Plant Response to Manganese Source, Rate and Method of Application[1]

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Abstract. $MnSO_4$ and Rayplex-Mn were found to be effective sources of Mn for tomato seedlings grown on a Mn deficient high organic sandy soil. Tomato seedlings absorbed Mn from $MnSO_4$ or Rayplex-Mn applied in the starter band on or under the seed with equal effectiveness. The amount absorbed was directly related to the Mn concentration in the band. $MnSO_4$ at 100 mg Mn/ft of row increased the Mn content of the tissue from 17 ppm to more than 100 ppm.

MnEDTA at a rate to supply 10 to 25 mg Mn/ft of row in bands on or under the seed did not affect seedling growth and Mn uptake was less than from the same rate of $MnSO_4$. Rates of 50 and 100 mg Mn/ft of row from MnEDTA in the starter band on or under the seed caused death or severe stunting of tomato seedlings because of toxicity. Band applications of Mn sources increased Mn composition of the tomato tissue relatively much more than did the broadcast application.

Introduction

Manganese deficiency of plants, grown on soils low in available Mn, has been corrected by Mn salts either as soil or spray applications. Nylund (3) found that the growth of onions on muck soil (pH 6.9) was equally improved by the application of $MnSO_4$ at 150 lb./A broadcast on the soil or as a foliar spray at 30 lb./A. Shepherd et al. (5) compared spray, broadcast and band treatments of $MnSO_4$, Nu Manese, Mangasoil, FN 239B and NuM on various crops on a muck soil. When the 5 carriers were mixed with the basic fertilizer and banded 2 inches below the seed, a significant yield response to Mn was obtained regardless of the carrier used. They found an increased availability of Mn on alkaline muck for MnEDTA followed by FN 239B, Nu Manese, and $MnSO_4$. Mixing the Mn carriers with mineral soils resulted in a significant yield increase by wheat but not by corn or beans. Banding was most effective for correcting Mn deficiency on the muck soil followed by broadcasting and spraying.

Several reports have shown chelated Mn to be less effective than other Mn salts. Fiskel and Mourkides (2) found that $MnSO_4$ was the best Mn source for tomato plants grown on a peat, marl, or sandy soil followed by MnO, MnO_2, and MnEDTA. DeKock and Mitchell (1) observed that the divalent cations, Co, Ni, Zn, Cu, which are taken up readily in the ionic form, were not readily absorbed when chelated, especially with EDTA. These metals were taken up more readily when associated with $FeCl_3$ than with FeEDTA. Rumpel et al. (4) found that MnEDTA was not an effective carrier of Mn when used on a muck soil to correct Mn deficiency in onions and soybeans. Wallace (6) stated that chelates can be toxic if not used at recommended concentrations.

Thus, these questions are posed: 1) what rate of Mn application will effectively satisfy the plant requirement from different Mn sources without resulting in carrier induced toxicity, and 2) how is plant growth and Mn uptake affected by various methods of applications on a Mn deficient soil?

[1]Received for publication October 11, 1968. Journal Paper No. 3488 from the Agricultural Experiment Station, Purdue University, Lafayette, Indiana.

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Materials and Methods

The experiments were carried out in plastic pots in the greenhouse using Maumee fine sandy loam, pH 6.9, that had a very low total Mn content of less than 10 lb./A and available Mn of 1.07 lb./A exchangeable. The experimental design was a randomized complete block with 4 replications.

Experiment 1. Tomato seedling growth as affected by on-seed banding of various Mn fertilizers was studied. Treatments of Mn at 25, 100, and 200 mg/ft of row as $MnSO_4$ and 25 mg/ft of row as MnEDTA were applied in solution with 10–34–0 liquid fertilizer diluted with water (67 mg P per 10 ml solution) and added in a 1 x 4 inch band on the seed. The $MnSO_4$ in solution caused a colloidal precipitate when added to the phosphate solution while the MnEDTA remained in solution.

Ten tomato seeds of variety 'H 1370' were planted and covered with ½ inch of soil. The pots were watered to field capacity and maintained moist to allow germination. Plants were thinned to one per pot 2 days after emergence. The plants were harvested 28 days after emergence. After drying in a forced air dryer at 70° C for 48 hr, the plants were weighed and then ground in a Wiley Mill. Composites of the 4 replications of each treatment were sent to the Purdue Plant Analysis Service for Spectrographic analysis.

