4$ mixed	1800	20.7	34.9	5.4
4 kg Zn as Na_2Zn EDTA mixed	1640	21.3	31.9	5.7
4 kg Zn as Na_2Zn EDTA mixed and 2 kg Cu as Na_2Cu EDTA mixed	1760	20.3	31.5	5.1

[1] Data from D. McKenzie and R.J. Soper

[2] Soil type was Reinland very fine sandy loam, a Gleyed Carbonated Rego Black having a pH of 7.7 and containing 3.48% $CaCO_3$ (equivalent) as well as .35 ppm and .36 ppm DTPA extractable Cu and Zn, respectively, in the surface 30 cm.

[3] Differences not significant at 5% level.

Table 13.[1] Effect of Zn carrier and placement method upon black bean grain yield and Zn uptake into 6-week old black bean shoots (early podding) in 1977 field site study 2.[2]

Treatment Description	Grain Yield	Zn Conc.	Zn Uptake	Cu Conc.
	(kg/ha)	(ppm)	(g/ha)	(ppm)
0 Zn	2510	16.1	31.9	4.3
10 kg Zn as $ZnSO_4$ side banded	2410	17.3	28.7	4.4
10 kg Zn as $ZnSO_4$ mixed	2410	22.4	39.2	4.4
4 kg Zn as Na_2Zn EDTA mixed	2370	22.3	34.7	4.1
4 kg Zn as Na_2Zn EDTA mixed and 2 kg Cu as Na_2Cu EDTA mixed	2940	24.1	41.4	5.4

[1] Data from D. McKenzie and R.J. Soper

[2] Soil type was Reinland fine sandy loam, a Gleyed Rego Black having a pH of 7.5 and containing 0.44% $CaCO_3$ (equivalent) as well as 0.29 ppm and 0.52 ppm DTPA extractable Cu and Zn, respectively in the surface 30 cm.

Table 14.[1] The effect of Zn and Cu fertilization on corn silage yield (oven dry) and on Zn and Cu concentrations in corn ear leaves at silking at location 1.[2]

Treatment Description	Silage Yield	Zn Conc. in Ear Leaves	Cu Conc. in Ear Leaves
	(tonnes/ha)	(ppm)	(ppm)
0 Zn and 0 Cu	15.0[3]	20.0	10.0
0 Zn and 10 kg Cu/ha (as $CuSO_4$ mixed with surface 15 cm)	13.6	19.6	11.2
15 kg Zn/ha (as $ZnSO_4$ mixed with surface 15 cm) and 0 Cu	13.6	28.2	9.5
15 kg Zn/ha 10 kg Cu/ha	15.7	27.0	9.8

[1] Data from D. McKenzie and R.J. Soper

[2] Soil was Reinland fine sandy loam, a Gleyed Carbonated Rego Black containing 0.68 ppm and 0.95 ppm DTPA extractable Zn and Cu to 40 cm, respectively. Experiment conducted in summer of 1978.

[3] Differences not significant at 5% level.

Table 15.[1] The effect of Zn and Cu fertilization on corn silage yield (oven dry) and on Zn and Cu concentrations in corn ear leaves at silking at location 2.[2]

Treatment Description	Silage Yield	Zn Conc. in Ear Leaves	Cu Conc. in Ear Leaves
	(tonnes/ha)	(ppm)	(ppm)
0 Zn and 0 Cu	14.1[3]	16.9	6.8
0 Zn and 10 kg Cu/ha (as $CuSO_4$ mixed with surface 15 cm)	15.3	18.8	8.4
15 kg Zn/ha (as $ZnSO_4$ mixed with surface 15 cm) and 0 Cu	14.8	21.5	7.4
15 kg Zn/ha 10 kg Cu/ha	16.8	21.4	8.0

[1] Data from D. McKenzie and R.J. Soper, Dept. of Soil Science, University of Manitoba.

[2] Soil was Reinland fine sandy loam, a Gleyed Carbonated Rego Black containing 1.18 ppm and 0.44 ppm DTPA extractable Zn and Cu to 30 cm, respectively. Experiment conducted in summer of 1978.

[3] Differences not significant at 10% level.

