Snap Bean Plant Responses to Zinc Sulfate and Manganese Sulfate Fertilization on Tile-drained Calcareous Glacial Till Soils

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Abstract. Effects of lateral movement of soil from tile lines based on soil and plant analysis, plus the effects of applications of ZnSO₄ and MnSO₄ on the concentrations of Zn, Mn, and other elements in the leaf blades of snap bean plants (*Phaseolus vulgaris*, var. *humilis* cv. Bush Blue Lake-47) and on the yield of snap bean pods at harvest were determined. Snap beans were grown across the tile lines and fertilized with five rates of ZnSO₄ and MnSO₄ fertilizers applied in a band at planting time. The soil decreased in pH and Ca and Mn content and increased in organic matter and Zn with distance from the tile lines. The leaf blades decreased in concentration of Ca and increased in concentrations of Mg, Zn, and Mn with distance from the tile lines. High rates of Zn and Mn fertilizers were required to obtain medium concentrations of Zn and Mn in plants grown over or near the tile lines. Concentrations of 24 to 30 µg of Zn per gram dry weight and 60 to 90 µg of Mn per gram dry weight in the leaf blades of the snap bean plants were adequate for highest yield of pods. Zinc sulfate at a rate of 0.5 to 0.7 g of Zn/m² produced the highest yield of pods at a distance of 3 m from the tile lines. Applied together, ZnSO₄ and MnSO₄ produced a yield response similar to application of only ZnSO₄. Twenty years after installation of the tile lines, the effects of the tile lines on soil and leaf analysis and yield of pods of snap bean plants extended 2 to 3 m in each direction from the tile lines, indicating that the soil moved laterally.

The soils of the northeast and north central United States, derived from calcareous glacial till with rolling topography, exhibit many areas with poor internal soil drainage. As a result, thousands of hectares in these areas have had soil underdrainage systems installed to improve their productivity. Tile drainage was originated in America in 1835 by a farmer, John Johnston, on his farm located just east of Geneva, N.Y. (Vittum, 1979). Since then, many types of soil drainage systems have been installed to improve the productivity of agricultural land (Goodman, 1953; Jones, 1952). For many years, the most common method of installing tile underdrainage was by using a wheel trenching machine (Jones, 1952) to excavate a trench ≈ 0.4 m wide and to a depth determined by slope for drainage requirements and soil type. As tiling machines advance across a field, the surface soil, subsoil, and parent material are mixed and deposited in a berm or ridge beside the trench. After the tile is laid in the bottom of the trench, the excavated material is pushed back into the trench to cover the tile and backfill the trench.

Soils derived from calcareous glacial till have high pH subsoils and are low in organic matter (Cline, 1961; Secor et al., 1947). In years following tile installation, zinc deficiency symptoms frequently occur on crops, especially snap bean plants, growing over the tile lines. Chemical analysis of recently expanded leaf blades of snap bean plants growing over the tile lines revealed a Zn concentration <15 µg of Zn/g of dry weight,

the critical level established for soybeans (Ohki, 1977). The Mn concentration was low, but not in the deficient range (Piggot, 1986). During recent years the visual Zn deficiency symptoms on snap beans appeared to be covering an area wider than the initial tile trench, suggesting lateral movement of subsoil away from the trench. The effects of soil factors on plant availability of Zn are described by Tisdale and Nelson (1966) but do not include the effects of lateral movement of calcareous subsoil into adjacent areas. Studies have shown that many years of normal tillage operations caused mixing of soils across plot boundary lines in the direction of travel of the tillage equipment in long-term fertility and lime experiments (MacDonald and Peck, 1976; Ohlrogge, 1954). An experiment was designed to determine the response of snap beans to ZnSO₄ and MnSO₄ when grown over and between tile lines.