Experiment 2. This consisted of further studies of on-seed Mn fertilizer placement with 'H 1370' tomatoes. Fifty ppm N as NH_4NO_3 and 100 ppm K as KCl were mixed with the soil. Treatments of Mn at 50, 100 and 200 mg/ft as $MnSO_4$, MnEDTA, and $MnSO_4$ plus Na_2EDTA equivalent to the EDTA in the MnEDTA were banded on tomato seed as in Experiment 1. The plants were grown, harvested and analyzed for Mn as in Experiment 1.

Experiment 3. Mn sources, methods of application and Mn rates for satisfying Mn requirements of tomato seedlings were compared. Nitrogen as NH_4NO_3 and K as KCl were each mixed with the soil at a rate of 75 ppm. Phosphorus was added as 10–34–0 either as a band 2 inches under the seed or on the seed depending upon the Mn treatments. Mn as $MnSO_4$, MnEDTA and Rayplex-Mn (a polyflavonoid complexing agent derived from Hemlock bark and sold by Rayonier Chemical Company) were used as the Mn sources. $MnSO_4$ at 25, 50, 100 and 200 mg Mn/ft of row, MnEDTA and Rayplex-Mn at 25, 50 and 100 mg Mn/ft of row were placed on the seed in a solution with 10–34–0 at a concentration of 200 mg P/ft of row. The same rates of MnEDTA and Rayplex-Mn as used on the seed and $MnSO_4$ at 200 and 400 mg Mn/ft of row were applied in bands 2 inches below the seed in solution with 10–34–0 fertilizer at a rate of 800 mg P/ft of row. Each of the 3 Mn sources were also applied as a broadcast treatment to the soil at a rate of 50 lb. Mn/A. The plants were harvested 28 days after emergence and processed as in Experiment 1.

Experiment 4. MnEDTA and $MnSO_4$ were applied at 10, 20 and 40 mg Mn/ft to snapbean variety 'Tenderette', and tomato variety 'H 1370'. The MnEDTA and $MnSO_4$ was applied in a solution of 10–34–0. The

10–34–0 was at a concentration to apply 200 mg P/ft of row. The fertilizer solution was banded one inch under the seed. The beans and tomatoes were thinned to one plant per pot after emergence. The beans were harvested 21 days after emergence and the tomatoes were harvested 28 days after emergence. The dried tissue was processed as in Experiment 1.

Results and Discussion

Experiment 1. One week after emergence the tomato plants that received 200 mg/ft of Mn as $MnSO_4$ had smaller epicotyledonary leaves and narrower cotyledonary leaves than other plants receiving the same rate of P starter but lower Mn rates. Plants that received no P starter were small and P deficient.

The Mn composition of the plants (Table 1) showed that Mn uptake by the plant from the $MnSO_4$ source was in direct relation to the rate of Mn applied. The plants that received 200 mg Mn/ft of row had developed toxicity symptoms on the leaves by harvest. The Mn as MnEDTA did not increase the Mn composition of the tissue even though it was applied at the commercially recommended rate. The starter fertilizer significantly increased growth and reduced Mn content of the plant. The Mn treatments did not significantly affect the plant growth at 25 and 100 mg Mn/ft of row. The 200 mg Mn/ft of row reduced growth compared with the 0 Mn treatment.

Table 1. Mn composition and growth of tomato seedlings from on-seed placement of the starter band, Experiment 1.

Treatment, Mn rate	Treatment, Mn source	Composition Mn	Dry weight
mg/ft		ppm	mg
0[a]		43	107
0[b]		27	268
25[b]	SO_4	78	243
100[b]	SO_4	205	229
200[b]	SO_4	775	193
25[b]	EDTA	24	221
L.S.D. 5%			62

[a]No starter fertilizer.
[b]200 mg/ft P as 10–34–0 carried the Mn source.

Experiment 2. One week after emergence the tomato plants that received 200 mg Mn/ft of row as MnEDTA or $MnSO_4$ + EDTA were dying or dead. Growth of the plants at 28 days that received Mn at 50 mg/ft of row as MnEDTA was less than half of the plants that received an equal rate of Mn as $MnSO_4$ (Table 2).

