MANGANESE AND SOIL PH EFFECTS ON YIELD AND QUALITY OF FLUE-CURED TOBACCO

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A study involving Mn rates and soil pH levels was conducted in 1985 and 1986 with flue-cured tobacco (*Nicotiana tabacum* L.) in Georgia since reports from North Carolina indicate that Mn may be beneficial for tobacco on some low Mn soils with pH levels of 6.2 and higher. The site was a Pelham loamy sand (thermic, Arenic Paleaquult) where yield response to Mn had been documented for corn (*Zea mays* L.), peanut (*Arachis hypogaea* L.), soybean [*Glycine max* (L.) Merr.], and wheat (*Triticum sativum* L.) in previous experiments. Factorial treatments initiated in 1977 were three soil pH levels (5.4, 6.2, and 7.2 in 1985) and Mn rates of 0, 10, 20 and 40 kg/ha applied annually as MnSO4 except in 1981 and 1985. Leaf Mn increased with increasing rates of Mn and decreased within each Mn rate as soil pH increased. Leaf yield and quality were not affected by Mn application even though leaf Mn ranged from 13 to 129 mg/kg in 1985 and from 21 to 307 mg/kg in 1986. A mild Mn deficiency symptom, "flecking", was observed where leaf Mn of mature cured leaves was 13 mg/kg. Leaf yield increased with increasing pH levels in 1986, but this was probably the result of a high incidence of fusarium wilt (*Fusarium oxysporium* f. *nicotiane*) on plants grown in low pH plots. The incidence of fusarium wilt decreased with increasing pH. Data agree with long term field observations in Georgia that Mn deficiency is more probable for major agronomic crops other than tobacco grown on high pH (>6.5) soils.

Additional index words: (*Nicotiana tabacum* L.), soil Mn, leaf Mn, limestone.

INTRODUCTION

Manganese deficiency in crops in Georgia generally is limited to soils in the Atlantic Coast Flatwoods province. These soils are located in Southeast Georgia within the Coast Plain region (1) and, in their native condition, are usually poorly-drained, sandy, acidic, and have a low cation exchange capacity (12). They require limestone for successful production of crops, including tobacco (*Nicotiana tabacum* L.). Indigenous Mn in these soils is relatively low and Mn deficiency in crops usually is the result of overliming (21) since Mn availability to plants decreases with increased soil pH (5, 16, 17). Unpublished data (M.B. Parker, 1985) for corn (*Zea mays* L.), soybean [*Glycine max* (L.) Merr.], and wheat (*Triticum sativum* L.) and published data (17) for peanut (*Arachis hypogaea* L.) show that Mn application increased yields markedly in a long term field study when soil pH in a Flatwoods soil was 6.4. The desirable soil pH for corn, peanut, soybean, and wheat was near 6.0 since neither Al toxicity nor Mn deficiency occurred at this pH.

Numerous instances of Mn deficiency, confirmed by plant analysis, have been observed in peanut and soybean grown in relatively high pH (>6.3) Atlantic Coast Flatwoods soils (3, 17). These observations and long-term limestone experiments provided evidence in Georgia to lower the recommended pH of 6.0 to 6.5 to a target pH of 6.0 for agronomic crops, with the exception of alfalfa (*Medicago sativa* L.), which remained at 6.5 (19).

In Georgia, vegetable crops are being grown in late summer and fall following tobacco harvest. Since the target pH of most vegetable crops is 6.0 to 6.5 and most agronomic crops is 6.0 (19), it is possible that some micronutrients, including Mn, may be limiting to flue-cured tobacco if the soil pH is increased by limestone to meet the upper limit of pH 6.5 recommended for vegetable crops. Approximately one-half of the flue-cured tobacco in Georgia is grown in the Atlantic Coast Flatwoods region but economic loss of tobacco resulting from Mn deficiency has not been documented (R.L. Miles, 1986, personal communication).