Materials and Methods

Five rates of ZnSO₄ and MnSO₄ (0, 0.4, 0.8, 1.2, and 1.6 g of Zn and Mn/m²) were applied in a band at planting time across tile lines and the concentrations of elements in leaf blades of snap bean plants and yields of snap bean pods were determined in 1986 and 1987. Clay tile drainage lines were installed using a wheel trenching machine for fields at the Vegetable Research Farm in Geneva. The tile lines were installed in 1966 at a spacing of 15 m across the width of fields 60 × 120 m (width/length). The trench was 0.4 m wide and varied from 0.75 to 1.25 m in depth. The soil was a Lima silt loam (0% to 3% slope, fine loamy, mixed mesic Glossoboric Hapludalf), a productive soil derived from calcareous glacial till. The field had had a vegetable-cover crop rotation with conventional tillage operations since 1966. On several occasions, Zn deficiency symptoms were observed on snap bean plants and other vegetables grown over the tile lines.

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Table 1. Effect of distance from the tile line on pH, organic matter (OM), and soil elements.

Distance from tile (m)	Soil characteristic							
	pH	OM (g·kg ⁻¹)	P	K	Ca	Mg	Zn	Mn
			<i>mg·kg⁻¹ dry wt at 0–0.25 m depth</i>					
0.5	7.6	30.4	23	65	5870	323	1.2	30
1.5	7.6	32.3	24	70	4600	305	0.9	25
2.5	7.5	33.8	23	70	3500	303	1.1	21
3.5	7.4	34.4	25	69	3030	310	1.1	20
4.5	7.3	35.2	26	75	2970	318	1.3	21
5.5	7.3	35.0	26	74	2970	313	1.4	21
Significance								
Distance	<0.01	<0.01	0.38	0.01	<0.01	0.86	0.11	<0.01
Linear	<0.01	<0.01	0.08	<0.01	<0.01	0.95	0.03	<0.01
Quadratic	0.74	0.02	0.87	0.74	<0.01	0.37	0.13	<0.01
cv%	2	3	10	5	14	8	20	13

Table 2. Effects of distance from the tile line, rates of ZnSO₄ and MnSO₄ fertilizers, and Zn and Mn treatments on the concentrations of P, K, Ca, and Mg in leaf blades of snap beans at flowering.

Criterion	Concn of elements (mg·g ⁻¹ dry wt)			
	P	K	Ca	Mg
Distance from tile (m) ^z				
0.5	3.0	16.9	22.6	3.9
1.5	3.0	17.0	22.1	4.3
2.5	3.0	17.0	21.6	4.6
3.5	2.9	15.7	20.9	4.7
4.5	2.9	15.9	20.3	4.6
5.5	2.8	16.3	19.4	4.4
Rate (g·m ⁻²) ^y				
0.0	3.1	16.7	21.4	4.6
0.4	3.0	16.6	21.1	4.5
0.8	3.0	16.3	21.1	4.5
1.2	2.8	16.6	20.6	4.2
1.6	2.9	16.4	21.7	4.6
(Zn) ^x				
– Zn	3.1	16.8	21.4	4.6
+ Zn	2.8	16.1	20.8	4.3
Mn ^w				
– Mn	3.0	16.4	21.3	4.5
+ Mn	2.9	16.5	21.0	4.4
Significance				
Distance	0.54	0.48	<0.01	<0.01
Linear	0.11	0.14	<0.01	<0.01
Quadratic	0.30	0.75	0.63	<0.01
cv%	7	7	4	3
Rate	0.02	0.70	0.19	<0.01
Linear	0.12	0.73	0.36	0.92
Quadratic	0.42	1.00	0.14	0.04
cv%	8	7	8	7
Zn	<0.01	<0.01	0.04	<0.01
Distance × Zn	0.29	<0.01	0.28	0.17
cv%	10	7	9	8
Mn	0.71	0.22	0.16	0.68
cv%	10	9	12	9

^zCombined rates × Zn × Mn treatments × replications.^yCombined distances × Zn × Mn treatments × replications.^xCombined distances × rates × Mn treatments × replications.^wCombined distances × rates × Zn treatments × replications.