The Mn composition of plants reflected the rate of Mn applied in the band from the $MnSO_4$ source. The Mn in the band at 50, 100 and 200 mg/ft of row increased the Mn content of the plant tissue from 16 ppm to 57, 153, and 251 ppm respectively. Plants that received 50 mg Mn/ft of row as MnEDTA or $MnSO_4$ + EDTA had the same Mn composition as those that received $MnSO_4$. However, the plants that received EDTA were much smaller than those that received $MnSO_4$. MnEDTA or $MnSO_4$ + EDTA applied at a rate to supply Mn at 100 and 200 mg/ft of row caused severe stunting and death of plants.

Table 2. Mn composition and growth of 4 week old tomato seedlings from on the seed placement of the fertilizer band, Experiment 2.

Treatment, Mn[a] rate	Treatment, Mn[a] source	Composition Mn	Dry wt per plant
mg/ft		ppm	mg
0		16	699
50	SO_4	57	580
100	SO_4	153	837
200	SO_4	251	641
50	EDTA	52	177
100	EDTA	—	29[c]
200	EDTA	—	all dead
50[b]	SO_4	55	299
100[b]	SO_4	132	42[d]
200[d]	SO_4	—	all dead
L.S.D. 5%			194

[a]200 mg/ft P as 10–34–0 combined with Mn salt.
[b]Na_2EDTA equivalent to chelate in EDTA source added.
[c]2 of 4 plants dead.
[d]1 or 4 plants dead.

Experiment 3. Placement of Mn on the seed as EDTA at 50 mg/ft of row reduced tomato seedling growth more than 50%, (Table 3), 100 mg Mn/ft of row as EDTA killed the seedlings. The Mn absorption from the MnEDTA was less than from the other Mn sources at the rate of 25 mg Mn/ft of row. Rayplex-Mn and $MnSO_4$ were equally effective sources when banded on or under the seed as indicated by the growth and Mn uptake data.

Table 3. Growth and Mn composition of tomato seedlings that received various Mn treatments in the starter band, Experiment 3.

Mn treatment		Mn composition Band placement		Yield dry weight Band placement	
Source	Band rate	On seed	2″ under seed	On seed	2″ under seed
	mg/ft	ppm		mg	
	0	17	26	1427	1687
$MnSO_4$	25	36	—	2145	—
	50	57		1730	
	100	112		1503	
	200	232	290	1770	1577
	400		583		1729
Chelate EDTA	25	23	66	1491	1091
	50	34	a	541	689
	100	a	b	103	b
Rayplex	25	48	82	1851	1700
	50	90	95	1327	1794
	100	148	134	1436	1925
	LSD 5%			380	

[a]2 of 4 plants dead.
[b]All plants died.

Broadcast application of $MnSO_4$ and Rayplex-Mn increased Mn absorption, (Table 4). The 50 lb./A rate of Mn as MnEDTA broadcast was toxic and killed most of the plants.

Table 4. Growth and Mn composition of tomato seedlings from soil that received various Mn broadcast treatments, Experiment 3.

Treatment Source	Treatment Mn rate	Mn composition	Dry wt
	lbs/A	ppm	mg
	0	14	1501
$MnSO_4$	50	27	2074
EDTA	50	a	133[a]
Rayplex	50	24	1748
LSD 5%			380

[a]3 plants died; not enough tissue for Mn analysis.

Experiment 4. The growth of the beans was significantly reduced by MnEDTA at 20 and 40 mg Mn/ft of row, (Table 5). Mn as $MnSO_4$ in the same concentration range did not affect the bean growth. The Mn composition of the tissue was higher from $MnSO_4$ than from MnEDTA at the same Mn rates. Tomato growth was significantly reduced by MnEDTA at 40 mg Mn/ft of row compared to the $MnSO_4$ at the same Mn rate. The stems of the tomato plants that received MnEDTA at 40 mg Mn/ft of row had a severe constriction at the soil surface. The Mn composition of the tomato tissue from the Mn rates commercially recommended for the MnEDTA was less than the tissue from the no Mn check. MnEDTA in

Table 5. Snapbean and tomato plant growth and Mn composition as affected by $MnSO_4$ and MnEDTA band treatments, Experiment 4.

Mn rate in band	Source	Bean		Tomato	
		Mn content	Dry weight	Mn content	Dry weight
mg/ft		ppm	mg	ppm	mg
0		39	928	38	438
10	MnEDTA	52	1088	35	385
10	$MnSO_4$	65	1068	46	412
20	MnEDTA	62	562	30	358
20	$MnSO_4$	85	1015	54	378
40	MnEDTA	68	370	60	178
40	$MnSO_4$	78	1000	45	382
LSD p = 5%			233		72

the range of rates that did not affect the tomato growth was not as effective a source of Mn as was $MnSO_4$.