Manganese deficiency symptoms rarely occur in tobacco grown under field conditions because tobacco normally is grown on relatively low pH soils under heavy fertilization and tobacco plants apparently contain luxuriant amounts of Mn (13). The average leaf Mn concentration in tobacco in a four-year study ranged from 70 to 140 mg/kg where no Mn was applied compared to an average of 365 mg/kg where 11 kg/ha of Mn was applied (2). Concentrations of Mn in leaves showing symptoms

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Table 1. Rainfall, irrigation, and average maximum air temperature data in 1985 and 1986.

Month	Rainfall†		Irrigation†		Maximum air temperature‡	
	1985	1986	1985	1986	1985	1986
	---- cm ----		---- cm ----		---- C° ----	
April	4.93	0.51	1.27	2.54	25.6	26.8
May	13.38	2.39	----	2.54	28.8	30.1
June	6.10	9.65	----	2.54	32.3	33.4
July	12.40	8.36	----	1.27	32.4	35.0
August	18.29	11.05	----	----	31.7	31.9
Total	55.10	31.96				

†Recorded at site.

‡Recorded from Coastal Plain Experiment Station weather site located about 9.6 km from research site.

of Mn deficiency were 22 mg/kg for plants growing in nutrient solution (13), 13 mg/kg in green field-grown lower leaves exhibiting considerable necrotic spotting, and 18 mg/kg after curing due to loss of volatile constituents during curing (6).

Reports (4, 18) indicate that Mn deficiency of flue-cured tobacco may be a problem on some soils with pH >6.2 in North Carolina. "Flecking" of leaves was the symptom described for Mn deficiency, but there was no documentation of leaf Mn concentrations or that leaf injury resulted in lower yields and quality than healthy leaves. In addition to "flecking", Mn deficiency of tobacco has been described as interveinal chlorosis (9, 14) which is the symptom also described for other broad-leafed plants including peanut (17) and soybean (3). Manganese is suggested for tobacco in North Carolina where Mn deficiency is suspected and also where some soils testing low in Mn with pH levels of 6.2 or higher indicate a high probability of response to Mn (4, 18).

The objectives of this study were to determine the influence of rates of Mn application at three soil pH levels on yield, mineral concentrations in soil and leaves, and quality of tobacco grown on an Atlantic Coast Flatwoods soil where Mn deficiency in corn, peanut, soybean, and wheat had been documented.

MATERIALS AND METHODS

Flue-cured tobacco ('North Carolina 2326') was grown in 1985 and 1986 on a Pelham loamy sand (thermic, Arenic Paleaquult) at the Tobacco Research Farm on the Coastal Plain Experiment Station near Tifton, Georgia. The soil tested high in P (91 kg/ha) and medium in K (91 kg/ha) in 1985. The tobacco research was a continuation of a long term pH-Mn study initiated in 1977. Soybean was grown in 1977-81, corn in 1982-83 with wheat preceding peanut in 1984.

Soil pH and Mn treatments were arranged in split plot, randomized block experimental design with five replications of each treatment. Whole plots were low, medium, and high pH levels with target values of 5.5, 6.0, and 6.5. Soil pH levels were established and maintained near target values until October 1983 by applying a total of 0, 5.6, and 22.4 MT/ha of limestone (29.3% Ca and 5.1% Mg) during 1977, 1978, and 1979. In October 1983 whole plot treatments received 0, 2.24, and 4.48 MT/ha of limestone for low, medium, and high pH levels, respectively. Subplots were Mn treatments of 0, 10, 20, and 40 kg/ha as $MnSO_4$ applied each spring to the soil from 1977 to 1984 except for 1981 and 1985 when residual effects were evaluated. These Mn treatments also were applied on 1 October 1985 for broccoli (*Brassica oleracea* L.) following tobacco and residual effects on tobacco were evaluated in 1986. Subplots were five rows spaced 112 cm apart and 6.1 m long.