Total dry matter yield of black beans grown in the environmental growth chamber on Lakeland Clay loam containing 0.45 ppm DTPA extractable zinc was substantially increased by zinc fertilization (Table 16) (4). Similar large yield increases were obtained from soybeans, while fababeans (Vicia faba) responded slightly to zinc fertilization. Buckwheat and Canola were not effected by supplemental zinc in the growth chamber. The critical zinc concentration in 6-week old shoots of black beans grown in the environmental chamber was estimated at 13.5 ppm (4). Barley in the growth chamber on Lakeland Clay loam containing (ppm DTPA extractable zinc responded to supplemental zinc (Table 17)(1). The critical zinc concentration in 6-week old barley shoots was estimated at 12.5 ppm (1). The greater severity of zinc deficiency in the environmental chamber and in black beans in the field in 1976 may have been at least partially caused by lower growing temperatures. However, future research should determine more precisely the influence of environmental factors other than zinc supply upon the incidence and severity of zinc deficiency. In addition, interaction between zinc and other micronutrients and macronutrients should be investigated. It is also evident that considerably more needs to be learned concerning soil and plant critical zinc levels.

Mixing zinc sulphate throughout the soil was more effective in increasing plant zinc concentrations than other placement methods for black beans in the field (Tables 12 and 13) and growth chamber (Table 16 and for barley in the field (Table 18) and growth chamber (Table 17). However, in contrast to the results for disodium copper EDTA, applying disodium zinc EDTA with the seed was perhaps slightly more effective than mixing throughout the surface 15 cm (Table 18). Mixing "Zn M-N-S" with the surface 15 cm was perhaps slightly more effective in increasing zinc concentrations in barley than applying "Zn M-N-S" with the seed (Table 18). In contrast to other inorganic zinc fertilizers, applying granular zinc sulphate with the seed of barley was more effective in increasing plant zinc uptake than mixing throughout the soil (Table 18).

Disodium zinc EDTA was about 2.5 times as effective as zinc sulphate in increasing zinc uptake by black beans when both carriers were mixed with the soil (Table 12 and 13). With barley, however, applying disodium zinc EDTA in the seed row was about five times as effective as mixing zinc sulphate with the surface 15 centimeters (Table 18). "Zn M-N-S" was nearly as effective as zinc sulphate when both were mixed throughout the soil (Table 18). Applying granular zinc sulphate in the seed row was as effective in increasing zinc uptake of barley as mixing zinc sulphate throughout the surface 15 centimeters (Table 18).

Results to research in recent years indicate that zinc deficiency in cereal crops is not likely to occur in Manitoba even on high lime soils. Zinc and copper in organic and inorganic forms have been applied to corn, sunflowers, lentils and soybeans at several locations on southern Manitoba. Although no significant yield increases to Zn have been observed, plant concentrations of Zn in these crops have been increased by Zn fertilization.[1] Further research should establish with more certainty the extent and severity of zinc deficiency and possible interactions between zinc and other nutrients.

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[1] Information from R.J. Soper and G. Hnatowich, Dept. of Soil Science, University of Manitoba.

Table 16.[1] Effect of $ZnSO_4$ placement method upon dry matter yield and Zn uptake of 6.5-week old black bean shoots in the growth chamber.[2]

Treatment Description	Dry Matter Yield	Zn Conc.	Zn Uptake
	(g/2 shoots)	(ppm)	(µg/2 shoots)
0 $ZnSO_4$	5.8	4.9	28
8 ppm Zn, point below seed	5.9	3.9	23
8 ppm Zn, banded below seed	8.6	7.6	65
8 ppm Zn, mixed throughout	8.4	16.1	135

[1] Data from M.M. Hedayat. 1978. The effect of zinc rate and method of placement on yield and zinc utilization of black beans (Phaseolus vulgaris var. Black Turtle) and fababeans (Vicia faba L. var. Minor). M.Sc. Thesis, University of Manitoba.

[2] Soil type was Lakeland clay loam, a Gleyed Carbonated Rego Black containing 0.45 ppm DTPA extractable Zn.