'Bush Blue Lake-47' snapbeans were grown in 1986 and 1987. Seeds were planted on 28 May 1986 and on 11 June 1987. The cultural practices, seed treatment, and herbicide applications

have been described (Peck et al., 1989). Fertilizer Zn from ZnSO₄ and Mn from MnSO₄ were applied at elemental rates of 0, 0.2, 0.4, 0.6, and 0.8 g per meter of row in rows 0.5 m apart (0, 0.4, 0.8, 1.2, and 1.6 g·m⁻²) in a band 5 cm to the side and 5 cm below the depth of the seed at planting for each year. The experimental design was a split plot with rates as main plots and with a two-level Mn × Zn factorial as subplots within each main plot. Rates were randomized within blocks, while the Zn × Mn factorial was randomized as Latin squares within the rates. An identical experiment was repeated in 1987 in the same field, with plots established not to overlap the plots of the previous year. There were two complete replications of main plots and subplots each year. Each main plot, 2 × 60 m (width/length), consisted of four differently treated rows (no Zn or Mn, Zn, Mn, and Zn plus Mn) 0.5 m apart on a level bed perpendicular to the tile lines. Wheel tracks of the tractor and the planter were outside the edge of each plot. All plots received constant rates of N, P, and K at 5 g·m⁻² (2.5 g per meter of row) for each element from a blend consisting of mono-ammonium phosphate (MAP), NH₄NO₃(NH₄)₂SO₄, KCl, and potassium-magnesium sulfate in a band at planting time. MAP supplied 2.4 g of N/m², the remaining 2.6 g of N/m² was supplied equally from NH₄NO₃ and (NH₄)₂SO₄ (1.3 g of N/m² from each source), and each K source supplied 2.5 g of K/m².

Soil samples were taken each year from each main plot to a 0.25-m depth at meter intervals starting from the center of randomly selected tile lines to a lateral distance of 6 m in each direction. The soil samples taken in July 1986 and June 1987 were analyzed for P, K, Ca, Mg, Mn, and Zn, using ammonium acetate-acetic acid extracting solution adjusted to pH 4.8 (MacDonald et al., 1978). Soil pH was determined in a 1 soil : 1 water (w/w) ratio and organic matter was determined by the titrimetric method (Greweling and Peech, 1965).

Plant tissue samples were taken on 8 to 10 July 1986 and on 21 July 1987 for chemical analysis. Blades of eight recently fully expanded trifoliate leaves of the snap bean plants were taken from each subplot at 1-m intervals starting at the center of the same tile line used for the soil samples and extending to a distance of 6 m in both directions from the sides of the tile lines. Samples were rinsed in demineralized water, blotted dry, placed in white paper bags, and dried in a forced-air drying oven at 70°C for 48 hr. Oven-dried leaf blade samples were ground in a stainless steel Wiley mill using a 850 µm screen, dry ashed, and analyzed for P, K, Ca, Mg, Zn, and Mn (Grew-

Fig. 1. Concentration of Zn ($\mu\text{g}\cdot\text{g}^{-1}$ dry weight) isoquants in leaf blades of snap bean plants at bloom stage for interaction of rates of Zn from ZnSO_4 and Mn from MnSO_4 (grams of Zn and Mn/ m^2) and for distance from the tile line (m) (see Table 4).

eling, 1976) except that the residue of salts was dissolved in 1.0 N HCl. Phosphorus was determined by the molybdenum procedure (Greweling, 1976). Potassium was determined in the emission made of a Jarrell-Ash Dial Atom-III atomic absorption spectrophotometer (Therma Jarrell Ash, Waltham, Mass.) Calcium and magnesium were determined by atomic absorption after addition of lanthanum solution, while Zn and Mn were determined directly by atomic absorption (Greweling, 1976).

Pods were not harvested in 1986 because of heavy rains at harvest time. In 1987 pods were harvested 6 Aug. Pods were hand-picked from 1-m sections of row from each subplot at 0 to 1 m, 3 to 4 m, and 5 to 6 m from the center of the tile line. Pods were separated into sieve-size grades by a Chisholm-Ryder double adjustable bar type grader (Peck and Van Buren, 1975).

GENSTAT (Lawes Agricultural Trust, Rothamsted Experiment Station, U.K.) was used to compute the analysis of variance for the level of significance and the regressions partitioned

Table 3. Effects of distance from the tile line, rates of ZnSO_4 and MnSO_4 fertilizers, and Zn and Mn treatment on the concentration of Zn and Mn ($\mu\text{g}\cdot\text{g}^{-1}$ dry wt) in leaf blades of snap beans at flowering.