Twelve plants were transplanted per 6.1 m of row (51 cm spacing) on 3 April 1985 and on 1 April 1986. A commercial tobacco fertilizer (6-2.6-15.N-P-K) supplied the following amounts of elements (kg/ha) each year: 67 N (1/2 $NaNO_3$ and 1/2 $(NH_4)_2SO_4$), 29P, 168 K, 56 Ca, 22 Mg, 112 S, 0.28 B, 1.12 Mn, 1.12 Zn, and 20 Cl. One-half of the fertilizer was applied on either side of the row during the first cultivation approximately one week after transplanting. The remaining one-half was applied at the second cultivation one week later. Recommended practices were followed for weed, insect, and sucker control. Monthly rainfall, irrigation and maximum air temperature data are shown in Table 1. The number of plants infected by *Fusarium oxysporium* f. *nicotiane* was recorded on 4 August 1986. The leaves of plants in the second and third rows of the five-row subplot were harvested in five primings, cured, and graded according to established standards (23). A random sample of leaf laminae from each priming, which constituted a proportional part of the total leaf weight, was composited from each plot to make a 454 g sample which was ground in a Wiley mill for chemical analysis.

Eight soil cores, measuring 2.54 cm in diameter by 15 cm in depth, were collected from each plot on 1 October 1985 and 15 September 1986. These samplings followed final harvest on 1 August 1985 and 6 August 1986. The soil was moldboard plowed before sampling in 1985 and disked before sampling in 1986. Nutrients, P, K, Ca, Mg, Cu, Mn, and Zn, in soils and cured leaves (7) and concentrations of total alkaloids, total N, and reducing sugars in cured leaves (8) were determined, but only those determinations which were affected significantly by treatments are reported. Soil pH was determined on a 1:1 ratio of soil and water and elements were extracted from the soil on a 1:4 (weight/volume) ratio using Mehlich-1 (0.05 M HCl + 0.125 M H_2SO_4) (22) or on a 1:2 (weight/volume) using DTPA (0.005 M DTPA + 0.01 M $CaCl_2$ + 0.1 M TEA) extractants (10).

RESULTS

The growing season in 1985 was hotter and dryer than that in 1986 (**Table 1**). Maximum air temperature during the 18 week growing season in 1986 averaged 1.3°C higher than in 1985. In addition, rainfall was only 60% of that received in 1985. Higher temperatures in 1986, coupled with moisture stress, resulted in lower yields, lower crop value, and shorter plants in 1986 than in 1985 (**Table 2**). More irrigation water was applied in 1986 than in 1985 to alleviate plant stress but the amount of water available for irrigation in 1986 was insufficient.

The only indication of visible Mn deficiency symptoms on tobacco occurred in 1985 when numerous brown flecks, 1-2 mm diam., were observed on 24 May for leaves on the lower ⅓ of plants in the highest pH plots with no Mn fertilizer. This mild leaf damage, however, had no significant effect on yield, quality,

Table 2. Effect of soil pH on plant height, disease incidence, leaf yield and value of tobacco. 1985-1986 (averaged over Mn treatments).

Soil pH		Plant height†		Diseased plants‡	Leaf yield		Value	
1985	1986	1985	1986	4 August 1986	1985	1986	1985	1986
		---- cm ----		------ % ------	--- kg/ha --		--- $/ha ---	
5.4	5.3	58.9	49.5	49.4	2815	1841	10,572	6,276
6.2	6.1	64.0	56.9	42.0	2763	2294	10,567	7,956
7.2	7.3	73.2	65.0	25.2	2867	2621	10,843	9,191
LSD (0.05)		7.6	9.4	18.1	N.S.	469	N.S.	1,776
CV (%)		7.9	11.2	32.1	3.9	14.3	3.4	15.6

†Measured on 22 May 1985 and on 29 May 1986.

‡Percentage of plants infected with Fusarium wilt.

or value of tobacco; however the five primings were composited for chemical analysis. Since all plant and soil parameters measured, except leaf and soil Mn, were not affected by Mn treatments and soil pH x Mn rate interactions were non-significant, the plant data in Tables 2 and 3 and the soil data in Table 4 are averaged over all Mn treatments.

Plant height, yield, and value varied with soil pH, but the effects were not consistent for yield and value both years (**Table 2**). Plant height increased significantly with increasing soil pH when measured 49 and 58 days after transplanting in 1985 and 1986, respectively.

Fusarium wilt was not a problem in 1985, but a relatively high number of plants was infected in 1986 especially at the lower pH levels (**Table 2**). The wilt problem did not occur on many of the plants until the late primings.