Table 17.[1] Influence of $ZnSO_4$ placement method upon dry matter yield and Zn uptake of 6-week old barley shoots (nearly heading) in the growth chamber.[2]

Treatment Description	Dry Matter Yield	Zn Conc.	Zn Uptake
	(g/12 shoots)	(ppm)	(μg/12 shoots)
0	16.5	9.1	150
8 ppm Zn, point below seed	18.9	9.9	187
8 ppm Zn, banded below seed	20.5	17.0	348
8 ppm Zn, banded with seed	22.6	19.5	441
8 ppm Zn, mixed throughout	23.1	38.5	889

[1] Data from F.A. Akinyede. 1978. Effect of rate and method of placement of $CuSO_4$ and $ZnSO_4$ on dry matter yield and nutrient uptake of barley (Hordeum vulgare L. var. Conquest). M.Sc. Thesis, University of Manitoba.

[2] Soil type was Lakeland clay loam, a Gleyed Carbonated Rego Black having a pH of 8.2 and containing 25.6% of $CaCO_3$ (equivalent) as well as 1 ppm DTPA extractable Zn.

Table 18.[1] Effect of application method and carrier of Zn on barley grain yield and on Zn concentration in barley shoots at heading.[2]

Treatment Description	Barley Grain Yield	Zn Conc.
	(kg/ha)	(ppm)
0 Zn	5,260[3]	14.4
1.5 kg Zn/ha[4] as Na_2Zn EDTA mixed	5,340	17.3
1.5 kg Zn/ha as Na_2Zn EDTA in seed row	6,220	20.0
7.5 kg Zn/ha[4] as $ZnSO_4$ mixed	5,730	19.2
7.5 kg Zn/ha as $ZnSO_4$ in seed row	5,800	15.2
7.5 kg Zn/ha[4] as "Zn M-N-S" (Cominco) mixed	5,680	18.4
7.5 kg Zn/ha as "Zn M-N-S" in seed row	6,120	17.3
7.5 kg Zn/ha[4] as granular $ZnSO_4$ (Eagle-Picher's "Zink Gro") mixed	5,400	15.7
7.5 kg Zn/ha as granular $ZnSO_4$ in seed row	5,820	19.6

[1] Data from L. Loewen-Rudgers

[2] Soil was Lakeland clay loam, a Carbonated Gleyed Rego Black containing 0.51 ppm DTPA extractable Zn to 30 cm. Experiment conducted in summer of 1977.

[3] Differences not significant at 5% level.

[4] "Mixed" treatment involved dissolving Na_2Zn EDTA or $ZnSO_4$ in water, spraying on soil surface and mixing with surface 15 cm. "In seed row" involved applying dried finely divided material down drill run with the seed. However, "Zn M-N-S" and "Zink Gro" were applied in granular form for both "mixed" and "in seed row" treatments.

Manganese

Previous research both in Manitoba and elsewhere had indicated that manganese deficiency is most likely to occur on imperfectly to poorly drained, alkaline, lake laid clay soils such as Red River, Osborne and Morris and on organic soils, especially when these soils are dry throughout most of the growing season and/or soil iron levels are high (5). Manganese deficiency in oats (grey speck) was observed on sandy lake laid soils, such as Gilbert sandy loam (3). However, there had been no confirmed response to manganese fertilization in the field in Manitoba prior to the initiation of current research.

Manganese was applied as manganese sulphate in 1974 with the seed of oats on Plum Ridge fine sandy loam and Osborne clay. In 1976 manganese sulphate was applied with the seed of wheat, barley and oats on a Red River clay and Osborne clay. All yields were low in 1974 due to drought whereas yields were high in 1976. In neither year were there responses to manganese fertilizer. However, banding manganese sulphate with the seed resulted in small or no increase in plant manganese concentrations. Perhaps for that reason, manganese fertilizer did not significantly increase grain yields. Reports in the literature indicate that broadcast manganese sulphate applications were seldom effective. Some researchers found that banding manganese sulphate with the seed was effective whereas others found it necessary to foliar apply manganese sulphate. Manganese sulphate was broadcast or applied with the seed of wheat and barley on two organic soils in 1980 (9). Neither method of manganese application resulted in significant yield increases. Earlier research indicated that manganese fertilizer applied with the seed, or as a broadcast treatment had little effect on manganese concentrations in plant shoots, and therefore little effect on yield could be expected. It was also observed that increases in manganese shoot concentrations occurred when manganese sulphate was applied to wheat and barley on organic soils, regardless of the method of application. There has been some speculation as to the beneficial effects of manganese foliar application, but to date yield responses to this method of manganese fertilization have not been observed in the field.