In the several experiments reported which were run over a period of one year in the greenhouse, manganese treatments were evaluated on a soil that in the field caused beans to exhibit moderate to severe deficiency symptoms. The general recommendations for correcting deficiency are 10 to 20 lb. available Mn/A as $MnSO_4$ or 1 to 2 lb. available Mn/A as MnEDTA or Rayplex-Mn. These recommendations would correspond to the band rates of 100 to 200 mg Mn/ft of row as $MnSO_4$ or 10 to 20 mg Mn/ft of row as MnEDTA or Rayplex-Mn. According to the experiments reported here, the $MnSO_4$ would be much more effective at these relative rates than the organic Mn sources. Mn was not absorbed from MnEDTA at the general recommended rate in Experiment 1 and so the rate was increased in Experiment 2 in an attempt to determine if the Mn was available to the plant from the MnEDTA source. Rates above 25 mg Mn/ft of row as MnEDTA did not increase Mn content of the plant and were toxic to the point of being lethal to the plant. The toxicity appeared to be due to EDTA since $MnSO_4$ + Na_2EDTA caused the same effect whereas plants that received $MnSO_4$ alone were healthy.

The inorganic and organic carriers, $MnSO_4$ and Rayplex-Mn, released Mn to the plant with equal effectiveness such that there does not appear to be any justification for the general recommendation of a 10 to 1 available metal bias in favor of the organic carriers.

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Effects of Potassium Nutrition on Growth and Cation Content of Potato Leaves and Tubers Relative to Plant Analysis[1]

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Abstract. Potato plants were grown outdoors in pots containing Alvolite, a low K material, under low and high K conditions. The blades of recently matured leaves were relatively constant in K concentration, whereas the petioles changed rapidly with growth and K supply. Sodium was largely excluded from the leaf tissue while Ca and Mg were higher with low K supply. Tubers under high and low K nutrition changed only from about 2.0 to 1.3% K, respectively, and the values of Na, Ca, and Mg were very low, ranging from only 0.06 to 0.30%. Therefore, an analysis of tubers is not useful in plant analysis.

The degree of K deficiency can be estimated by following the rate of K decline in reference to the K critical level of 2.3% for the petiole and 1.1% for the blade tissues as illustrated by present results and of a field experiment.

Introduction

A plant physiologist often uses the water-culture technique to determine the nutrient requirements of plants (1, 2), whereas a horticulturist often uses the results of field tests for the same purpose (5). Quite often there is difficulty in reconciling results from nutrient solutions with field usage. In these instances, an intermediate study may be useful, such as a controlled pot test, to bridge the gap between water-culture results and those of the field.

Fong and Ulrich (2) determined the critical K level of potato plants to be 2.3% for the petiole and 1.3% for the blade tissues of a recently matured leaf for plants grown in water culture with stolon and tubers removed. In the present study, tubers were retained in an open pot solution culture experiment, using Alvolite, a low K material, and the daily watering with nutrient solutions. Results for a low and high-K series, relative to plant analysis concepts, are reported in this paper.

Materials and Methods

Potato plants, *Solanum tuberosum*, L. var. 'White Rose,' were grown outdoors in 5-gal pots containing Alvolite. Four plants, 4–6 inches tall, were transplanted to each of 24 pots on May 9. Thereafter, 12 pots were watered daily with a minus K solution of the following composition in millimoles per liter: 3.75 $Ca(NO_3)_2 \cdot 4H_2O$; 0.5 NaCl; 1.0 $NaH_2PO_4 \cdot H_2O$ and 1.0 $MgSO_4 \cdot 7H_2O$. Another 12 pots were watered daily with a high K solution of the following composition in millimoles per liter: 2.5 $Ca(NO_3)_2 \cdot 4H_2O$; 0.5 KH_2PO_4; 2.5 KNO_3; 1.0 $MgSO_4 \cdot 7H_2O$ and 0.5 NaCl. Both solutions contained microelements in mg per liter; 0.25 B, 0.25 Mn, 0.025 Zn, 0.01 Cu, and 0.005 Mo. Iron (2.5 mg per liter) was added as ferric-sodium ethylenediamine tetraacetate complex (3).

Leaf samples from only 2 of the 12 pots of each treat-

[1]Received for publication November 4, 1968. Department of Soils and Plant Nutrition.