Leaf yield and tobacco crop value/ha increased with increased pH levels in 1986 (**Table 2**), but these factors were not affected by treatments in 1985. Grade index averaged 40 in 1985 and 45 in 1986 (date not shown), but there was no significant difference among treatments.

The concentrations of total alkaloids, N and P in tobacco leaves (data not presented) were not affected by treatments either year, but there were significant differences in other constituents among soil pH levels for either one or both years (**Table 3**). Total alkaloid concentrations averaged 3.39% in 1985 compared to 4.26% in 1986 while N averaged 2.10 and 2.04% in 1985 and 1986, respectively. Leaf P averaged 0.24% in 1985 and 0.26% in 1986. Concentrations of reducing sugars in tobacco leaves were significantly higher at soil pH of 5.4 in 1985 compared to higher pH values, but there were no significant differences in reducing sugar levels among treatments in 1986.

Concentrations of K, Cu, and Zn in leaves decreased and Ca and Mg increased with increasing pH levels (**Table 3**). However, leaf K was influenced by treatment only in 1985. Leaf Mg, Cu, and Zn tended to be higher in 1986 than in 1985, but leaf K was higher in 1985 than in 1986. Leaf Ca values were similar for both years. Even though content of some chemical constituents in tobacco leaves varied among soil pH levels, there was no indication that leaf quality, yield, price, or value/ha were affected by plant chemistry.

Soil pH and extractable levels of several elements in the soil were determined, but only soil pH and extractable levels of P, Ca, and Mg were affected by limestone treatments (Table 4). Target soil pH values near 5.5 and 6.0 for low and medium levels, respectively, were maintained closely by limestone treatments over the 10 year period (all data not shown). However, the most recent limestone application in October 1983 increased the soil pH for the high lime treatment above the high target pH of 6.5. Soil levels of Ca and Mg in the soil were increased markedly by increased rates of limestone.

Soil P increased with increasing soil pH levels and P levels were higher in 1986 then in 1985 (**Table 4**). Levels of soil K and Cu remained similar between years with K averaging 108 and Cu 1.8 kg/ha, respectively, over years (data not shown). Concentrations of Zn in soil were greater in 1986 than 1985 averaging 5.3 and 3.0 kg/ha, respectively (data not shown). Increased levels of soil Ca and Mg were reflected by increased levels of leaf Ca and Mg, but there was no significant relationship between soil and leaf

Table 3. Effect of soil pH on concentrations of reducing sugars and selected elements in leaves of tobacco. 1985-1986 (averaged over Mn treatments).

Soil pH		Reducing sugars		Element concentration in leaves									
				K		Ca		Mg		Cu		Zn	
1985	1986	1985	1986	1985	1986	1985	1986	1985	1986	1985	1986	1985	1986
		%								mg/kg			
5.4	5.3	20.2	13.5	2.01	1.53	1.33	1.52	0.33	0.58	37	43	95	128
6.2	6.1	17.8	14.0	1.84	1.48	1.72	1.67	0.47	0.63	27	29	57	69
7.2	7.3	17.5	14.3	1.84	1.52	2.20	2.15	0.44	0.68	23	20	36	48
LSD (0.05)		2.2	N.S.	0.13	N.S.	0.17	0.18	0.04	0.06	5	5.8	8	11
CV (%)		8.1	5.1	4.6	8.7	6.6	6.9	6.0	6.0	11.0	13.0	8.7	8.8

Table 4. Effect of limestone rates on soil pH and concentrations of selected elements in a Pelham loamy sand. 1985-1986 (averaged over Mn treatments).

Limestone rate‡	Soil pH		Element concentration in soil†					
			P		Ca		Mg	
	1985	1986	1985	1986	1985	1986	1985	1986
MT/ha			kg/ha					
0	5.4	5.3	47	80	317	290	30	47
7.84	6.2	6.1	58	95	775	772	92	103
26.88	7.2	7.3	66	98	1530	1470	164	207
LSD (0.05)	0.2	.12	11	14	120	129	10	17
CV (%)	2.2	1.29	14.1	10.9	9.4	10.4	7.3	9.8

†Mehlich-1 extractant.