It was noted in several field studies that yields and manganese plant concentrations in cereals varied greatly from year to year. It was postulated that weather conditions, particularly soil temperature variations were largely responsible for the variations in the Mn concentrations (9). In the growth chamber increasing the temperature of an organic soil from 10°C to 20°C resulted in a two fold increase in manganese concentration in barley and wheat at the early boot stage (Table 19).

Some of the variation in field results on organic soils may be explained in terms of this relationship between soil temperature and manganese concentration. Future research in Manitoba should investigate the influence of soil temperature on manganese availability to plants as well as the efficiency of methods of manganese fertilizer application methods.

Table 19. Effect of soil temperature on manganese concentration in barley and wheat shoots grown on an organic soil.[2]

Soil Temperature	Crop	
	Barley	Wheat
10°C	15 a[3]	40 a
15°C	25 b	59 a
20°C	35 c	83 b
25°C	26 d	86 b

1. From Reid, M.J. 1982. Availability of Manganese and Effects of Soil Temperature on Availability of Manganese to Plants Grown on Organic Soils. M.Sc. Thesis, University of Manitoba.

2. Soil was a Terric Mesisol from near Stead.

3. Duncan's Multiple Range Test.

Iron

Research in Manitoba and elsewhere had established that iron is most likely to be deficient on high lime soils, particularly in crops such as flax, soybeans and field beans which are very susceptible to iron deficiency. Also, flax may be deficient in iron when growing on water logged soils, due to high levels of plant available manganese in such soils (7). Small statistically insignificant responses to foliar applied iron sulphate ($FeSO_4$) had been obtained in flax which had been growing on water logged clay soil and was yellow at the time of iron application.[1] However, prior to initiation of the current research there had been no confirmed responses to iron fertilization.

Ferrous sulphate has been foliarly applied to field beans, soybeans and flax in several experiments over the past two years. Iron application has sometimes corrected chlorosis but has never increased crop yields. Although research concerning iron nutrition will likely be continued, it now appears that iron deficiency is not prevalent in Manitoba field crops.

Summary

Results to research indicate that crops grown on mineral soils in Manitoba are not likely to respond to micronutrient fertilizers. Seven field experiments with black beans and 16 with corn have only produced 1 significant yield response to zinc for each crop, while cereals, flax and alfalfa yields in a number of experiments were not increased as a result of micronutrient fertilizer application. However, yield increases were obtained from micronutrient applications in several greenhouse studies, in which a much greater demand was placed on soil nutrient reserves than in the field. It is thus possible that micronutrient fertilizers may be required even in the field when and if yields and the demand for nutrients increase dramatically above those of today.

It has been established that organic soils are copper deficient, and may be Mn deficient when soil temperatures are low.

Copper sulphate and zinc sulphate were effective in increasing plant micronutrient uptake, especially when mixed with the surface soil as opposed to banded or seed placed. Chelated micronutrient fertilizers, banded or mined, were very effective in increasing plant uptake of Cu and Zn by plants.

Sufficient information has been obtained to allow the Manitoba Provincial Soil Testing Laboratory to determine micronutrient levels in plant material and interpret the levels as sufficient and deficient. However, before a routine micronutrient soil service can be initiated, more work is required to precisely establish soil critical levels for a wide variety of crops.

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[1] Information from G. Racz. Dept. of Soil Science, University of Manitoba.

Table 20.[1] Summary of Micronutrient Field Experiments on Mineral Soils in Manitoba.

Crop	No. of Experiments	No. of experiments which responded
Black beans	7	1
Corn	16	1
Cereals	8	0
Flax	6	0
Alfalfa	20 *	0

1. Data from G.J. Racz. Soil Science Department, University of Manitoba.

* Refers to 20 station years of data.

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