Criterion	Concn of elements	
	Zn	Mn
Distance from tile (m) ^z		
0.5	19	50
1.5	21	54
2.5	24	79
3.5	25	91
4.5	25	87
5.5	25	80
Rate ($\text{g}\cdot\text{m}^{-2}$) ^y		
0.0	18	60
0.4	20	64
0.8	24	73
1.2	23	77
1.6	25	79
Zn ^x		
- Zn	18	75
+ Zn	28	72
Mn ^w		
- Mn	23	60
+ Mn	23	87
Significance		
Distance	0.09	<0.01
Linear	<0.01	<0.01
Quadratic	0.15	<0.01
cv%	14	16
Rate	<0.01	<0.01
Linear	<0.01	<0.01
Quadratic	0.04	0.15
cv%	13	17
Zn	<0.01	0.20
Rate $\times$ Zn	<0.01	0.38
cv%	23	20
Mn	0.24	<0.01
Rate $\times$ Mn	0.13	<0.01
cv%	18	28

^zCombined rates $\times$ Zn $\times$ Mn treatments $\times$ replications.

^yCombined distances $\times$ Zn $\times$ Mn treatments $\times$ replications.

^xCombined distances $\times$ rates $\times$ Mn treatments $\times$ replications.

^wCombined distances $\times$ rates $\times$ Zn treatments $\times$ replications.

to linear and quadratic responses in the order given. MINITAB (Minitab, University Park, Pa.) was used for the regression analysis. Figures 1 through 4 were produced using the GCONTOUR procedure of SAS/GRAPH (SAS Institute, Cary, N.C.).

Results and Discussion

Weather and years. The growing season weather during 1986 and 1987 was similar. There were few interactions with $P \leq 0.01$ among years $\times$ distance from the tile lines $\times$ rates of Zn and Mn fertilizers on the concentrations of elements in the leaf blades at flowering. The year effect was very slight on soil test results. Thus, the results given are for combined years.

Soil tests. Soil pH decreased gradually with distance from the tile lines, while soil organic matter increased with distance (Table 1). Soil K consistently and Zn generally increased with distance from the tile lines. Soil Ca declined rapidly with distance from the tile lines, while distance had no effect on soil Mg (Table 1). Soil Mn decreased with distance from the tile lines. Thus, soil Mn increased as soil pH increased as measured by the soil test method used. Our previous results (unpublished

Table 4. Regression equations for concentrations of Zn ($\mu\text{g}\cdot\text{g}^{-1}$ dry wt) in leaf blades of snap bean plants at bloom stage for rates (R) of Zn from ZnSO_4 and Mn from MnSO_4 (grams of Zn and Mn/ m^2) and for distance (D) from the tile line (m)².

Zn rates						
Zn ($\mu\text{g}\cdot\text{g}^{-1}$)	= 13.0 +	3.57 D +	11.7 R -	0.479 D ² -	3.94 R ² +	0.86 R × D
SD	1.9	1.1	3.0	0.2	1.6	0.4
P value		<0.01	<0.01	0.01	0.02	0.07
Mn rates						
Zn ($\mu\text{g}\cdot\text{g}^{-1}$)	= 14.0 +	2.45 D +	2.83 R -	0.26 D ² -	1.41 R ² -	0.12 R × D
SD	0.8	0.5	1.3	0.1	0.7	0.2
P value		<0.01	0.04	<0.01	0.05	0.53
Zn + Mn rates						
Zn ($\mu\text{g}\cdot\text{g}^{-1}$)	= 11.9 +	4.26 D +	10.1 R -	0.54 D ² -	1.49 R ² +	0.56 R × D
SD	2.4	1.4	3.7	0.2	2.0	0.6
P value		<0.01	0.01	0.02	0.46	0.32

²n = 30; SD = standard deviation.

Table 5. Regression equations for concentrations of Mn ($\mu\text{g}\cdot\text{g}^{-1}$ dry wt) in leaf blades of snap bean plants at bloom stage for rates (R) of Zn from ZnSO_4 and Mn from MnSO_4 (grams of Zn and Mn/ m^2) and for distance (D) from the tile line (m)².