‡Total amount of limestone applied since 1977.

P, K, Cu, and Zn. Correlation coefficient values between soil and leaf concentrations of Ca and Mg were consistent each year and averaged 0.85 (P = 0.0001) for Ca and 0.53 (P = 0.0001) for Mg.

Leaf Mn was increased by residual Mn rates in 1985, but values for each rate declined with increasing soil pH **(Table 5)**. Concentrations of leaf Mn increased with Mn rates and were higher in 1986 than in 1985, regardless of treatment, except for the highest pH value where values were similar. Additional amounts of Mn were applied in October 1985 prior to the 1986 crop **(Table 5)** and yields were lower in 1986, especially for the lowest pH treatment. Perhaps the higher yields in 1985 could have had a dilution effect on leaf Mn in 1985.

Concentrations of leaf Mn ranged from 13 to 129 mg/kg in 1985 and from 21 to 307 mg/kg in 1986 **(Table 5)**. "Flecking", a mild Mn deficiency symptom, was observed only in 1985 on plots where Mn concentration of harvested leaves was 13 kg/mg. Leaf Mn concentrations of 21 and 23 mg/kg in 1985, and 21 mg/kg in 1986 in harvested leaves apparently were sufficient since deficiency symptoms were not observed and maximum yields were obtained for treatments corresponding to those leaf Mn concentrations.

Mehlich-1 extractable Mn increased with increasing rates of Mn, but levels for each Mn treatment tended to be higher for the highest pH level compared to the lower pH levels **(Table 5)**. Soil Mn extracted by DTPA also increased with rates of Mn, but the range in Mn concentration corresponding to Mn rates was lower for DTPA than Mehlich-1 extractants. However, decreasing amounts of Mn were extracted by DTPA with increased pH levels for each particular Mn rate. Therefore, leaf Mn corresponded better to DTPA than to Mehlich-1 extractable Mn. Correlation coefficients for Mehlich-1 extractable Mn vs leaf Mn were 0.166 (N.S.) in 1985 and 0.0019 (N.S.) in 1986. In comparison, DTPA extractable Mn vs leaf Mn was 0.916 (P = 0.001) in 1985 and 0.869 (P = 0.001) in 1986.

DISCUSSION

The increase in yield and value with increasing soil pH in 1986 may be the result of a combination of factors. This experimental site was infested with *F. oxysporium* f. *nicotiane* and the incidence of disease caused by this organism was highest at low soil pH and diminished with increasing pH **(Table 2)**. This agrees with a report that low levels of Ca increase the susceptibility of tobacco to Fusarium wilt (11). Thus, yield reduction due to the disease may have occurred under more acid conditions but the disease became apparent only during the later stages of harvest and may not account for all the yield reduction. In addition, root development may have been better at higher soil pH. This could have resulted in more efficient use of the limited amounts of soil water available in 1986 and may partially account for the yield response in 1986. The lack of yield difference in 1985 suggest that soil acidity per se was not the limiting factor. A soil pH of 5.3 is reported to be satisfactory for tabacco (9).

Manganese deficiency was expected on tobacco grown on the highest pH plots (>7.0); but it was observed only in 1985 and did not affect yield and quality of tobacco. Visible symptoms of Mn deficiency, flecking of lower leaves, were at a low incidence level. A level of 22 mg/kg Mn in leaves was reported as the critical concentration in tobacco leaves from plants grown in a nutrient solution (14) but sufficiency levels in Georgia (20) for uppermost fully developed leaves at bloom is 30-250 mg/kg. In our study 13 mg/kg Mn in cured, mature leaves apparently were adequate for maximum yield and leaf Mn levels of 21 to 25 mg/kg were sufficient to prevent Mn deficiency symptoms. Miner et al found that 13 mg/kg of Mn in cured leaves was sufficient to produce high yields of flue-cured tobacco and this leaf Mn concentration was considerably lower than published Mn critical levels (15).