Zn rates						
Mn ($\mu\text{g}\cdot\text{g}^{-1}$)	= 24.3 +	21.2 D -	4.78 R -	2.43 D ² +	3.5 R ² +	0.44 R × D
SD	4.3	2.5	6.7	0.4	3.6	1.0
P value		<0.01	0.48	<0.01	0.34	0.66
Mn rates						
Mn ($\mu\text{g}\cdot\text{g}^{-1}$)	= 20.1 +	24.7 D +	52.0 R -	3.03 D ² -	16.8 R ² +	0.07 R × D
SD	10.4	6.1	16.4	0.9	8.8	2.4
P value		<0.01	<0.01	<0.01	0.07	0.98
Zn + Mn rates						
Mn ($\mu\text{g}\cdot\text{g}^{-1}$)	= 13.0 +	31.0 D +	18.8 R -	3.98 D ² -	0.52 R ² +	2.52 R × D
SD	8.4	4.9	13.2	0.8	7.1	2.0
P value		<0.01	0.17	<0.01	0.94	0.21

²n = 30; SD = standard deviation.

Table 6. Regression equations for yield of snap bean pods (grams fresh wt/ m^2) for rates (R) of Zn from ZnSO_4 and Mn from MnSO_4 (grams of Zn and Mn/ m^2) and for distance (D) from the tile line (m)².

Zn rates						
Yield of pods	= 1110 +	167 D +	527 R -	20 D ² -	231 R ² -	66 R × D
SD	123	74	226	12	124	29
P value		0.05	0.04	0.13	0.10	0.05
Mn rates						
Yield of pods	= 1199 -	2D -	143 R +	11.9 D ² +	204 R ² -	45 R × D
SD	152	91	277	14	152	35
P value		0.98	0.62	0.43	0.21	0.23
Zn + Mn rates						
Yield of pods	= 1176 +	208 D +	282 R -	32 D ² -	77 R ² -	50 R × D
SD	119	72	217	11	119	27
P value		0.02	0.23	0.02	0.53	0.10

²n = 15; SD = standard deviation.

data) and those reported by Mohebbi and Mahler (1988) showed that soil Mn decreased with increasing soil pH. Krauskopf (1967) showed that of the sedimentary rocks, limestone had the highest concentration of Mn. The soil-extracting solution, ammonium acetate-acetic acid adjusted to pH 4.8, extracted Mn in proportion to the amount of limestone, especially near the tile lines.

The increase in soil organic matter was primarily a dilution effect, as Secor et al. (1947) showed organic matter in the soil decreased with depth. Peck et al. (1976) showed soil P and K decreased with depth regardless of past fertilization practices. Soil Ca was affected by distance from the tile lines more than any other soil variable, showing a large decrease with distance from the tile line, while soil pH gradually declined with distance (Table 1). Soil pH of soils derived from calcareous glacial till depends on the CO_2 pressure in the soil air (Bradfield, 1941). Soil Zn values were variable, displaying a 20% cv (Table 1).

Incomplete backfill from the berm side of the trench could account for distance effects on the soil test results; however, the soil was sampled in both directions from the tile lines with no effects of direction on the results. Thus, the soil tests indicated lateral movement of the soil from the tile lines during the 20 years following installation, and the lateral movement extended 2 to 3 m in each direction from the tile lines.

P, K, Ca, and Mg in leaf blades. The concentration of P in the leaf blades was not affected by distance from the tile lines (Table 2). Fertilizer Zn from ZnSO_4 decreased the concentration of P in the leaf blades. Jackson et al. (1967) reported a P vs. Zn effect on sweet corn (*Zea mays* L.), especially on plots that received applications of lime, and explained the effect as a dilution due to the greater yield of the combined lime-Zn treatment. The concentration of K (Table 2) in the leaf blades was not affected by distance from the tile lines but was decreased

Fig. 2. Concentration of Mn ($\mu\text{g}\cdot\text{g}^{-1}$ dry weight) isoquants in leaf blades of snap bean plants at bloom stage for interaction of rates of Zn from ZnSO_4 and Mn from MnSO_4 (grams of Zn and Mn/ m^2) and for distance from the tile line (m) (see Table 5).