Manganese is not recommended for tobacco production in Georgia because Mn deficiency has not been a problem even on Atlantic Coast Flatwoods soils where Mn deficiency has been observed and confirmed on corn, peanut, soybean, and wheat. However, 3.36 kg Mn/ha banded and 11.2 kg Mn/ha broadcast are suggested for flue-cured tobacco production in North Carolina where soil pH is 6.2 or higher and the soil test Mn availability index is less than 26 (4, 18). However, tobacco yields were not increased by foliar or soil applied Mn in North Carolina on three soils which varied from pH 6.3 to 6.5 and from 17 to 24 in Mn availability indices (15). In our study, "flecking", a problem which may be related to weather effects or Mn deficiency, did not cause enough leaf injury to justify more than the 1.12 kg/ha Mn application on a Pelham loamy sand even at a soil pH of 7.2.

Earlier data from the same experimental site show that soybean, corn, peanut, and wheat suffered a yield reduction from Mn deficiency but flue-cured tobacco apparently was able to obtain sufficient Mn from this high pH soil (pH >6.7). Crop yield and leaf Mn levels for soybean in 1981, corn in 1982, and peanut in 1984 ranged from 1.04 to 1.57 MT/ha for soybean leaf Mn concentrations of 16 to 33 mg/kg, 3.01 to 9.72 MT/ha for corn ear leaf Mn concentrations of 6 to 15 mg/kg (M.B. Parker, 1985, unpublished), and 3.41 to 6.74 MT/ha for Mn concentrations of 7 to 26 mg/kg in peanut leaves collected 9 weeks after planting (17).

Data from this study agree with field observations over many years in South Georgia that Mn deficiency is much more pro-

Table 5. Effect of soil pH and Mn rates on concentrations of Mn in tobacco leaves and in a Pelham loamy sand by two soil extraction methods. 1985-1986.

1985					1986				
Treatments			Extractable soil Mn		Treatments			Extractable soil Mn	
Soil pH	Residual Mn†	Leaf Mn	Mehlich-1	DTPA	Soil pH	Residual Mn‡	Leaf Mn	Mehlich-1	DTPA
	kg/ha	mg/kg	---- kg/ha -----			kg/ha	mg/kg	----- kg/ha -----	
5.3	0	84	4.1	2.6	5.3	0	120	5.5	1.9
5.4	71	98	7.7	4.7	5.3	81	153	7.6	2.6
5.4	141	117	9.0	6.6	5.3	161	191	9.9	3.2
5.4	282	129	12.0	8.5	5.3	322	307	12.8	4.5
LSD (0.05)		26	2.0	1.1			90	1.6	0.8
CV (%)		17.8	17.7	14.7			34.0	12.4	18.8
6.3	0	27	3.5	1.4	6.1	0	41	5.5	0.9
6.3	71	42	6.8	2.2	6.2	81	62	9.1	1.4
6.2	141	47	8.6	3.4	6.2	161	79	10.2	1.7
6.1	282	63	11.8	4.9	6.1	322	121	14.7	2.7
LSD (0.05)		7	0.9	0.7			14	1.4	0.6
CV (%)		11.6	8.7	15.1			13.1	10.7	23.9
7.3	0	13	5.4	1.1	7.3	0	21	9.0	0.7
7.1	71	21	8.3	1.7	7.2	81	25	9.2	0.8
7.1	141	23	10.0	2.1	7.3	161	35	14.4	1.0
7.3	282	37	15.7	2.9	7.3	322	41	19.3	1.4
LSD (0.05)		6	1.8	0.6			10	2.6	0.2
CV (%)		16.3	12.8	19.1			23.2	14.6	14.5

†Total amount applied from 1977-1985 in 7 equal applications.

‡Total amount applied from 1977-1986 in 8 equal applications.

bable for major agronomic crops other than tobacco grown on high pH (>6.5) soils. The desirable soil pH for flue-cured tobacco on sandy soils appears to be near 6.0, but moderate or severe Mn deficiency is not likely to occur if the soil pH is maintained between 6.0 and 6.5. These data show that Mn fertilizer amounts greater than 1.12 kg/ha were not needed for tobacco even with soil pH levels >7.0

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