slightly by an application of fertilizer Zn. Application of Zn fertilizer and distance interacted with the concentration of K in the leaf blades. Without Zn fertilizer, the K concentration decreased with distance, but with Zn fertilizer the K concentration remained constant with distance from the tile lines (data not shown). The concentration of Ca (Table 2) was influenced by distance from the tile lines, more than from applications of Zn fertilizer, decreasing with distance while Zn fertilizer had a slight effect. Soil Ca was highest at or near the tile line (Table 1). The concentration of Mg increased with distance from the tile line, while application of Zn fertilizer decreased the concentration of Mg even though all plots received a uniform band application of $2.5 \text{ g Mg}/\text{m}^2$ from potassium-magnesium sulfate. Fertilizer Mn from MnSO_4 had no effect on the concentration of P, K, Ca, and Mg in the leaf blades (Table 2). The concentrations of P, K, Ca, and Mg in the leaf blades were affected

Fig. 3. Yield isoquants ($\text{g fresh weight}/\text{m}^2$) of snap bean pods for interaction of rates of Zn from ZnSO_4 and Mn from MnSO_4 (grams of Zn and Mn/ m^2) and for distance from the tile line (m) (see Table 6).

by the highly calcareous subsoil at or near the tile lines and by applications of fertilizer Zn.

Zn and Mn in leaf blades. Increasing rates of ZnSO_4 fertilizer caused an increase in the concentration of Zn in the leaf blades (Table 3). The concentration of Zn in the leaf blades as a function of rates of ZnSO_4 and distance from the tile lines showed that this concentration depended on both rate and distance (Fig. 1, Table 4). The concentration of Zn in the leaf blades as a function of rates of MnSO_4 and distance from the tile line showed that the concentration of Zn in the leaf blades was most dependent on distance (Fig. 1, Table 4). When Zn and Mn were applied together, the concentration of Zn in the leaf blades depended on both rate and distance from the tile lines (Fig. 1, Table 4).

Applications of Zn and Mn fertilizers together caused an increase in the concentration of Zn in the leaf blades at 0.5 m from the tile lines more than Zn alone. A rate of $>1.6 \text{ g of Zn}/\text{m}^2$ was required to obtain a concentration of $24 \mu\text{g}$ of Zn dry weight in the blades when applied alone, while only 1.2 g of

Table 7. Regression equations for size of pods (percent of pods sieve-size 4 and under) for rates (R) of Zn from ZnSO₄ and Mn from MnSO₄ (grams of Zn and Mn/m²) and for distance (D) from the tile line (m)².

Zn rates						
% 4s and under =	85.5	- 0.84 D	- 5.20 R	- 0.48 D ²	+ 2.92 R ²	+ 0.06 R × D
SD	4.2	2.6	7.8	0.4	4.3	1.0
P value		0.75	0.52	0.27	0.51	0.95
Mn rates						
% 4s and under =	86.7	- 1.60 D	- 7.27 R	+ 0.02 D ²	+ 3.15 R ²	+ 0.27 R × D
SD	2.5	1.5	4.6	0.2	2.5	0.6
P value		0.31	0.14	0.95	0.24	0.65
Zn + Mn rates						
% 4s and under =	86.8	- 2.92 D	- 5.86 R	+ 0.26 D ²	+ 4.48 R ²	- 0.52 R × D
SD	4.4	2.6	8.0	0.4	4.4	1.0
P value		0.30	0.48	0.55	0.34	0.62

²n = 15; SD = standard deviation.

Fig. 4. Size of pods isoquants (percent of pods sieve-size 4 and under) for interaction of rates of Zn from ZnSO₄ and Mn from MnSO₄ (grams of Zn and Mn/m²) and for distance from the tile line (m) (see Table 7).

Zn/m² was required when Zn and Mn were applied together (Fig. 1). At a distance of 2 to 3 m from the tile lines, a rate of

0.4 g of Zn/m² maintained a level of 24 µg of Zn/g dry weight in the leaf blades from applications of Zn alone or with Mn (Fig. 1). When no Zn was applied or Mn was applied alone, the Zn concentration in the blades increased from <16 µg of Zn/g dry weight at 0.5 m from tile lines to 20 µg/g dry weight at a distance of 3 m and maintained that concentration to a distance of 5.5 m. Therefore, the increase in soil Zn did affect the Zn concentration in the leaf blade, but the increase was not great enough to raise the concentration in the leaf blade to an adequate level.

Increasing rates of MnSO₄ fertilizer caused an increase in the concentration of Mn in the leaf blades (Table 3). Zinc fertilizer had no effect on the concentration of Mn. The concentration of Mn in the leaf blades as a function of rates of MnSO₄ and distance from the tile lines showed that the concentration of Mn in the leaf blades was most dependent on distance (Fig. 2, Table 5).

Applications of Zn and Mn fertilizers together did not lead to an increase in the concentration of Mn over the tile lines as much as did an application of Mn fertilizer alone. A rate of >1.6 g of Mn/m² was required to obtain a concentration of 60 µg of Mn/g dry weight in the leaf blade at 0.5 m from the tile lines when fertilizer Zn and Mn were applied together. When Mn fertilizer was applied alone, a rate <0.8 g of Mn/m² was required to obtain the same concentration at 0.5 m from the tile lines (Fig. 2).

Soil test results showed that soil Mn was higher at 0.5 m from the tile lines and decreased with distance (Table 1), whereas the plant revealed that high rates of Mn fertilizer were required to increase the concentration of Mn in the leaf blade over the tile lines (Fig. 2). When no Mn fertilizer was applied, or Zn fertilizer was applied alone, the concentration of Mn in the leaf blade increased from <40 µg of Mn/g dry weight at 0.5 m from the tile lines to ≈70 µg of Mn/g dry weight at greater distances from the tile lines.

Yield. The yield of pods as a function of distance from the tile lines and of rates of ZnSO₄ showed yields were affected by distance, rate, and distance × rate interaction (Fig. 3, Table 6). Application of rates of MnSO₄ showed no significant effects of distance or rate on yield of pods (Fig. 3, Table 6). When ZnSO₄ and MnSO₄ were applied together, yields were affected by distance from the tile lines (Fig. 3, Table 6).

Yield of pods was more affected by Zn than by Mn. Zinc and manganese applied together elicited a response similar to that of applications of Zn only (Fig. 3). The highest yield from applications of Zn only occurred at a distance of 3 m from the tile lines with 0.5 to 0.7 g of Zn/m². Yields decreased in both

directions from there (Fig. 3). The addition of Mn to the Zn produced a yield response that covered a wider area than that of Zn alone, with high yields obtained <2 m from the tile line. Rates of 1.2 g of each Zn and Mn were required to produce the high yields near the tile lines. High rates of Zn only or Zn plus Mn decreased yields at distances beyond 3 m (Fig. 3).

Size of pods. No significant effects of distance from tile lines or rates of Zn and Mn fertilizers on pod size were noted (Table 7), although a trend of increasing pod size with distance was indicated (Fig. 4).

Drainage. Precipitation during the growing season for the 2 years was above average, with 302 and 226 mm from planting to harvesting for 1986 and 1987, respectively, with the average being 168. mm for the period involved (Vittum et al., 1983). As a result, there were periods of excess water (Peck et al., 1989). The high yields obtained midway between the tile lines and at 6 m may in part have been due to good drainage. The soil over the tile lines may have been too calcareous to produce high yields, while soil farther away from the tile lines was more poorly drained, thus probably limiting yields. Distance from the tile lines and rate of fertilizer Zn and Mn had no effect on plant stand and no significant interactions were present.

Twenty years after installation, the effects of the highly calcareous subsoil backfilled into the trench over the tile lines were still very prominent, as shown by soil and plant analysis. The effect extends 2 to 3 m in each direction laterally from the sides of the tile lines. The growth and yield of the snap bean plants can be improved over and near the tile lines by the addition of both Zn and Mn fertilizer in the band at planting time. However, it appears that the calcareous subsoil over and near the tile lines will still prevail for years to come, and should be recognized as a factor that affects the concentrations of elements in the plant tissues, as well as limiting yield and delaying maturity of the crop.

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